UCLA
Institute of the Environment and Sustainability

Assessing Groundwater Contamination in Maywood, California

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JAS, KSW, and ARMat researched treatment strategies, health effects, and legal complications. ARM and ARMat compiled industrial sources. ARM mapped industrial sources using ArcGIS. JAS, KSW, KP, KNV, ARMat, ARM and EAR conducted water sampling in the field. KP, KNV, EAR compiled the water quality database. KP, KNV, and EAR managed data, assessed hydrology of the Central Basin, and modeled contaminant distribution in ArcGIS. EAR submitted Well Completion Reports. KNV, EAR, and KP contacted governmental agencies. KNV, EAR, and KP analyzed central basin hydrogeology and water quality comparisons. KP prepared, modeled, and analyzed contaminant data in R. All of the authors discussed the results and commented on the manuscript. All authors edited and approved the final manuscript.

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Acronyms

AAS - Atomic Absorption Spectroscopy

AES - Atomic Emission Spectroscopy

ATSDR - Agency of Toxic Substances and Disease Registry

BAT - Best Available Technology

CalEPA - California Environmental Protection Agency

CCR - California Code of Regulations

CWA - Clean Water Act

DAF - Dissolved Air Flotation

DC - Direct Current

DDW - Department of Drinking Water

DO - Dissolved Oxygen

DTSC - Department of Toxic Substance Control

DWR - Department of Water Resources

ERH - Electrical Resistive Heating

GAC - Granular Activated Carbon

GAMA- Groundwater Ambient Monitoring and Assessment

IDW - Inverse Difference Weighting

IOCME - Induced Oxide Coated Media Effect

IOCS - Iron Oxide Coated Sand

MCL - Maximum Contaminant Level

MOCS - Manganese Oxide Coated Sand

MTBE - Methyl Tert-Butyl Ether

MWD - Metropolitan Water District

ND - Not Detectable

NPDWR - National Primary Drinking Water Regulations

NSDWR - National Secondary Drinking Water Regulations

OK - Ordinary Kriging

PCE - Tetrachloroethylene

PVC - Polyvinyl Chloride

RWQB - Regional Water Quality Board

SDWA -Safe Drinking Water Act

SMCL - Secondary Maximum Contaminant Level

SWIMS - Solid Waste Information Management System

SWRCB - State Water Resources Control Board

T&O - Taste and Odor

TCE - Trichloroethylene

TDS - Total Dissolved Solids

TRI - Toxic Release Inventory

EPA- United States Environmental Protection Agency

USGS - United States Geological Survey

VOC - Volatile Organic Compound

WCR - Well Completion Report

WRD - Water Replenishment District of Southern California

WTP - Water Treatment Plant

Table of Contents

Figures

Tables

Executive Summary

Maywood, California is a small, underrepresented community in Los Angeles County that has experienced severe groundwater contamination for over a decade. Constituents of concern in the groundwater include: manganese, trichloroethylene (TCE), and lead. Since this community relies almost exclusively on groundwater for its drinking water supply, this issue is one that necessitated increased research and attention than it previously had gotten. Recently, there has been some indication that Maywood's water quality is improved, but residents have continued to voice concern regarding their drinking water, and are unsure if the water is safe to use.

Our project aimed to investigate the groundwater contamination in Maywood by:

1. Researching the health effects and treatment of manganese in drinking water as well as assessing policy relating to regulation of manganese;
2. Compiling and assessing potential sources of the contamination;
3. Mapping the concentration distribution of manganese, TCE, and lead;
4. Conducting drinking water testing at several locations in Maywood.

Through our research, we have concluded that extreme overexposure to manganese in drinking water has adverse health effects for both the general population as well as several at-risk populations, notably infants and children, fetuses, seniors, and those with impaired livers and iron deficiency. These health effects are primarily neurotoxic effects as well as reproductive and developmental complications. While it is inconclusive whether manganese's status should be changed from a secondary contaminant to a primary contaminant, further research should be conducted on the matter.

Water treatment facilities should keep track of possible manganese contamination through effective monitoring of source water and should be aware of the potential removal processes available. While site-specific remediation is an option, most facilities will likely adopt a common water treatment technique. However, these facilities should only do so after careful consideration of source water characteristics, oxidant properties, and potential complexities associated with the chosen technology.

In our investigation of potential sources of manganese, TCE, and lead, we have concluded that it is extremely difficult to determine the direct source of pollution, particularly due to the several limitations of our approaches and available data. For manganese, it is possible that the contamination is actually a result of the conditions in the groundwater aquifers and surrounding soil. However, manganese could also be potentially originating from industries that manufacture iron, steel, batteries, among other sources. Overall, a source of manganese has proven to be extremely difficult to determine. We have identified numerous sources that have released TCE, a completely anthropogenic chemical, and those sources need to be examined further.

While our contamination distribution maps have limitations, we can conclude that the areas of highest concentrations of manganese, TCE, and lead are likely the most accurate. In our database, manganese appears in untreated groundwater as high as 1,000 times the legal limit, suggesting that this is an extremely prevalent constituent in Maywood's groundwater. Moreover, TCE levels reached, at times, over 2,500 times the legal limit, while lead's maximum value was around 5 times the legal limit. Our investigation into the historical and current contamination of Maywood's groundwater further solidified the notion that this community continues to struggle with environmental hazards to their health, safety, and livelihoods.

While our project was able to make large strides in this historically stagnant water quality issue, much more research must be undertaken to fully understand and continue to ensure the safety of Maywood's water. We recommend that future research should focus on the possible correlation of manganese and natural groundwater conditions such as levels of dissolved oxygen and microbial activity in the soil. In addition to this, agencies at all levels should offer more accessible data on water quality and encourage better communication. We hope our work will aid in providing direction to finally giving Maywood the clean water it critically needs.

Introduction

1.1 Purpose

Over the past decade, the small, underserved City of Maywood, California, located in Southeast Los Angeles County, has been forced to rely on heavily contaminated groundwater as the primary drinking water supply. Contaminants in the water include the heavy metal manganese, as well as other pollutants such as trichloroethylene (TCE), tetrachloroethylene (PCE), and lead. The manganese contamination leaves the community's drinking water murky, and possibly poses detrimental health effects to Maywood residents. Both city officials, the Department of Toxic Substances Control (DTSC), and the U.S. Environmental Protection Agency (EPA) acknowledge that the concentration levels of manganese exceed federal secondary maximum contaminant levels. However, the lack of a known source of the pollution, issues enforcing federal standards, environmental justice issues, and political bureaucracy, have delayed the cleanup of Maywood's groundwater pollution.

Our first step was to investigate the issues surrounding the groundwater contamination. Both state and federal policy were analyzed to uncover specific rules and regulation that applied to the contamination issues in and around Maywood. Another research component was to analyze possible health impacts of manganese on at-risk communities, such as fetuses, infants and senior citizens was to investigate potential treatment techniques, and possible impacts of the current treatment approaches in Maywood. Our final research component synthesizes past research studies and determines how they relate to the current situation in Maywood.

We also conducted a technical analysis of the groundwater contamination distribution in the Maywood area and possible industrial sources. We mapped possible contamination distributions over the study area for manganese, TCE, and lead, as well as created an industrial source map identifying possible sources for the three contaminants. For the potential source and contaminant distribution maps, we utilized data from various agencies public databases the EPA's Toxic Release Inventory (TRI), the California State Water Resources Control Board Division of Drinking Water (SWRCB) and Regional Water Quality Control Boards (RWQCB), DTSC, Geotracker Groundwater Ambient Monitoring and Assessment (GAMA). The data from these agencies allowed us to piece together the wide variety of possible sources of pollution as well as contaminant concentrations from monitoring and drinking water wells in the Maywood area. For the contaminant distribution, we used known points from our database, and used a geostatistical interpolation method to create an approximation of the concentrations throughout Maywood's groundwater. These results were further analyzed in ArcGIS where source locations and the contaminant distributions were used in conjunction with each other. The information depicted on our maps allow future researchers to focus on identifying facilities (if applicable) that may be potential sources of the contamination.

The final portion of our work included conducting limited drinking water sampling in Maywood. We visited parks, government offices, local businesses, schools, and local residences to collect drinking water samples and test the concentration levels of various contaminants.

Over the course of our project, we experienced many obstacles and complications which have lead us to create a list of recommendations and further research avenues for state agencies. Given the complex nature of investigating groundwater contamination in Maywood, our project is ultimately a first step of many towards an increased understanding of this issue.

1.2 Characteristics and Background of Maywood, California

1.2.1 Demographics

Maywood is one of the smallest incorporated cities in California, only 1.18 square miles, and has only 27,395 residents (see Table 1). Located in Southeast Los Angeles County, Maywood exhibits one of the highest proportions of Latinos, undocumented immigrants, and immigrants in Los Angeles County. The average income per household is $35,965/year, compared to the Los Angeles County average of $52,684/year, with more than 21% of Maywood's residents living below the poverty line (Table 1). This community is highly disadvantaged and underrepresented, with only 6,000 registered voters, and has experienced great difficulty getting their water contamination problem solved (Kintz 2015).

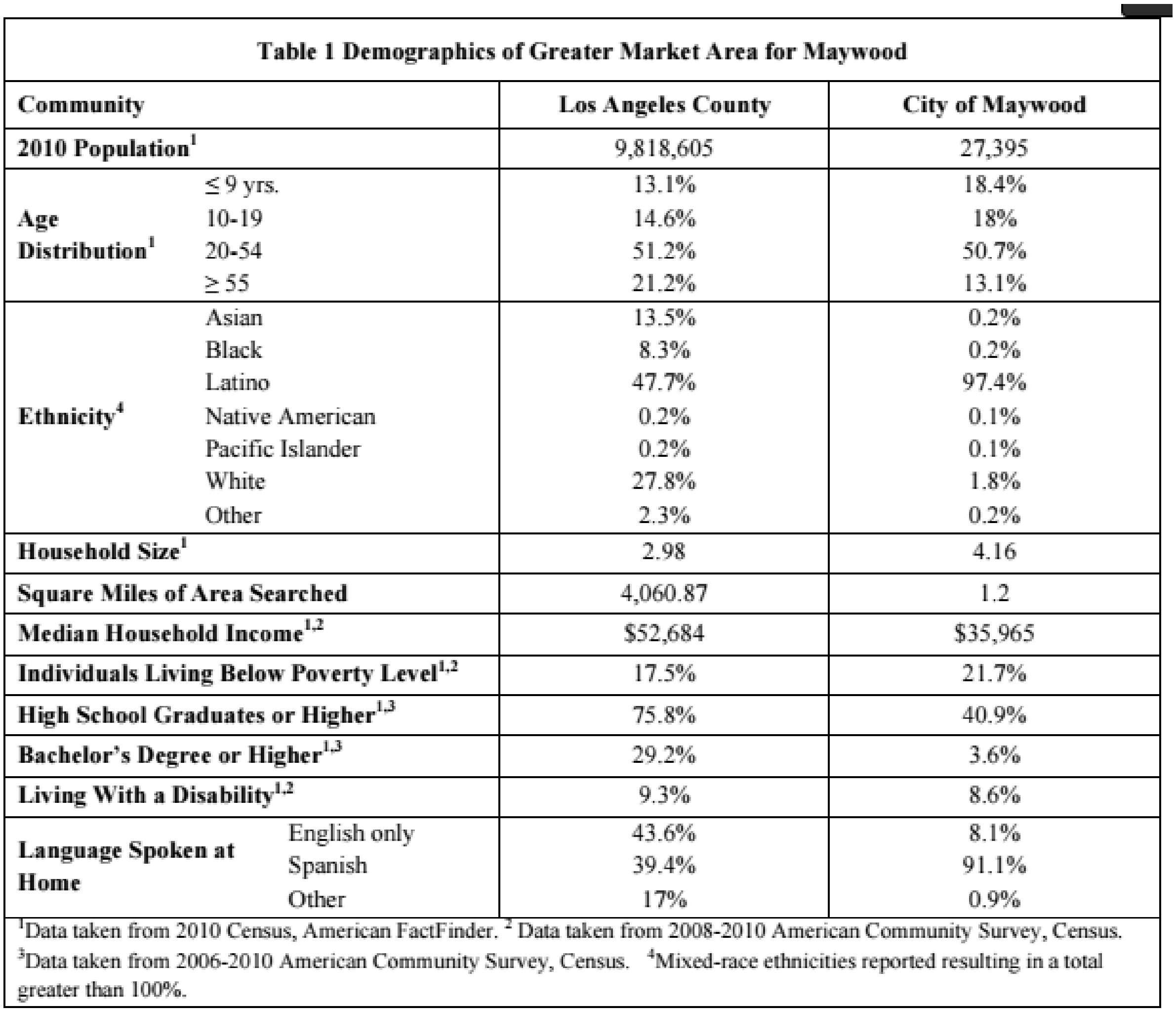

Table 1 Demographics of Greater Market Area for Maywood

Community		**Los Angeles County**	**City of Maywood**
2010 Population[1]		9,818,605	27,395
Age Distribution[1]	≤ 9 yrs.	13.1%	18.4%
	10-19	14.6%	18%
	20-54	51.2%	50.7%
	≥ 55	21.2%	13.1%
Ethnicity[4]	Asian	13.5%	0.2%
	Black	8.3%	0.2%
	Latino	47.7%	97.4%
	Native American	0.2%	0.1%
	Pacific Islander	0.2%	0.1%
	White	27.8%	1.8%
	Other	2.3%	0.2%
Household Size[1]		2.98	4.16
Square Miles of Area Searched		4,060.87	1.2
Median Household Income[1,2]		$52,684	$35,965
Individuals Living Below Poverty Level[1,2]		17.5%	21.7%
High School Graduates or Higher[1,3]		75.8%	40.9%
Bachelor's Degree or Higher[1,3]		29.2%	3.6%
Living With a Disability[1,2]		9.3%	8.6%
Language Spoken at Home	English only	43.6%	8.1%
	Spanish	39.4%	91.1%
	Other	17%	0.9%

[1] Data taken from 2010 Census, American FactFinder. [2] Data taken from 2008-2010 American Community Survey, Census. [3] Data taken from 2006-2010 American Community Survey, Census. [4] Mixed-race ethnicities reported resulting in a total greater than 100%.

Table 1. Demographics of the City of Maywood compared to Los Angeles County (USACE 2013).

1.2.2 Water Supply

Maywood residents historically and currently buy their drinking water from three private, yet non-profit, Mutual Water Companies, Maywood Mutual Water Companies (MMWC) 1, 2 and 3 (Figure 1). Mutual Water Companies 1 and 2 supply groundwater mixed with treated surface water imported from the Metropolitan Water District (MWD) while Mutual Water Company 3 distributes only treated groundwater (WRD 2015). Each Mutual Water Company is responsible for treating, maintaining, and supplying water to its customers (WRD 2015). Maywood Mutual 1 is responsible for supplying 13% of Maywood's water, Maywood Mutual 2 supplies 52%, and Maywood Mutual 3 supplies 35% (Figure 1).

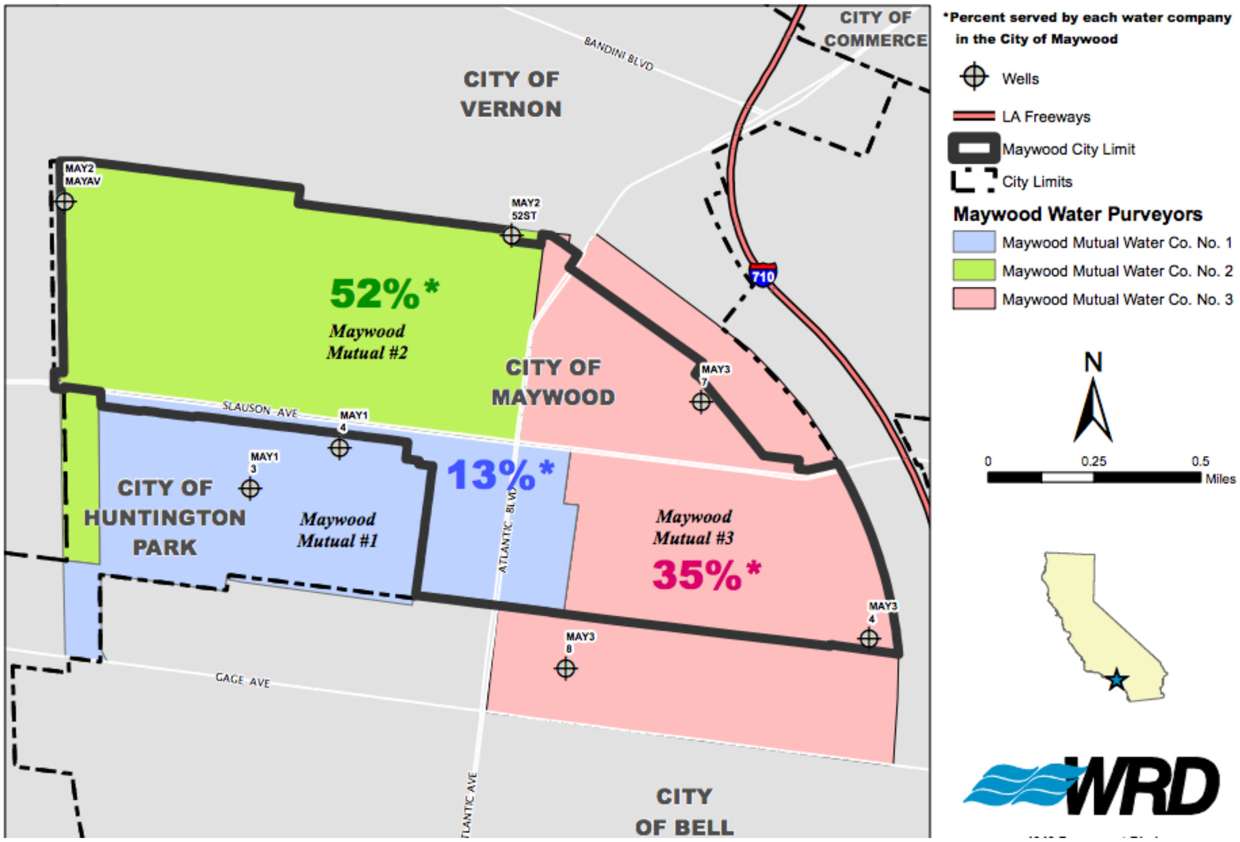

Figure 1. The city of Maywood in relation to the supply area of the three Maywood Mutual Water Companies and their groundwater supply well locations (WRD 2015).

1.2.3 Drinking Water Contamination Issues

The Maywood community has dealt with drinking water contamination issues for over a decade. This community is classified by CalEnviroScreen, an environmental health screening tool created by the California Environmental Protection Agency (CalEPA) and the Office of Environmental Health Hazard Assessment, as one of the top 5% of environmentally impacted areas in the state (Kintz 2015 and OEHHA 2016). Maywood not only suffers from groundwater manganese contamination, but also 30th of 492 areas of concern regarding TCE contaminated groundwater as ranked by the EPA and the DTSC (Kintz 2015). Maywood is nestled between highly industrialized cities including Vernon, Bell, Commerce, and Huntington Park. A former federal Superfund site, Pemaco Chemical Corporation, is located within its small 1.18 square mile area. Pemaco, a decommissioned chemical blending facility, has had a large hand in contaminating Maywood’s groundwater, soil, and air with industrial strength solvents, especially TCE (Section 7.1) (USACE 2013). Maywood is also located near two Exide Technologies battery recycling sites (Environment Now 2015). One of the sites, in Vernon, is about 1.37 miles away from Maywood and has recently been shut down in order to avoid felony changers and is subject a state response clean-up. Since manganese is used in battery manufacturing, it is possible that manganese may have been released at or infiltrated the groundwater at these sites near Maywood (EPA 2004). Subsection 1.21.1 will discuss this in more detail.

Parts of infrastructure, including pipes utilized by the Maywood Mutual Water companies, are over 90 years old (USACE 2013). This is problematic because outdated infrastructure may be contributing to the pollution distribution. Further discussion on this matter is presented in Section 1.5.

Despite visible pollution concerns in the drinking water and data clearly showing groundwater contamination, the Maywood Mutual Water Companies insist that the water is safe to drink. However, manganese is only a secondary contaminant and is not regulated for clean-up efforts at any concentration, even above the secondary maximum contaminant level (SMCL) of 50 μg/L (EPA 2016). This is because EPA regulations consider manganese to be a secondary contaminant, only known to cause cosmetic and aesthetic effects, but not to pose a health risk, and is not enforceable at the federal level (USACE 2013).

Since 2007, DTSC has conducted water sampling for manganese, TCE, and other contaminants in Maywood. In 2010, the DTSC's Phase 1 Assessment, found manganese exceedances of the SMCL in 12 locations throughout Maywood (Kintz 2015). As a result of this assessment, Maywood Mutual Water Company 2 installed a manganese treatment system, in 2011 (Kintz 2015).

In August of 2012, DTSC conducted a follow up assessment. Sampling concluded that the treatment system at Maywood Mutual Water Company manganese treatment system "significantly reduced manganese levels to well below the secondary standard" (Kintz 2015). However, the well source water from both Maywood Mutual Water Company 1 and 2 exceeded secondary drinking water standards (Kintz 2015). While the end source water may be safe to drink by EPA SMCL standards, the groundwater is still above the SMCL and must be treated. As of 2015, Maywood Mutual Water Company 3 is awaiting treatment installation. The status of installment and funding processes to proceed with treatment is unknown.

Additionally, in the same 2012 assessment, traces of lead also appeared in the water. This was most likely as a result of the old pipes and water fixtures used by the homes and buildings where they sampled (Kintz 2015). In addition, in two of the wells owned and operated by MMWC 3, TCE was found in exceedence of the Public Health Goals (PHG) set by the California Public Health Department, but lower than the maximum contaminant level (MCL) set by the EPA (Kintz 2015). The DTSC 2015 Phase II Assessment report thus determined the water as safe to drink (Kintz 2015).

1.2.4 Constituent of Concern: Manganese

Identifying sources of manganese in groundwater supply has been challenging given that it is naturally occurring. Manganese is one of the most abundant metals in Earth's crust, occurring naturally in soils, rocks, and minerals, and is regularly found in water, air, and food, as well as in decomposed plants (O'Neal et al. 2015; EPA 2004). Manganese usually occurs naturally with iron, which is why iron and manganese are often removed from water together. The major natural sources of atmospheric manganese are crustal rock, volcanic activity, vegetation, forest fires, ocean spray, and, to a lesser extent, aerial erosion of dusts and soils. Manganese can also accumulate in soils from animal excrement, decomposing plant and animal material, plant and surface runoff, atmospheric deposition, and microbial communities. The decomposition of minerals containing manganese as well as acidic environments are other potential sources of environmental manganese (Howe et al. 2004). Manganese is also used in human activities, especially in iron and steel production. This can lead to elevated levels of manganese in the surrounding environment (Kohl and Medlar 2006). Additionally, manganese contamination can occur through "industrial facility effluent discharge, landfill and soil leaching, and underground injection" (EPA 2004).

Mn(II) dissolves easily in water, especially in water that is slightly acidic, low in dissolved oxygen (DO), and in very deep groundwater aquifers (Goldrath et al. 2012; Katsoyiannis and Zouboulis 2004). DO is a water quality measurement that can be an indicator of groundwater quality and in some cases can be used to assess the stability of trace metals in the system (Rose & Long 1988). The dissolution of manganese into groundwater is dependent on DO content and bacterial processes (Jaudon et al. 1989). When groundwater is highly deficient in oxygen, bacteria reduce Mn (IV) adsorbed to groundwater sediments into the water soluble form Mn (II) (Jaudon et al. 1989). Thus, manganese can continually be dissolved into the groundwater as DO is increasingly depleted (Jaudon et al. 1989). This may be of particular importance for the Maywood area; in a report conducted by the United States Geological Survey (USGS), most of the wells in the Central Basin with high relative-concentrations of manganese, were also areas with very low DO (Goldrath et al. 2012). A further discussion of dissolved oxygen and manganese will be discussed in Section 7.1.

Additionally, in the environment, manganese acts similar to other elements in that it will not chemically decompose; it must change chemical states by either attaching to or separating from other particles (ATSDR, 2012). The form of manganese and the type of soil governs the rate at which manganese travels through the soil and how much manganese is held within the soil (ATSDR, 2012). Soil and bedrock can solubilize naturally-occurring manganese into soluble divalent manganese (Mn (II)), allowing it to reach surface and groundwater (Ljung et al. 2007). Ultimately, there may be multiple pathways for manganese to enter water.

One reason that the issue of manganese in Maywood's drinking water has not been resolved is because of its classification as a secondary pollutant the federal level. EPA classifies potential contaminants in drinking water as either primary or secondary based on the health effects of the contaminant. Primary contaminants are enforceable, but the EPA is not allowed to enforce its secondary maximum concentration level (SMCL) of 50 µg/L (EPA 2016). Instead, secondary contaminant standards are used as guidelines for public water systems (USACE 2013). However, individual states, like California, can choose to regulate and enforce secondary contaminant standards (SCRWQCB 2006). Even though there is evidence of maximum concentration exceedances for manganese in Maywood, the water companies have not been cited for violations. Secondary standards do not guarantee safety to any populations with drinking water contamination problems, due to lack of enforceability.

There is clear evidence of adverse health impacts of manganese (Section 1.4); while manganese in small doses is imperative for human development, excessive exposure via drinking water consumption can impair fetal development and cause other health complications (Rahman et al. 2015). These health complications include neurotoxic effects, as well as reproductive and developmental impacts (USEPA 2004). Furthermore, at-risk populations include infants and children, fetuses, seniors, and those with impaired livers or iron deficiency. Scientific research on the health impacts of consuming manganese-contaminated water has clearly documented associated health effects. However, further research should be done in order to determine if manganese should be considered a primary contaminant or secondary contaminant.

1.2.5 Other Contaminants

While manganese has been the main worry of residents due to its visible nature, reports have indicated that various other contaminants have been frequently found in this region.

Both trichloroethylene (TCE) and lead have been identified by the Water Replenishment District (WRD) as contaminants of concern in Maywood's groundwater. These two contaminants in particular have even more unfavorable health effects and could work as a tool to expedite cleanup of manganese. Table 2 demonstrates the health limits for manganese.

1.2.5.1 TCE

TCE is a completely anthropogenic contaminant utilized in various industries as a metal degreaser, cleaner and refrigerant. (WRD 2015; EPA 2016) It is commonly used as a solvent, mixed into various products such as paint and adhesives. According to a 2015 WRD report, TCE is "has contaminated groundwater due to improper use or disposal at industrial facilities" (WRD 2015). TCE exposure both acute and chronic can have negative effects on the central nervous system, brain, liver and kidney (Chui 2013). Additionally, TCE is strongly linked to various cancers such as liver and kidney cancer (Scott 2011). Table 2 demonstrates the health limits for TCE.

1.2.5.2 Lead

Lead is a naturally occurring metal that has been historically used in various common products such as gasoline, pipes and paint. EPA has stated that there is no safe level of lead presence in drinking water and aims to keep levels at zero (EPA 2015). Lead exposure is especially dangerous for young children due to higher absorption of lead and heightened effects on developing brains and bodies. For adults, lead can cause lower kidney function, and reproductive problems. Higher levels of exposure can have large effects on brain function and cause various mental disabilities (CDC 2013). Table 2 demonstrates the health limits for lead.

Constituent	DLR (ug/L)	MCL* (ug/L)
Manganese	20	50
TCE	0.5	5
Lead	5	15
***SMCL for manganese**		

Table 2. Table including detection limit for reporting (DLR) and maximum contaminant limits (MCL) for TCE and lead. Secondary contaminant limit (SMCL) for manganese.

1.2.6 Current Water Quality of Maywood Drinking Water Wells

We compiled data for purposes of constructing a water quality database that could conceivably be used for contaminant modeling and future work in Maywood. Data was compiled from several California water management agencies and groundwater quality monitoring programs including: WRD, DDW, and GAMA. Our compilation efforts are presented in a comprehensive deliverable that includes information regarding well information, analyte concentration, sample date, and well construction characteristics if relevant. Table 3 below presents a summary for solely 2014-2015 drinking water data water quality, presented by average and maximum values. Note that there are spikes above twice the SMCL for manganese, as well as detectable TCE levels in raw groundwater. Additionally, in recent years, common water quality parameters such as alkalinity, calcium, and total dissolved solids (TDS) were not sampled for Maywood Mutual #1 and Maywood Mutual #2, limiting the ability to properly assess conditions in the drinking water aquifer. For a more comprehensive look at monitoring well data, refer to the comprehensive water quality database deliverable.

	Maywood Mutual # 1				**Maywood Mutual #2**				**Maywood Mutual # 3**			
	1910084-002		**1910084-003**		**1910085-001**		**1910085-002**		**1910086-004**		**1910086-009**	
Analyte	AVG	MAX	AVG	MAX	AVG	MAX	AVG	MAX	AVG	MAX	AVG	MAX
Alkalinity (mg/L)							190	190	210	210	190	190
As (µg/L)							2	2	2	2	2	2
Ca (mg/L)							56	56	48	48	79	79
Fe (µg/L)	27	520	26	160	54	140	142	350	100	100	53	100
Mn(II) (µg/L)	40	150	79	88	62	230	60	96	28	28	20	20
Ni (µg/L)							10	10	10	10	10	10
Pb (µg/L)							5	5	5	5	5	5
PCE (µg/L)	1	1	1	1	1	1	1	1	1	1	1	1
pH									8	8	8	8
TCE (µg/L)					3	5	1	1	1	1	4	5
TDS (mg/L)							360	360	370	370	490	490

Table 3. Current Water Quality of Maywood Drinking Water Wells (2014-2016).

1.2.7 Central Basin Hydrogeology

Maywood is located in the Central Basin, part of the Coastal Plain of Los Angeles Groundwater Basin, adjacent to the Los Angeles River. In this portion of the Central Basin, many of the groundwater aquifers drop to deeper depths (725-1150 fbg) compared to the surrounding region (see Figure 3). The area surrounding Maywood has many drinking water wells and environmental monitoring wells that can provide information on the groundwater quality.

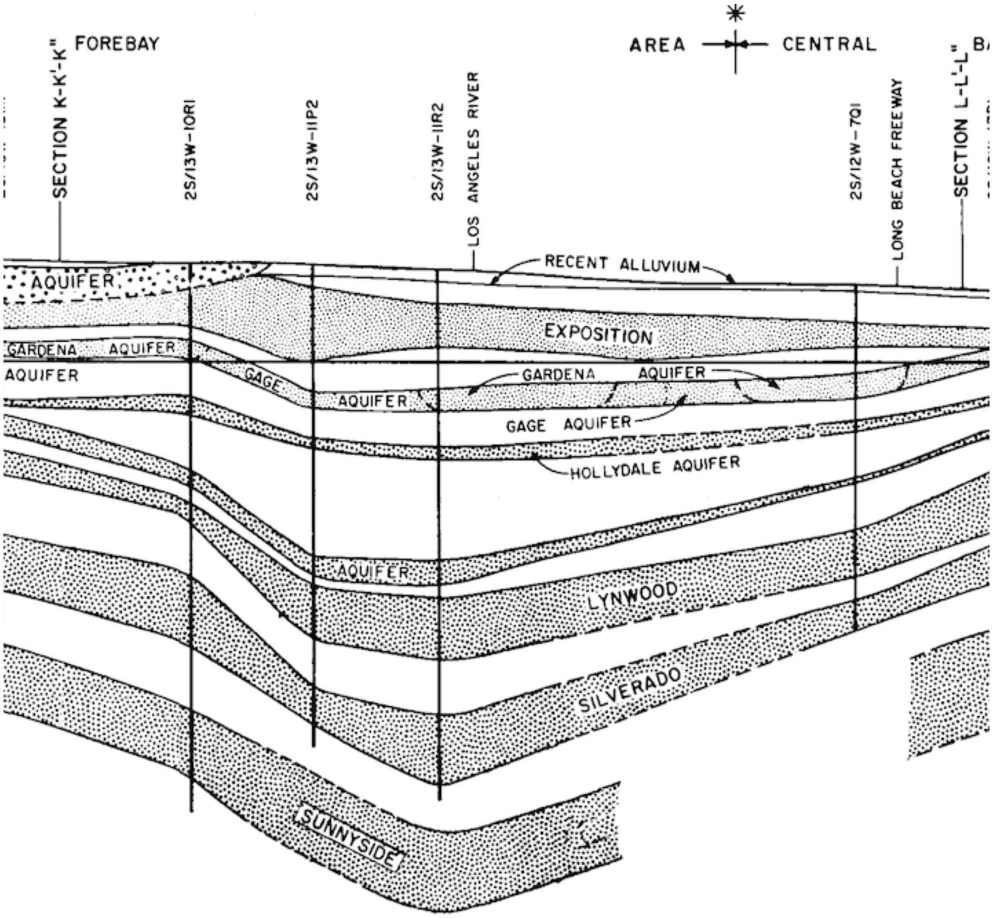

Figure 2. Map of hydrogeology detailing the names and depths of aquifers near Maywood, CA (Plate A of DWR 1961).

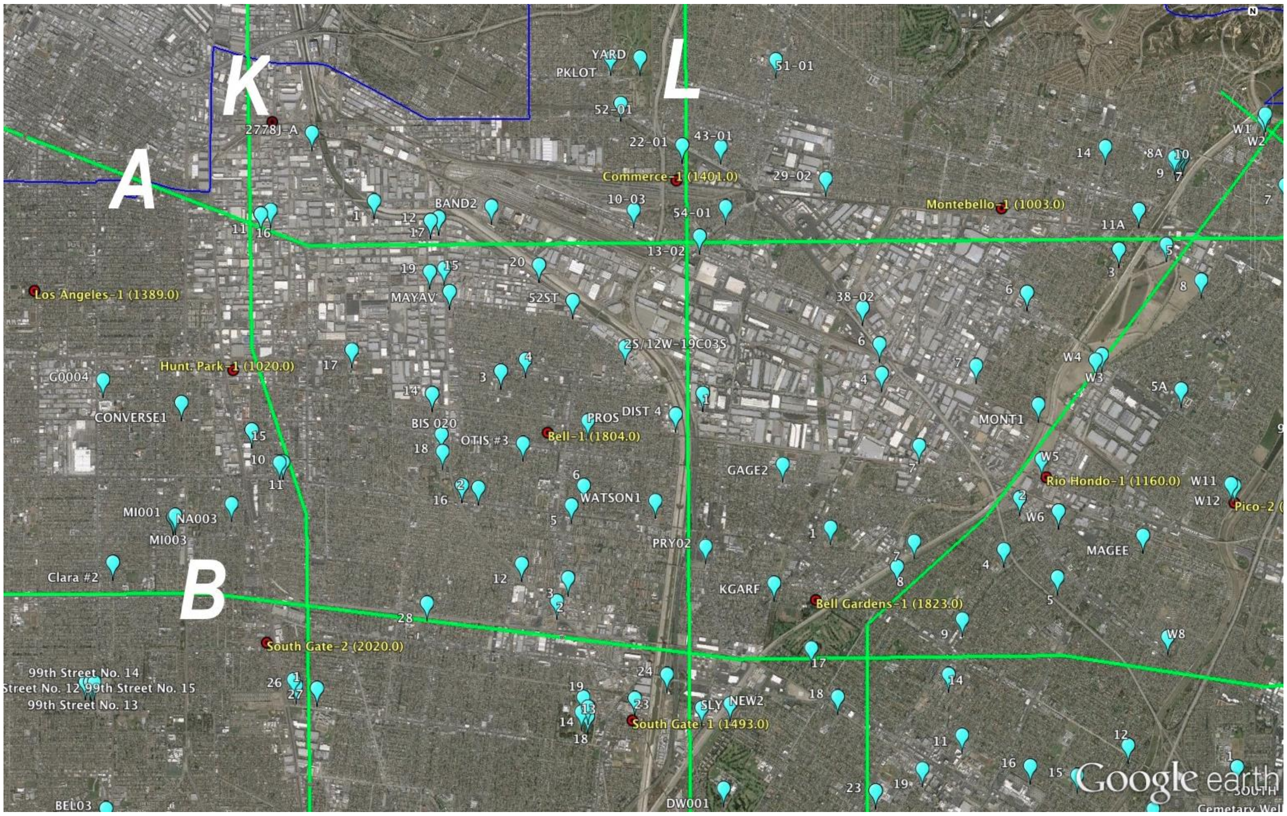

Figure 3. Google Earth image of the Maywood area, showing the cross section defined by Plate A (DWR 1961) and the locations of some drinking and monitoring wells in the region.

Drinking water in this region of the Central Basin is mainly pulled from the Silverado aquifer; however, Lynwood and Sunnyside aquifers are also heavily used for water supply purposes (Ponti et al. 2014; WRD 2016). These three aquifers are in the deepest zones of the groundwater basin (WRD 2016).

The three Maywood Mutual Water companies each have 2 active wells, totaling 6 active drinking water wells, with known depths ranging from 800-1400 feet below ground (fbg) (Table 4). Well depths from Maywood Mutual Water Company #2 could be shallower than this range, but it is still unknown as discussed in Section 1.8.4. Bell #1 and Commerce #1 drinking water wells, also pull from Sunnyside and Silverado aquifers, at a range of 590-1215 fbg (Table 5). Therefore, since Maywood and Bell/Commerce are pulling from similar depths, we can assume that the Maywood wells are most likely pulling from Sunnyside and Silverado as well.

Mutual Co.	Well Name	Well ID	Well Depth (fbg)
Maywood 1	Well 3	1910084-002	1400
	Well 4	1910084-003	1250

Maywood 2	52nd St. Well	1910085-001	Undetermined
	May Ave. Well	1910085-002	Undetermined
Maywood 3	District 4	1910086-004	900
	Well 7	1910086-009	800
	Well 8	N/A	800

Table 4. Table of the known well depths for drinking water wells in Maywood, CA.

Well Name	Well ID	Zone	Well Depth (fbg)	Aquifer
Bell #1	102041	1	1750	Pico Formation
	102042	2	1215	Sunnyside
	102043	3	985	Silverado
	102044	4	635	Silverado
	102045	5	440	Hollydale
	102046	6	270	Gage
Commerce #1	100881	1	1390	Pico Formation
	100882	2	960	Sunnyside
	100883	3	780	Sunnyside
	100884	4	590	Silverado
	100885	5	345	Hollydale
	100886	6	225	Gage

Table 5. Table of the known depths of Bell #1 and Commerce #1 drinking water wells.

Policy, Health Impacts and Removal of Manganese

This section aims to 1) discuss the regulatory issues associated with manganese and its establishment as a secondary contaminant, 2) cover the existing research on the potential health impacts of consuming manganese contaminated water, and 3) discuss widely-used technologies used to remove manganese from drinking water and describe the ways in which manganese treatment can exacerbate contamination issues.

1.3 Current Policy

1.3.1 Federal regulations

The Safe Drinking Water Act (SDWA) was enacted in 1974 to "protect public health by regulating the nation's public drinking water supply" (EPA 2016). In 1996, the SDWA was amended to expand its regulative powers to protect the quality of rivers, lakes, reservoirs, springs, and groundwater wells. If drinking water is pulled from any of these sources, the water must meet standards set in the SDWA. In this specific way, the SDWA is a more powerful tool for protecting public drinking water supplies than the federal Clean Water Act (CWA), which was enacted in 1972 to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." While the CWA effectively serves as the principal federal water pollution control law in the United States, its scope is generally limited to protection of surface waters, where the SDWA affords protection to all sources of public drinking water – whether surface water, groundwater, or other. There is substantial overlap between the two laws, however.

The EPA is responsible for adopting and implementing the standards set in the SDWA and has authority over all public water systems. Private wells which serve fewer than 25 individuals are not regulated by the SDWA. The EPA has the decision-making power to determine which water contaminants to monitor and regulate under the SDWA. Currently, the EPA regulates over ninety contaminants through the National Primary Drinking Water Regulations (NPDWR) program (EPA 2016). The contaminants regulated by the NPDWR, known as primary contaminants, each have a Maximum Contaminant Level (MCL) that must be met. Legally, the EPA is only allowed to regulate primary contaminants, which are contaminants that are known to cause harm human health if ingested (40 CFR §141). The EPA suggests standards for secondary contaminants, which are known to cause only cosmetic effects, but their suggestions do not have to be complied with because the EPA does not have means to enforce secondary contaminants.

At the federal level, the process to add a contaminant or move a secondary contaminant to the list of primary contaminants is long and arduous. When identifying new contaminants to monitor, the EPA must follow the selection process set in the Safe Drinking Water Act (SDWA) (40 CFR §141). The first step of this process is to add the contaminant to the Contaminant Candidate List (CCL), which can be done through public nominations. Once a contaminant is added to the CCL, the EPA will make a formal decision on whether or not to initiate a process and develop a national primary drinking water standard for that specific contaminant (EPA 2016). The process of determining whether a particular contaminant meets criteria for establishing a primary contaminant MCL can be complex and subject to uncertainty, and there is often controversy about which contaminants should be included, or which should be identified as primary or secondary. Manganese is a pivotal example of a contaminant that some community groups believe should be classified as a primary contaminant (Torres 2016).

However, the California State Water Board can enforce secondary maximum contaminant levels (SMCLs) the same way they enforce primary contaminants. The secondary Maximum Contaminant Level (MCL) for Manganese is 0.05 mg/L and is enforceable in California for community water systems (22 CCR § 64449). A community water system is defined as a public water system that serves at least 25 people per day for at least 60 days per year. The Maywood Mutual Water companies fall under this category (EPA 2015). Each community water system is required to sample its groundwater sources every three years and its surface water sources annually (22 CCR § 64449). If the results from monitoring show that any constituent exceeds an MCL, the community water system must take the following steps:

1) If monitoring quarterly, determine compliance by a running annual average of four quarterly samples 2) If monitoring less than quarterly, begin monitoring quarterly and determine compliance based on the average of the initial sample and the next three consecutive quarterly samples 3) If a violation has occurred based on the compliance determinations from (1) or (2), the community water system must inform the State Board when reporting 4) After one year of quarterly monitoring during which all results are in compliance, the system may request the State Board to allow them to monitor less frequently (22 CCR § 64449). If a community water system's average of four consecutive quarters of sample results is below three times the secondary MCLs for every constituent, it may apply for a nine-year waiver of a secondary MCL (22 CCR § 64449.2).

1.3.2 State Regulations

The California Water Code was written in 1969 to give California more stringent navigable and drinking water regulations. Title 23 of the California Code of Regulations (CCR) gives the State Water Board and Regional Water Quality Boards effective governing power over specific divisions of the Water Code, including general provisions, appropriation of water rights, determination of water rights, recordation of water extractions and diversions, statements of water diversions and use, appropriation of water by department of water resources, and water quality (23 CCR § 641). These divisions encompass important chapters, such as measuring and monitoring, enforcement procedures, and reportable quantities and reporting requirements.

Notably for drinking water, California has passed its own state Safe Drinking Water Act, meant to "improve upon the minimum requirements of the federal Safe Drinking Water Act Amendments of 1996, to establish primary drinking water standards that are at least as stringent as those established under the federal Safe Drinking Water Act, and to establish a program . . . that is more protective of public health than the minimum federal requirements." (Cal. Health and Safety Code § 116270(f).)

1.3.2.1 Enforcement procedures

Water suppliers are required to follow a time schedule for compliance with water quality. The water supplier must comply as soon as “reasonably possible” (23 CCR § 2243). Time schedules are reviewed periodically so that compliance is met at the earliest possible date with immediate corrective measures (23 CCR § 2243). Dischargers are expected to alter plant operations in order to achieve prompt compliance, and in some cases they must build new emergency facilities (23 CCR § 2245). These emergency facilities include chemical treatment, additional disinfection, aeration, and any other steps which can be immediately implemented (23 CCR § 2245). If a facility cannot afford to build emergency facilities, then the board should consider further action against the discharger, because cost is not a reasonable excuse for failure to comply (23 CCR § 2245).

1.3.2.2 Reportable quantities and reporting requirements

The CCR states that any person who discharges at least the reportable quantity of water specified that could affect California’s water must immediately report the discharge (23 CCR § 2260). The reporting requirements do not apply to discharges in compliance with waste discharge requirements, conditions of waiver of waste discharge requirements, or other provisions of Division 7 of the Water Code (23 CCR § 2260).

1.3.3 Environmental Health - Secondary Drinking Water Standards

1.3.3.1 Use of Sources that Exceed a Secondary MCL and Do Not Have a Waiver

If a water supplier does not have a waiver and it exceeds one or more secondary MCLs, it may still be used under certain conditions (22 CCR § 64449.4). In order to continue using a water source that exceeds an MCL, the water system must meter the source’s monthly production and submit the results to the State Board by the 10th day of the following month. The water supplier must also conduct public notification by including dates, constituent levels, and reason in the Consumer Confidence Report, which is available online (22 CCR § 64449.4). They source must also inform the public through electronic media, local newspaper, and/or information in customer billing prior to use of the water. Finally, the water source must take corrective measures after the source is used to minimize residual levels of the constituent in the water distribution system (22 CCR § 64449.4).

1.3.3.2 Distribution System Physical Water Quality

To determine the physical water quality in the distribution system, the water supplier must review at least one of the following: flushing records, consumer complaint records indicating location and duration of the physical water quality issue, or other relative data. If the State Board determines that the supplier does not have sufficient data on physical water quality, the supplier will be required to collect samples for color, odor, and turbidity (22 CCR § 64449.5). The frequency that these samples must be collected depends on the size of the community the water source is supplying. Water suppliers that serve 200 or more people must take at least one sample per month, but those that serve less than 200 take samples as required by the State Board.

1.4 Health Effects of Manganese

Manganese contamination in drinking water can cause severe health effects, particularly in at-risk populations such as infants and children, fetuses, the elderly, and iron-deficient and liver impaired people. Because of this, the ongoing contamination issues in drinking water remain a serious concern for the residents of Maywood. Here, we provide a detailed description of manganese and its health impacts in drinking water.

Manganese exposure is classified into two categories: environmental and occupational exposure. Environmental exposure can be from contact with natural occurrences of manganese as well as from anthropogenic activity. Because manganese dissolves in water, it can get into drinking water by catchment erosion, leaching and weathering of rock, and dissolution of manganese from dust sediment (Alves et al. 2014; Abesser & Robinson 2010; Bouchard et al. 2011), as well as from human activity - including landfill leachate, industrial effluent, and underground injection (EPA 2004). While manganese can occur naturally, occupational exposure in the workplace via inhalation is the main source of manganese poisoning, and is common in miners, smelters, steel manufacturing workers or welders, and workers in dry-cell battery factories (O'Neal et al. 2015).

In addition to inhalation, humans can be exposed to manganese orally. Oral exposure can be from consumption of food or water with high levels of manganese, as well as from the consumption of milk or soy based infant formula, which is known to have high concentrations of manganese (O'Neal et al. 2015). Because this section explores the health impacts of manganese contamination in drinking water, it is important to note that while manganese exposure is typically far higher from food than from drinking water (EPA 2004), exposure via drinking water can be especially detrimental since it is metabolized differentially than manganese that is ingested via diet (Bouchard et al. 2011). This can cause manganese to accumulate in the body at a higher rate when consumed via drinking water, resulting in more detrimental health effects (Bouchard et al. 2011). Because exposure via drinking water can additionally impact health in different ways, the potential health impacts are of critical importance to Maywood's residents.

Manganese typically is absorbed through the gastrointestinal tract. Once manganese enters the circulation system, it is primarily distributed to the liver, brain, and bone. It appears that the "brain is the target organ of manganese toxicity" (O'Neal et al. 2015). In fact, magnetic resonance imaging (MRI) studies have showed that people who were exposed to manganese while working (occupational exposure) had increased levels of manganese in the brain, especially in the globus pallidus. Also, there is significant accumulation of manganese in human bones-about 40% of the total manganese in the body. The large distribution of manganese to the brain is likely the cause of the many neurotoxic health effects of overexposure to manganese, discussed further below. Manganese is also eliminated from the body "via the fecal hepatobiliary excretion with limited urinary excretion" (O'Neal et al. 2015). It is likely that the elimination rate from the brain tissue is slower than that from the liver or kidney, further underlining the neurotoxic effects of manganese (O'Neal et al. 2015).

1.4.1 Health Impacts

Most studies done on the health effects of manganese are on its neurological effects from inhalation. Manganese is a known neurotoxin, and manganese poisoning, or manganism, is caused by exposure to high levels of manganese via inhalation of fumes or dust and is known to resemble Parkinson's disease (EPA 2004). Manganism causes "weakness, anorexia, muscle pain, apathy, slow speech, monotonous tone of voice, emotionless 'mask-like' facial expression, and slow clumsy movement of the limbs" (EPA 2004) and was first documented in 1837 in five pyrolusite mill workers (Mergler 1999). A serious concern with manganism is that it progresses very quickly even after exposure has stopped (Mergler 1999).

Hundreds of cases have been documented of manganism primarily in industrial workers and miners all over the world. For instance, 36 welders in Beijing who exhibited symptoms of manganese intoxication had symptoms including "headache and insomnia (88%), memory loss (75%), emotional instability (35%), exaggerated tendon reflexes (83%), hyper-myotonia (75%), hand tremor (23%), speech disturbances (6%) and festinating gait (3%)" (Crossgrove et al. 2004). Furthermore, a study of 811 shipyard and fabrication welders in Washington showed that these welders had a significantly higher prevalence of parkinsonism than those who were unexposed (Racette et al. 2012). Because manganese is a standard constituent of welding fume, this study further highlights the relationship between manganese exposure and neurotoxic effects.

Studies have also been done on the effects of manganese through oral exposure, such as through consumption of drinking water. The first documented case of adverse health effects of manganese in drinking water was in Japan, where individuals had been exposed to contaminated drinking water due to leachate from 400 dry cell batteries buried close to a drinking water well (Kawamura et al. 1941). 15 individuals had symptoms of manganese poisoning including "lethargy, increased muscle tonus, tremor and mental disturbances" (EPA 2004). At study done by Krishna et al. (2013) examined the effects of consuming manganese contaminated drinking water on adult mice. Using magnetic resonance imaging (MRI), results showed "significant manganese deposition in all examined brain regions" as well as neurobehavioral deficits in the mice, which are early signs of manganese neurotoxicity (Krishna et al. 2013). Most studies documenting the neurotoxic effects of manganese in drinking water are on children, and will be discussed later in this paper.

While the neurotoxic effects of manganese are the primary topic of study, other studies have documented reproductive and developmental impacts of manganese as well. Male workers overexposed to manganese have been shown to have "reduced libido and endocrine imbalance" (Figa-Talamanca 2001). Additionally, there is a possibility that high levels of manganese can cause infertility in men. A study of 63 miners, 38 electric welders in mechanical fields, and 110 electric welders in shipbuilding who were occupationally exposed to manganese for at least one year were shown to have "increased semen liquification time and decreased sperm count and viability" (Wu et al. 1996). Li et al. (2012) did a study on the relationship between manganese and the quality of semen in healthy men who were not occupationally exposed to manganese. From studying 1,179 subjects ages 20-59 years old from six provinces in China, researchers found that those with higher levels of serum manganese concentration suffered from negative effects on sperm viability, morphology, and progressive motility (Li et al. 2012). A study done by Lauwerys et al. (1985) on male workers exposed to manganese dust showed that the workers exposed to manganese had a significantly lower number of children than the workers in the control group. These results suggest a negative effect on male fertility from manganese (Lauwerys et al. 1985). Furthermore, a study done by Wirth et al. (2007) examined 200 subjects who were patients at an infertility clinic. Results showed that those with high blood levels of manganese had an increased risk of low sperm motility, concentration, and morphology (Wirth et al. 2007). However, Gennart et al. (1992) found no difference between the probability of live birth between Belgian workers who were exposed to manganese and those who were not. These conflicting studies show that the issue of whether or not exposure to high levels of manganese can cause male infertility should be looked into further.

Research demonstrates the threat that extreme exposure to manganese presents and that such exposure to manganese contaminated drinking water has the potential to result in a number of health impacts. Further concern focuses around several populations that are especially at-risk for impacts from manganese, including children, fetuses, seniors, and those with impaired livers or iron deficiency.

1.4.2 At-risk populations

1.4.2.1 Infants and Children

Much of the research on the health impacts of manganese in drinking water focuses on childhood development. This is most likely because infants and children are at a higher risk due to increased absorption and lower excretion of manganese than adults (Ljung et al. 2007).

Studies have shown a decrease in manganese concentration with age (Henn et al. 2010). Adults are not nearly as at risk as children and infants because once manganese is ingested, homeostatic control results in low absorption by the gastrointestinal tract; homeostasis ensures that when a large amount of manganese is ingested, gastrointestinal absorption is reduced. In addition, manganese in adults is excreted quickly from the liver in bile (Ljung et al. 2007). Infants and children, on the other hand, do not absorb and excrete manganese in the same manner, resulting in higher manganese concentrations. This puts them more at risk for overexposure of manganese in drinking water. Higher absorption of manganese may be due to “lower gastrointestinal pH and prolonged emptying rate of newborns compared with those of adults as well as the immature gastrointestinal tract of newborns where immature epidermis and increased skin hydration may facilitate a higher absorption” (Ljung et al. 2007).

It follows that there is higher manganese retention in infants than adults. There could be several reasons for this result, including the “low output of manganese in bile” in infants (Lönnerdal 1994). However, another cause could be that “certain tissue sites have a high affinity for manganese, and although these sites are saturated in adults, they strongly retain manganese in infants” (Ljung et al. 2007). Henn et al. (2010) also shows that “since manganese regulatory mechanism such as biliary excretion are not fully developed in neonates, 12-month-old children may be more sensitive to pro-oxidant effects of high manganese levels, but by 24 months of age, sufficient maturation of these systems may have occurred to limit absorption or enable more effective manganese metabolism and excretion.” Another study done by Woolf et al. (2002) examined a specific case in which a family’s well water became contaminated with high levels of manganese. The cause of the contamination is unknown, but the family lived in a highly industrialized town with toxic waste dumps nearby. Health assessments of the family, two parents, one 16-year-old son and one 10-year-old son, showed that only the 10 year old boy exhibited markedly high concentrations of manganese in his blood, urine, and hair. The 16-year-old boy also had elevated, though significantly lower, levels of manganese in his hair. (Wolf et al. 2002). This study reinforces that infants and children appear to absorb and retain manganese at higher rates than adults.

Another reason why the increased levels of manganese in infants are significant is because commonly used infant formulas contain additionally high levels of manganese. In fact, “compared with breast milk, most infant formulas contain approximately 100-fold higher manganese concentrations”

(Ljung et al. 2007). Furthermore, many infant formulas are in powdered form and require mixing with water before being fed to children. If this water is contaminated with manganese, it only increases the amount of manganese that infants fed with formula are exposed to (Ljung et al. 2007).

Many studies have documented the neurotoxicity of manganese in children. This is significant because, in addition to higher absorption and retention rates, "infants have a more sensitive nervous system" than adults (Ljung et al. 2007) and because the neurotoxic effects are "usually irreversible and actually continue to progress, despite removal from the exposure scene" (O'Neal et al. 2015). For instance, high exposure to manganese can impact children's learning abilities. Khan et al. (2012) studied 840 children, aged 8-11 years old, in rural Bangladesh to examine the effects of manganese exposure via drinking water on academic performance. Children with exposure to high manganese concentrations scored 6.4% lower on mathematics exams than children exposed to normal levels of manganese (Khan et al. 2012). However, academic performance in both English and Bangla did not seem to be affected by high or low exposure to manganese (Khan et al. 2012). A child's exposure to manganese was determined by testing his or her local well and his or her urine for manganese content (Khan et al. 2012). Teachers, blind to a child's exposure, provided test results to the researchers (Khan et al. 2012). An issue with this study lies in the methods for analyzing academic performance. Also, it should be noted that using conclusions from this study to talk broadly about other populations is risky. For instance, urban children may not have the same sociodemographic characteristics.

Other studies may serve to solidify the finding that drinking water with high concentrations of manganese negatively impact children's cognitive ability. A study done in Canada found that children ages 6-13 years old exposed to high levels of manganese scored 6.2 points lower on an IQ test than those exposed to low levels of manganese (Bouchard et al. 2011). Different from Khan et al. (2012), this study collected manganese exposure indicators from the children's hair and from their home tap water (Bouchard et al. 2011). To test intelligence and academic performance, Bouchard et al. (2011) administered the Wechsler Abbreviated Scale of Intelligence (WASI). To acknowledge a possible confounding factor of manganese contamination correlating with socioeconomic status, they adjusted IQ scores for socioeconomic status and other metals in the tap water (Bouchard et al. 2011). Another key finding of this study was that homeostatic regulation does not prevent overload when exposure happens via drinking water (Bouchard et al. 2011), again providing more evidence that manganese-contaminated water affects the body differently than manganese in the air.

Using similar methods as Bouchard et al. (2011), Wasserman et al. (2011) and Graziano et al. (2011) both studied the relationship between manganese exposure via drinking water and IQ in Bangladesh. By studying approximately 300 children in each study, aged 8-11 years old, Wasserman et al (2011) and Graziano et al (2011) reached the same conclusions as Bouchard et al (2011). Manganese concentrations in local wells negatively impacted children's ability to learn, reason, and speak (Wasserman et al. 2011; Graziano et al. 2011).

Another study done by Oulhote et al. (2014), authored by the same researchers as Bouchard et al. (2011), examined 375 children ages 6-13 years old in Quebec, Canada. About half of the children lived in homes connected to an aqueduct supplied by groundwater, while the other half lived in homes with private wells. Results showed that children living in houses connected to the aqueduct had higher concentrations of manganese in their hair than children living in houses with a private well. Hair manganese levels were also higher in children with a lower family income (less than or equal to 50,000 dollars a year) than with children from a family with higher income. Even though only 4.3% of homes had manganese concentrations in drinking water above the U.S health reference value of 300 μg/L, the EPA "health-related benchmark" (EPA 2003), it was clear that higher concentrations of manganese exposure were correlated with “poorer performance of memory, attention, and motor functions, but not hyperactivity, in children” (Oulhote et al. 2014). This suggests that manganese contaminated drinking water, even at “low levels commonly encountered in North America” is a serious cause of concern for neurobehavioral effects in children (Oulhote et al. 2014).

Tsanidou et al. (2015), unlike the majority of research covered in this section, studied the effects of manganese levels in drinking water on dental caries, or cavities. By studying 573 children, aged 5, 6, 11, and 12 years old, Tsanidou et al. found that high manganese concentration in drinking water increased the amount of dental cavities. This study was unique because the children were all of similar socioeconomic class, thus reducing the effects of different home lives on the prevalence of dental cavities. Also, this study focused on dental health impacts, rather than the more commonly studied neurological effects of manganese in drinking water documented by Bouchard et al. (2011) and Khan et al. (2012).

1.4.2.2 Fetuses

Manganese is important for fetal growth and development, but can result in detrimental developmental impacts at higher levels (Chung et al. 2015). During pregnancy, maternal blood and fetal cord blood normally have very high concentrations of manganese, suggesting that manganese plays an important role in development (Chung et al. 2015). In fact, mean maternal blood manganese concentrations have been reported to range from 20.4 μg/L to 24 μg/L, while mean cord blood manganese concentrations range from 34.3 to 45.0 μg/L (Chung et al. 2015). This could be due to “increased physiological demands for fetal and neonatal development” (Chung et al. 2015). Fetuses are at-risk for overexposure to manganese-contaminated drinking water because this element is able to pass through the placenta from mother to fetus (Rodrigues et al. 2015; Guiner et al. 2014). A study done in rural Bangladesh and one in California both found that manganese in fetal cord blood is positively correlated with maternal exposure to manganese in drinking water (Rodrigues et al. 2015; Guiner et al. 2014). Both studies used similar methods; using well water samples and cord blood samples taken at birth, they were able to study the effects of maternal exposure to manganese in drinking water on infant manganese exposure (Rodrigues et al. 2015; Guiner et al. 2014). A limitation of Rodrigues et al.’s study was that they only performed two water samples over the duration of the study: once when women enrolled in the study, and again one month after giving birth. This is problematic because manganese concentrations more than likely fluctuated during their 9 months of pregnancy. A replication of this study could take water samples during each month of pregnancy, which could possibly develop a better understanding of the women’s exposure to manganese.

Rahman et al. (2015) studied pregnant women in rural Bangladesh that consumed well water with varying concentrations of manganese. Using maternal blood samples, well water sampling, and newborn measurements, Rahman et al. (2015) focused on the impacts of manganese exposure on birth outcomes. This study found that women exposed to drinking water with high concentrations of manganese (1495 μg/L) gave birth to babies that were 0.49 centimeters shorter than those exposed to drinking water with low levels of manganese (56 μg/L) (Rahman et al. 2015). Therefore, manganese exposure *in utero* correlated with slower, impaired fetal growth. A limitation of this paper includes: missing well water data from about 30% of their sample population. While Rahman et al. (2015) mentions that this lack of data was adjusted for in their analysis, they did not explicitly explain how this was done. Possibly a more detailed explanation of this limitation would provide further credibility in their methodology. Therefore, while the conclusions of fetal growth impairment may indicate potential impacts of manganese consumption, a more robust method of data collection would help to solidify this finding.

While most studies conducted on manganese exposure via drinking water found negative health effects, one study found something different. A study conducted in rural Bangladesh found that pregnant women exposed to the highest concentrations of manganese in drinking water (1,292 μg/L) were about 35% less likely to have spontaneous abortions compared to women of lowest exposure (56 μg/L) (Rahman et al. 2013). In early pregnancy, excessive exposure to manganese can be beneficial, as it can act as a defense from antioxidant stress (Rahman et al. 2013). While this seems to be in contrast to Rahman et al.'s 2015 study, it may actually be complementary. Manganese exposure may protect malnourished women during pregnancy, but continued exposure can then stunt growth in fetuses. The researchers point out that it is possible manganese only acts as a protectant when the mother is malnourished, and it may not be relevant to extrapolate to other populations (Rahman et al. 2013).

Health effects of drinking water manganese exposure *in utero* have not been documented extensively in primary literature. The studies that have been done focus primarily on populations living in rural areas, making their results potentially unsuitable to generalize to other, more urban populations. However, the research done so far has been relatively consistent in finding that fetal exposure to manganese can be harmful to development during a woman's pregnancy. Further research needs to be conducted in order to cover a more general population of women and strengthen findings from studies lacking extensive data.

1.4.2.3 Seniors

Studying elderly people is imperative for documenting the effects of manganese in drinking water. Research on elderly populations can speak to the long-term health effects of excess exposure to manganese. Lucchini et al. (2014) studied 255 subjects in Italy, aged 65-75 years old, to examine the effects of manganese exposure via drinking water. By putting subjects through neurobehavioral assessments of motor, cognitive, and sensory abilities, Lucchini et al (2014) was able to draw important conclusions. Elderly people, with a lifetime of exposure to elevated concentrations of manganese, show declines in motor skills, odor identification, and cognitive ability (Lucchini et al. 2014). An important limitation of this study was the use of urine and hair as biomarkers. Biomarkers for manganese are difficult to come by because blood and urine manganese levels might be homeostatically regulated, so they do not reflect the actual levels of manganese in a subject's system. However, since Luchini et al. (2014) also used environmental measurements of manganese, this limitation does not inhibit the strength of their findings. Also, many of the other studies reviewed in this paper had similar methodology for using biomarkers (Tsanidou et al 2015; Rahman et al. 2013; Rodrigues et al. 2015; Guiner et al. 2014).

Additionally, elderly people (50 years and older) are more susceptible to adverse effects of manganese, especially neurotoxic effects (EPA 2004). This may be due to "loss of neuronal cells" and "less effective homeostatic control" from aging (EPA 2004).

1.4.2.4 Liver Impairment

Those with impaired livers are at higher risk from manganese exposure because the liver is the organ responsible for the excretion of manganese. This could include those with liver disease, as well as elderly people with decreased liver function, or infants and young children with developing organs (EPA 2004). Hauser et al. (1996) studied the relationship between chronic liver disease and manganese concentrations, and found a clear relationship between high levels of manganese and patients with hepatic cirrhosis. Additionally, Zerón et al. (2011) studied the relationship between hepatic encephalopathy and manganese concentrations. Hepatic encephalopathy is a "complication of both acute and chronic liver failure" (Zerón et al. 2011). This study showed a correlation between increased mortality in patients with hepatic encephalopathy and cirrhosis and high concentrations of manganese (Zerón et al. 2011). However, a limitation in this study was the low number of subjects and the "lack of a well-recognized bioindicator of exposure" (Zerón et al. 2011).

1.4.2.5 Iron-Deficient

Those who are iron-deficient are at a higher risk of exposure to manganese because lack of iron is correlated with increased absorption of manganese (EPA 2004). This could be because "manganese and iron appear to share the same absorption pathways" and "during iron deficiency the number of transporters in enterocyte membranes is increased in order to maximize iron absorption" meaning there is higher manganese absorption when there is a lack of iron (Smith et al. 2013). Evidence shows that iron deficiency specifically results in higher levels of manganese in the brain, causing neurobiological effects such as changes in cognition, behavior, and neurotransmitter metabolism (Erikson et al. 2005). This is significant because iron deficiency is a very common nutritional problem, affecting approximately one-third of the global population (Park et al. 2013).

Children are particularly at risk of iron deficiency. In a study done by Park et al. 2013, 31 iron-deficient infants from ages 6 months to 2 years old were studied in comparison to a control group of 36 healthy infants. Results showed the control infants had a lower average blood manganese concentration (1.499 µg/dL) than iron-deficient infants (2.550 µg/dL). Additionally, when the iron-deficient infants underwent iron therapy, their manganese levels decreased significantly (Park et al. 2013). Furthermore, low-income children are especially at risk. Research has been done showing an association between increased costs of foods containing micronutrients such as vegetables and meat, and higher rates of iron deficiency anemia in low-income school-aged children (Skalicky et al. 2005). This suggests that because food with vital nutrients is more costly, low-income children often lack these necessary nutrients in their diets, resulting in a higher prevalence of iron deficiency. In fact, according to the US Centers for Disease Control and Prevention, 7% of 1 to 2 year old children are iron deficient from all income levels, while 17% of 1 to 2 year old Mexican American children are iron deficient, and 12% of 1 to 2 year old children in low income households suffer from iron deficiency (Schneider et al. 2005).

1.4.3 Conclusion

There are clearly adverse health impacts from overexposure to manganese through both occupational exposure and environmental exposure. While these effects exist for the general population, there are several populations that are especially at risk of experiencing health complications from drinking manganese contaminated water, notably infants and children, fetuses, seniors, liver impaired people, and iron-deficient people. The primary health impacts of manganese are neurotoxic effects as well as reproductive and developmental effects. While more studies should be done on the health impacts on the general population, government agencies should do more to take into account the at-risk populations when determining health standards.

The negative health impacts of manganese have recently been receiving more attention. For example, Massachusetts, Connecticut, and Canada have all adopted more stringent standards for manganese concentrations in drinking water. Acknowledging the higher risk that overexposure to manganese poses to infants, the Department of Environmental Protection in Massachusetts has extended the age cutoff in their Drinking Water Standards and Guidelines, by stating that infants one years old or younger (instead of 6 months) should not be exposed to drinking water exceeding 0.3 mg/L in manganese concentration for more than ten days (Commonwealth of Massachusetts 2015). Additionally, the Department of Public Health in Connecticut has recently set a drinking water Action Level of 0.5 mg/L, which aligns with the World Health Organization guidance level, in order to prevent manganese toxicity (Connecticut Department of Public Health). While it is not yet official, Health Canada is in the process of creating a health-derived value for manganese in drinking water as well (Jane MacAulay, Health Canada, Senior Scientific Evaluator in the Water and Air Quality Bureau, personal communication, May 31, 2016).

Donald Smith, a Professor of Environmental Toxicology at the University of California, Santa Cruz, states that “there are enough human and animal studies to indicate that elevated exposures to manganese in drinking water are associated with adverse health effects in humans, and that the current SMCL may not reflect the best available science now” (Donald Smith, UC Santa Cruz, personal communication, May 23, 2016). Similarly calling into question the SMCL, according to staff at the Massachusetts Department of Environmental Protection, the cosmetic effects or palatability of water failing to meet the current secondary MCL have not effectively served to discourage people from drinking the water; in Massachusetts, cases were observed in which people would regularly drink water with Mn(II) levels that exceeded the EPA secondary MCL.[1] While it appears that there are adverse health effects from overexposure to manganese in drinking water, it is inconclusive whether or not its status should be changed from a secondary contaminant to a primary contaminant. Further studies should be done by the EPA.

1.5 Treatment and Remediation of Manganese in Groundwater and Water Supply Systems

1.5.1 History of Treatment in Maywood

DTSC has conducted water sampling for manganese, TCE, and other contaminants in Maywood since 2007. In the results of a 2010 Phase 1 assessment of the City’s drinking water, manganese exceeded secondary pollutant concentrations in 12 locations throughout Maywood (Kintz 2015). According to the DTSC Maywood Drinking Water Assessment Project report, DTSC “completed, tested and analyzed 140

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[1] Diane Manganaro, Massachusetts Department of Environmental Protection, Office of Research and Standards, personal communication, May 26, 2016.

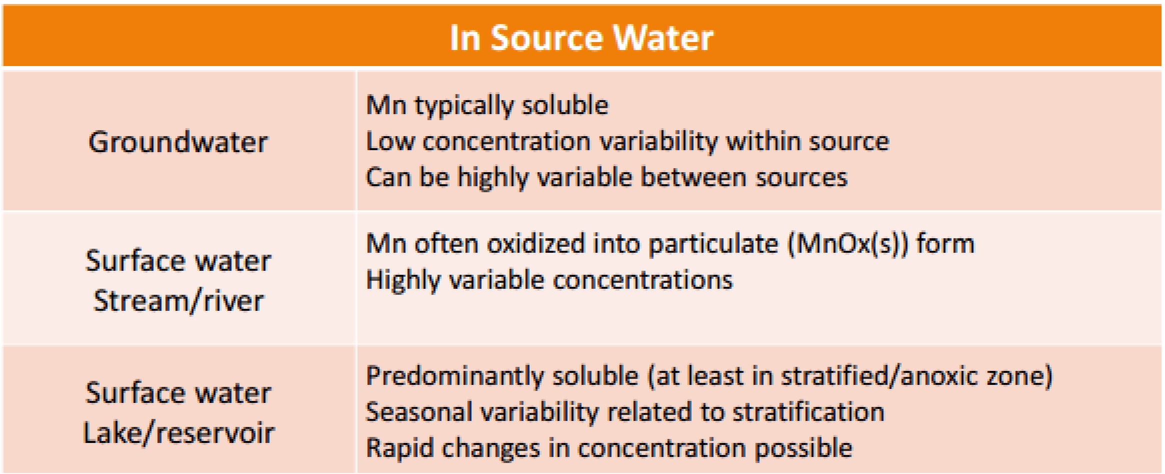
samples in 2010, 2012, and 2013 from residences, public buildings, parks, and source wells from the three water companies" (Kintz 2015). However, it is unclear where and how many exceedances occurred in each year of sampling. As a result of their assessment, Maywood Mutual Water Company 2 installed a manganese treatment system that will be discussed in more detail below. DTSC conducted a second assessment in August of 2012, and found that “water in public buildings and homes [met] EPA drinking water standards” (Kintz 2015). They also concluded that the manganese treatment system installed at Maywood Mutual Water Company 2 was “effective in significantly reducing manganese levels” (Kintz 2015). As of late January of 2015, Maywood Mutual Water Company 1 is awaiting grant funding from the California Department of Public Health to install a treatment system for manganese (Kintz 2015). Additionally, a well owned and operated by Maywood Mutual Water Company 3 was found to have exceedances of TCE; however the utility also has yet to install a treatment system (Kintz 2015).

Assembly Bill 240 (2013) granted $1,000,000 to WRD in order to fund water improvement projects in Maywood (AB 240). WRD is responsible for managing groundwater from the Central and West Coast Basins for almost four million residents in 43 cities of southern Los Angeles County (WRD). In an effort to allocate this funding, WRD produced an Action Plan with 3 separate phases of mitigation measures to improve water quality in the City (WRD 2015). Phase I involves installation of treatment systems at wellheads and changes to water infrastructure at each of the Maywood water systems (WRD 2015). Phase II consists of upgrading disinfection techniques from chlorination to chloramination also in each of the Maywood water systems (WRD 2015), which can have an impact on manganese levels in the supply system, as will be discussed further below. Phase III entails an evaluation of the flushing programs and pipe maintenance for the water systems, as well as possible programmatic improvements (WRD 2015). WRD has stated that Phase I is the most essential to improving Maywood’s water quality, and that it could possibly resolve all the water contamination issues on its own (WRD 2015). Accordingly, the Action Plan recommended that all of the funding be used to install a well treatment system on Mutual Water Company 2’s May Avenue Well which has consistently had manganese levels above the SMCL (WRD 2015). It remains unclear how the AB 240 funding was appropriated.

1.5.2 Manganese as a Constituent

1.5.2.1 Chemistry of Manganese

Manganese has several common forms in drinking water. The reduced form of manganese is Mn(II) which is soluble and colorless, thus invisible to the naked eye (Knocke et al. 2015). Manganese can also exist as oxidized particulate manganese (such as MnO_x) which gives water a brown or black color depending on its concentration (Knocke et al. 2015). Another form of manganese is oxidized soluble manganese (Mn(VII) found as permanganate MnO^-) which imparts a pink or purple color depending on the concentration (Knocke et al. 2015). Lastly, manganese can exist as particulate manganese that is bigger than 0.45µ, which is filterable, or as colloidal manganese which is smaller than 0.45µ and formed when a strong oxidant is used in low-hardness water (Knocke et al. 2015). Soluble manganese (Mn(II)) is removed via chemical oxidation (conversion to $MnO_x(s)$) or adsorption onto a manganese oxide-coated media filter (discussed below) whereas particulate or colloidal $MnO_x(s)$ is treated with solid-liquid separation processes (e.g., settling, filtration) (Knocke et al. 2015). Effectively controlling manganese at a treatment plant first requires having considerable knowledge about the influent source water. For instance, groundwater typically contains soluble manganese whereas surface water manganese is likely to be oxidized into its particulate form (Table 5) (Knocke et al. 2015). This is crucial as the manganese removal strategy will be chosen based on the form of the influent manganese (Figure 5).



In Source Water	
Groundwater	Mn typically soluble Low concentration variability within source Can be highly variable between sources
Surface water Stream/river	Mn often oxidized into particulate (MnOx(s)) form Highly variable concentrations
Surface water Lake/reservoir	Predominantly soluble (at least in stratified/anoxic zone) Seasonal variability related to stratification Rapid changes in concentration possible

Table 6. Summary table comparing characteristics of various source waters (Knocke et al. 2015).

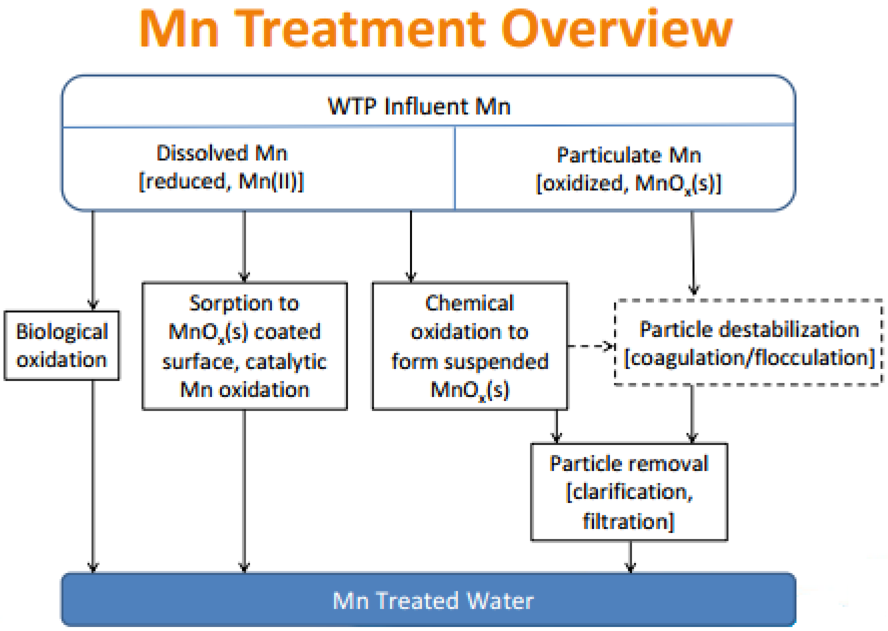


Figure 4. Flow diagram displaying manganese treatment techniques used depending on the state of influent manganese at the water treatment plant (Knocke et al. 2015).

1.5.2.2 Detection Methods

As discussed above, manganese contamination may be present as a number of different compounds. Each compound may require different methods of removal from water sources and while there are several methods for detecting and analyzing the level of Mn in water, none of these distinguish between the types of compounds present. The Agency for Toxic Substances and Disease Registry (ATSDR) published a report in 2008 that discusses well established methods for detection and analysis of manganese in water. The most common technique used for determining manganese concentrations is atomic absorption spectroscopy (AAS) and atomic emission spectroscopy (AES). Atomic absorption spectroscopy is commonly used to determine concentrations of manganese in biological samples but can also be used for analyzing water samples. This technique can detect levels of manganese as low as 0.01 μg/L (ATSDR 2000). Neutron activation analysis is an alternative method that requires little handling of the sample, which means that the risk of contamination of the sample is minimal. One study by Beklemishev et al. (1997) used a catalytic kinetic method involving an indicator reaction catalyzed by Mn(II). Catalytic kinetic methods have a much lower detection limit of 0.005 μg/L and are also easy to transport for field tests at the physical water source (ATSDR 2008). However, because manganese is thought harmless at levels that low, it's generally sufficient to use AAS and AES methods for analyzing drinking water samples.

1.5.2.3 Introduction to Manganese Removal

Mn(II) can be removed in several ways, including: in-situ treatment, biological treatment, chemical oxidation, oxide-coated media, physical separation, ion exchange, precipitation, and sequestration. The most common procedures involve oxidizing the manganese with compounds such as potassium permanganate (and subsequently filtrating), or by catalytic oxidation to the Mn(IV) state. Ion exchange and direct filtration are also prevalent in pilot studies and have been implemented in water treatment plants in a number of systems (Kohl and Medlar 2006). The proceeding sections will seek to discuss common treatment options for removal of Mn(II) from drinking water sources, the cost of manganese removal in various economies of scale, various challenges associated with manganese removal, and possible site-specific remediation options.

1.5.3 Treatment Methods

There are four distinct approaches for water treatment to remove manganese:

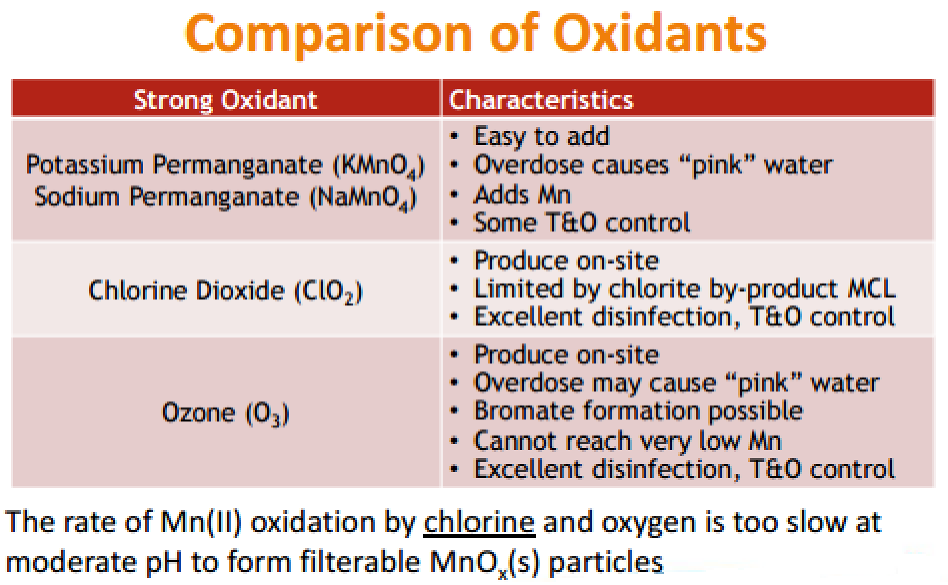
- Oxidizing and filtration is the first and most common approach. The process uses chlorine, potassium permanganate, air, or ozone with settling and/or filtration (Kohl and Medlar 2006).
- Absorbance and catalytic oxidation of manganese on the oxide-coated filter media. This process uses an oxidant, usually potassium permanganate or chlorine, to oxidize the soluble Mn after it has adsorbed onto a filter. Filters are typically dual media filters, manganese greensand, or plants that rely on a small dose of chlorine prior to filtration to maintain the coating of manganese dioxide (Kohl and Medlar 2006).

- Ion exchange, in which manganese cations are exchanged with some other cation, usually sodium**.** This approach relies on all the manganese present to be in the Mn(II) state (Kohl and Medlar 2006).
- Use of membrane filters to remove all particulate manganese. The membrane selection depends on the valence state of manganese. For example, if the manganese is dissolved then reverse osmosis (RO) is used (Kohl and Medlar 2006).

This section will discuss the first three of these treatment techniques, which are commonly used by water treatment plants to remove manganese from drinking water. Additionally, reverse osmosis will be explored.

1.5.3.1 Oxidation and Filtration

Oxidation/precipitation and filtration is the most common method for removing manganese. Most processes oxidize the soluble manganese, Mn(II) into a solid, insoluble form, Mn(IV), which can then be easily removed via filtration (Carlson et al. 1997). There are two methods used for oxidation: aeration and the use of strong oxidizing agents. Aeration involves the injection of air into the water in order to precipitate the soluble manganese present. For manganese removal, aeration is a slow process and requires that the water have a pH above 9.5, which is not common in drinking water (Kohl and Medlar 2006). More commonly, treatment facilities use strong oxidizing agents, including chlorine dioxide, potassium permanganate, ozone, and hypochlorite. Chlorine dioxide is the most economic option and it doubles as a disinfectant. However, it is more effective at removing iron than manganese and also produces disinfection byproducts which would need to be removed later in the treatment process. Potassium permanganate ($KnMnO_4$) is stronger than hypochlorite and chlorine and is easy to transport and use (Raveendran, Ashworth, and Chatelier 2001). It also generates a manganese dioxide precipitate, $MnO_2(s)$, which can then act as an adsorbent and help remove other natural organic material and causes of turbidity. Additionally, it reduces disinfection byproducts and interferes very little in other treatment processes. Ozone is the most expensive option which is why it is used less often than the other options (Kohl and Medlar 2006). Aeration and oxidizing agents can be also be very effective when used in conjunction, with aeration being performed at the water source and agents being used at the treatment plants (Kohl and Medlar 2006). A summary table comparing common strong oxidants is shown in Table 7.



Comparison of Oxidants

Strong Oxidant	Characteristics
Potassium Permanganate ($KMnO_4$) Sodium Permanganate ($NaMnO_4$)	• Easy to add • Overdose causes "pink" water • Adds Mn • Some T&O control
Chlorine Dioxide (ClO_2)	• Produce on-site • Limited by chlorite by-product MCL • Excellent disinfection, T&O control
Ozone (O_3)	• Produce on-site • Overdose may cause "pink" water • Bromate formation possible • Cannot reach very low Mn • Excellent disinfection, T&O control

The rate of Mn(II) oxidation by chlorine and oxygen is too slow at moderate pH to form filterable MnO_x(s) particles

Table 7. Summary table comparing characteristics of strong oxidants (Knocke et al. 2015).

Oxidation of Mn(II) works best under slightly basic conditions since Mn(II) dissolves more easily in water under acidic conditions. A drawback to oxidation is that the process requires a relatively long detention time because Mn(II), especially at low concentrations, has a very slow reaction rate (Gregory and Carlson 2003).

In the removal of Mn(II), oxidation is frequently coupled with filtration to capture the precipitated Mn(IV). For example, microfiltration is often coupled with oxidation using potassium permanganate and ultrafiltration with inline prechlorination. In some filters, membrane fouling can become a problem when removing Mn(II), which is why ultrafiltration with prechlorination can only achieve about an 80% efficiency. Tangential flow membranes address the fouling problem and can achieve 95% efficiency (Ellis et al. 2000).

There are multiple filter media configurations that can be employed, including a highly prevalent sand/anthracite dual media filter and less common Granular Activated Carbon (GAC)/sand dual media filters that have been used in various pilot studies (Hazen and Sawyer 2013). Recent research has explored a more effective oxide-coated media (manganese oxide-coated and iron oxide-coated sand). In such cases, insoluble Mn precipitates, or soluble Mn adsorbs, onto filter media, rendering a physical separation mechanism through surface charge mechanisms (Ahammed and Meera 2010).

1.5.3.2 Adsorption and Surface Oxidation

Another common treatment method involves using the induced oxide-coated media effect (IOCME) at a controlled pH (Kohl and Medlar 2006). This effect entails coating a filter such as manganese greensand in manganese dioxide, which adsorbs dissolved Mn(II) onto the filter's surface (Kohl and Medlar 2006). After adding an oxidant such as chlorine, the soluble Mn(II) is oxidized into insoluble Mn(IV), allowing it to accumulate on the filter (Kohl and Medlar 2006). This process is highly complex to implement, however. For instance, occasionally small colloidal clumps of MnO_2 can form under high oxidation conditions, which can then pass through filters (Kohl and Medlar 2006). Similarly, the addition of excess oxidant can produce soluble MnO_4 which also escapes filtration (Kohl and Medlar 2006). Lastly, Mn(II) can be reduced from MnO_2 which is able to enter the distribution system (Kohl and Medlar 2006). In addition to chemical complications, regulations on disinfectants have led to numerous treatment plants decreasing or entirely phasing out the addition of chlorine in the filtration process (Kohl and Medlar 2006). Without chlorination however, the IOCME cannot take place and dissolved manganese will pass into distribution systems (Kohl and Medlar 2006). It is important to note that chlorine on its own is poor oxidant for direct oxidation of manganese but is very effective when combined with a sorption and surface oxidation process (Knocke et al. 2015).

1.5.3.3 Ion Exchange

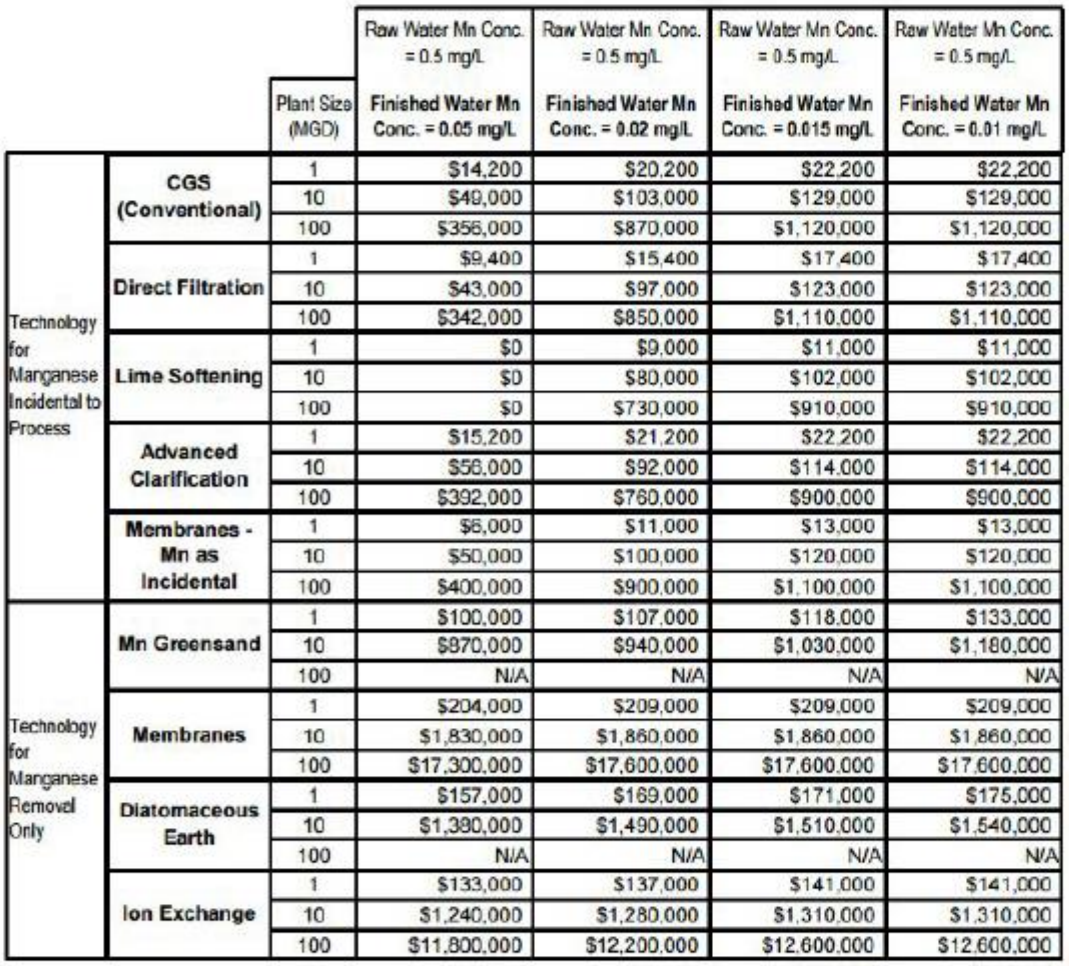
Ion exchange resins are used for ion exchange processes, which involve using an oppositely charged resin base to destabilize target anions or cations. There are varying degrees of ion exchange, whereby anion exchange can be utilized with a weak base or strong base, and cation exchange has similar strong and weak acid components. At a pH of 7-8, manganese ion exchange involves the use of cation exchange, usually with zeolites, and natural zeolites as the resin bed (Puretech). As raw water flows through the resin bed, the zeolites adsorb the Mn(II) metals and cation exchange subsequently occurs. Overtime, the resin bed requires regeneration as hardness accumulates and must be backwashed with a brine solution, which removes hardness and prevents any potential clogging of the resin bed (Sommerfield 1999).

1.5.3.4 Reverse Osmosis

Another physical-chemical process is reverse osmosis. The basics of the process involve pumping groundwater into a treatment facility and forcing it through a fine mesh or screen, thereby trapping the manganese and other contaminants in the mesh while allowing water to pass through. Unfortunately, reverse osmosis will produce leftover manganese and a small amount of water containing very high concentrations of pollutants, making it highly unsafe for disposal (Subramani et al. 2012). However, an emerging technology known as high recovery reverse osmosis can reduce the creation of by-products (Ning et al. 2006; Subramani et al. 2012; Rahardianto et al. 2008). The most successful primary treatment technique coupled with reverse osmosis to further filtration for manganese is electrocoagulation. This process uses dissolved electrodes and hydrogen gas bubbles, causing particles of heavy metal to float to the top of the tank where they can be easily removed. (Subramani et al. 2012). This primary treatment is still being developed, however one study showed that after electrocoagulation treatment and reverse osmosis, levels of manganese in a water sample were reduced to undetectable amounts from previously extreme concentrations of 150,000,000 µg/L (Subramani et al. 2012). In addition to having great success with the removal of manganese, this treatment technique has 95% more recovery than typical use reverse osmosis (Subramani et al. 2012). Using electrocoagulation as a primary treatment for reverse osmosis is a particularly promising remediation technique for groundwater contaminated with manganese.

1.5.4 Treatment Costs

The cost and intensity of treatment will largely influence how viable a manganese removal technology is for a site as well as whether the removal is needed for small, individual households or for large scale commercial use. Based on the pH and oxygen levels in an aquifer, as well as the degree of dissolved particulates present, constituents present in addition to manganese need a suitable multi-contaminant treatment approach such as oxidation-filtration or point-of-use reverse osmosis (DES 2013). For higher manganese concentrations that co-occur with sulfide and/or arsenic and that are above the SMCL, a whole-house oxidation filtration system may be necessary, which can cost anywhere from \$1,500 to \$3,000 (DES 2013). If concentrations are below the SMCL, a point-of-use reverse osmosis system may suffice, and while these systems can only be used at one location, such as a kitchen sink, they only cost around \$150, excluding installation (DES 2013). At the commercial level, pricing for manganese treatment depends on which removal technology is applied, whether removing manganese is the main intention or secondary to the removal of other chemicals, the size of the treatment facility, and the preferred final water concentration (Kohl and Medlar 2006). Treatment options intended to remove only manganese can be one or two orders of magnitude more expensive than those that incidentally treat manganese (Kohl and Medlar 2006). The cost of removal technologies also increases for smaller manganese concentrations and larger treatment facilities (Kohl and Medlar 2006). Table 7 displays the total annual costs associated with different manganese treatment technologies.



			Raw Water Mn Conc. = 0.5 mg/L	Raw Water Mn Conc. = 0.5 mg/L	Raw Water Mn Conc. = 0.5 mg/L	Raw Water Mn Conc. = 0.5 mg/L
		Plant Size (MGD)	Finished Water Mn Conc. = 0.05 mg/L	Finished Water Mn Conc. = 0.02 mg/L	Finished Water Mn Conc. = 0.015 mg/L	Finished Water Mn Conc. = 0.01 mg/L
Technology for Manganese Incidental to Process	**CGS (Conventional)**	1	$14,200	$20,200	$22,200	$22,200
		10	$49,000	$103,000	$129,000	$129,000
		100	$356,000	$870,000	$1,120,000	$1,120,000
	Direct Filtration	1	$9,400	$15,400	$17,400	$17,400
		10	$43,000	$97,000	$123,000	$123,000
		100	$342,000	$850,000	$1,110,000	$1,110,000
	Lime Softening	1	$0	$9,000	$11,000	$11,000
		10	$0	$80,000	$102,000	$102,000
		100	$0	$730,000	$910,000	$910,000
	Advanced Clarification	1	$15,200	$21,200	$22,200	$22,200
		10	$56,000	$92,000	$114,000	$114,000
		100	$392,000	$760,000	$900,000	$900,000
	Membranes - Mn as Incidental	1	$6,000	$11,000	$13,000	$13,000
		10	$50,000	$100,000	$120,000	$120,000
		100	$400,000	$900,000	$1,100,000	$1,100,000
Technology for Manganese Removal Only	**Mn Greensand**	1	$100,000	$107,000	$118,000	$133,000
		10	$870,000	$940,000	$1,030,000	$1,180,000
		100	N/A	N/A	N/A	N/A
	Membranes	1	$204,000	$209,000	$209,000	$209,000
		10	$1,830,000	$1,860,000	$1,860,000	$1,860,000
		100	$17,300,000	$17,600,000	$17,600,000	$17,600,000
	Diatomaceous Earth	1	$157,000	$169,000	$171,000	$175,000
		10	$1,380,000	$1,490,000	$1,510,000	$1,540,000
		100	N/A	N/A	N/A	N/A
	Ion Exchange	1	$133,000	$137,000	$141,000	$141,000
		10	$1,240,000	$1,280,000	$1,310,000	$1,310,000
		100	$11,800,000	$12,200,000	$12,600,000	$12,600,000

Table 8. Summary table displaying total annual costs of different manganese treatment technologies (Kohl and Medlar, 2006).

1.5.5 Complications with Manganese Treatment

1.5.5.1 Treatment Challenges

The chemistry of manganese is very complex, making it a difficult species to remove from drinking water. As described in the section on adsorption and surface oxidation, under certain conditions, manganese dioxide can be formed into a colloid which can be smaller than 1μ (Knocke et al. 2015). These colloidal particles are hard to capture on a filter because they do not settle and must be removed by combined coagulation and filtration or by utilizing ultrafiltration (Knocke et al. 2015). When too much oxidant is added to the process, however, soluble MnO_4 can pass into the distribution system. Moreover, when manganese dioxide happens to be reduced to Mn(II), soluble Mn(II) can also pass into the distribution system. Oxidation of manganese can also be accidentally caused by aeration due to pumping, disinfection of influent water with chlorine, and raising pH for corrosion control (Protasowicki 2015).

Overall, many factors can contribute to making the behavior of manganese a complicated phenomenon in drinking water (Kohl and Medlar 2006).

1.5.5.2 Manganese Accumulation within Distribution Systems

Even at levels below the SMCL, manganese can accumulate in drinking water distribution systems, become oxidized due to various processes, and ultimately cause the water that reaches end-users to appear discolored and/or turbid if it is not adequately removed during treatment (Protasowicki 2015).

For instance, bacteria within the distribution systems can also affect levels of manganese in consumers' drinking water if the incoming treated water still contains dissolved manganese (Kohl and Medlar 2006). Specific species of bacteria that accumulate in distribution systems (*Pedomicrobium manganicum* and *Metallogenium*) can form biofilms within pipes and oxidize the dissolved manganese into its insoluble form, promoting the growth of manganese deposits on internal pipe surfaces (Kohl and Medlar 2006). Without sufficient chlorination from the treatment plant to control the growth of biofilms, manganese deposition will continue to occur (Kohl and Medlar 2006). However, if soluble manganese continues flowing into distribution systems, increasing chlorination will not decrease the amount of manganese deposition (Kohl and Medlar 2006). In fact, treatment plants attempting to increase chlorination may actually increase the oxidation of manganese and thus its deposition within the distribution system pipes (Kohl and Medlar 2006). When water suppliers change the hydrostatic pressure and flow rates within their systems, manganese deposits will then be released and resuspended within the water, causing the water that arrives to the end user to contain high concentrations of manganese and thus be visibly discolored (Kohl and Medlar 2006; Schlenker, Hausbeck and Sorsa 2008).

Other physical and chemical changes to the distribution system can resuspend the deposits such as flow reversals, construction occurring aboveground, changes to water pH, and many other chemical alterations (Friedman 2010; Larkin and Bryan 2007). The amount of manganese deposited within distribution systems is essentially determined first by the quantity of manganese in the inflowing water (Kohl and Medlar 2006). The deposition also is determined by the capability of the pipes to attract manganese oxides, which changes based on the water velocity (Kohl and Medlar 2006). In general, manganese deposition is typically found to decline with distance from the treatment facility (Kohl and Medlar 2006).

The pipeline material of a drinking water distribution system can also have a significant impact on the amount of manganese that ends up in drinking water. The levels of acidity and carbon dioxide in the water supply are two of many factors which influence the corrosion of distribution pipes (Alvarez-Bastida et al. 2013). In one study, water sampled from distribution wells was found to be especially corrosive and pipes featured in distribution systems that were made out of polyvinyl chloride (PVC) and steel were found to be particularly affected by the corrosiveness of the water (Alvarez-Bastida et al. 2013). As plastic and steel pipes corrode, manganese is deposited on the internal surfaces of the pipes, though the exact processes behind this phenomenon are not well understood (Valentukevičienė et al. 2012). As metal corrodes, metal ions are released which have a high affinity for heavy metals, especially manganese (Valentukevičienė et al. 2012). Researchers have demonstrated that drinking water from distribution systems utilizing plastic pipelines had a total manganese concentration 35 times that of drinking water conveyed by iron pipes (Cerrato et al. 2006). Similarly, drinking water transported by galvanized steel pipes had manganese concentrations over 10 times as high as water delivered with other materials (Valentukevičienė et al. 2012). Again, changing the flow conditions in the distribution system can cause the release of these manganese deposits which can then reach end-users (Valentukevičienė et al. 2012).

1.5.5.3 Treatment Plant Operations and Management

The individual characteristics of a treatment plant may also influence manganese’s presence in distribution systems and thus drinking water. For instance, rather than filtering out manganese, some treatment plants utilize sequestration (Kohl and Medlar 2006). Sequestration however, can be inferior because first, the chemicals used in sequestration break down over time and will therefore be ineffective if the water stagnates for a long time within the distribution system (Kohl and Medlar 2006). Second, sequestration chemistry requires exceedingly precise balancing; excess sequestering agents will release manganese deposits within pipes, while a lack of chemicals will sequester manganese incompletely (Kohl and Medlar 2006).

1.5.5.4 Additional Information

For additional information on treatment, readers should view Water Research Foundation Report #4373 which is a comprehensive resource on manganese in drinking water. This guidance manual address manganese treatment in water sources and at the treatment plant. Additionally, this resource discusses how manganese treatment fits into overall treatment objectives. It is worth noting that the intended users of this manual are water quality managers, treatment plant operators, and design and process engineers.

1.6 Site Specific Remediation Options for Manganese

This section will cover various available techniques that can be applied to remediate site-specific manganese groundwater contamination. It is important to note that remediation is not always the best option for water utilities and many will decide to utilize treatment of source water at the plant rather than at the source. In fact, remediation is generally seen as a high risk activity to utilities because many techniques are highly experimental. However, it is still important for water treatment facilities to realize that there is potential to remediate manganese at the source. The types of remediation techniques discussed here will fall into one of three general categories: chemical, biological, or physical-chemical processes.

1.6.1 Chemical Processes

Chemical processes such as oxidation, reduction, and neutralization reactions can be used to decrease the toxicity and mobility of pollutants. An oxidation reaction adds oxygen to the groundwater to help facilitate the remediation. In a reduction reaction, oxygen is removed from the groundwater. Most reduction reactions involve the injection of a reagent that creates a zone in the groundwater that reduces out the oxygen. During this reaction, the toxic pollutant becomes less potent or more immobilized so that it is unable to reach consumers (Hashim et al 2011; Evanko and Dzombak 2015). This section outlines the following groundwater remediation methods for manganese: gold nanoparticle absorption, ozone oxidation, and an reduction-oxidation reaction with caustic magnesium.

The use of gold nanoparticles is a new method that is being examined to clean up surface water and groundwater that are polluted with heavy metals. Gold nanoparticles have different properties than bulk gold and thus are much more economically friendly than one might imagine (Qian et al. 2013). The nano-particles have a very high binding affinity for mercury and lead as well as a high surface-to-volume ratio, which is ideal for maximum absorption of the pollution in the groundwater (Lo et al. 2012). Gold nanoparticles have high levels of absorptivity to take up heavy metal pollutants. Not only can gold nanoparticles help clean up source waters, they can also be used to detect the quality of the water by sensing and absorbing different parts of the toxins in the presence of heavy metals (Kim et al. 2001). Gold nanoparticles have been shown to immobilize the metal alloys in aluminum and mercury laced ground water due to their poor electrostatic conduction (Qian et al. 2013). While gold nanoparticles have been very successful with other heavy metals, additional research is needed to examine how this emerging process performs with manganese and other groundwater contaminants.

Gold nanoparticles, as well as copper and silver, can also be used to help identify the pollutant concentration of toxic groundwater. The nanoparticles could be used as high accuracy colorimetric reports (Kim et al. 2001). A colorimetric report is simply a color changing substance or fluid that changes when a chemical, or in this case a pollutant, is present. There are proofs of concept that show how the nanoparticles could be used in the field to obtain quick results by changing color when they react with a specific pollutant. By absorbing the pollutant, the particles will reflect different colors of light, which can be analyzed to determine which pollutant is in the groundwater. Lab tests have been shown to have positive accurate responses to a variety of heavy metals, including lead, mercury, zinc, and cadmium (Kim et al. 2001). While this process has shown conclusive successful evidence in the lab, more research should be conducted before it is performed on a large scale in the field.

An additional chemical process for removing manganese is ozone oxidation. This process simply injects ozone into contaminated groundwater, which then reacts with manganese and iron, causing them to precipitate out of the water (Seo et al. 2010). The ozone and manganese can later be collected by sand filtration, thus removing them from the water (Seo et al. 2010). Researchers have used this process in a pilot scale program in Korea to help remediate manganese contaminated groundwater in an abandoned mine. In their program, the researchers tested two different levels of ozone doses at 7.5 and 24 grams per hour. To run the experiment, each ozone dose was put into an ozone reactor in the groundwater. After 6 hours, the 24 gram per hour dose brought contamination levels in the water down below the legal drinking requirement in Korea, resulting in less than 30 μg/L of manganese and iron (Seo et al. 2010). One drawback of this process is that it increases the pH of the water, resulting in more alkaline groundwater. Despite this, the researchers found that the concentration of sulfate was not affected (Seo et al. 2010). More research should be conducted on the high pH level of water and how it could affect future groundwater remediation solutions. Overall this process appears to be quite effective in site-specific remediation of manganese polluted groundwater.

1.6.2 Biological Processes

Biological processes for remediation in this context are defined as using plants or a microorganism to naturally reduce contaminant levels found in groundwater. Many of the processes in this category do not apply to heavy metals and are mostly used for organic pollution. However, there is emerging research that suggests that certain processes could also be used to remediate heavy metal toxins in groundwater supply. This section will outline the following biological methods for groundwater remediation of manganese: using fungus and an air filtration bag, passive limestone removal beds, and biological absorption using a *Rosa Centifolia* flower.

The use of fungi to mitigate manganese oxide in groundwater is one method of bioremediation that has proven to be successful at a Superfund site. Researchers at North Carolina State used the fungi phyla *ascomycota* and *basidiomycota* to treat the groundwater, each of which are made up of at least 90% the same genetic material (Gardner et al. 2013). In the experimental setup, a water intake valve took groundwater and passed it through an air filtration bag (Gardner et al. 2013). Next, the water flowed into tanks where all of the air was removed from the water before it flowed into an intermediate tank containing the fungi (Gardner et al. 2013). At this point, manganese oxide was removed from the water and formed a sludge that was passed through a series of ion exchange columns (Gardner et al. 2013). The researchers found that the process worked well to remediate the manganese oxide from 4,820 μg/L to 3,230 μg/L, however it may not work very well on a larger scale (Gardner et al. 2013). While this method did not have a tremendous effect, it demonstrates that with future advances in the technology, bioremediation may have the potential to be successfully implemented to reduce manganese oxide pollution in groundwater.

A second biological process for remediation of groundwater is the use of passive manganese removal beds. This type of passive clean-up process has been used in abandoned mines all over the eastern United States, particularly the Appalachian Mountains, and has been especially successful in Pennsylvania (Chaput et al. 2015; Berghorn and Hunzeker 2001). This type of treatment uses biologically activated limestone treatment beds to remove manganese cheaply and safely from abandoned mine areas (Chaput et al. 2015; Berghorn and Hunzeker 2001). These limestone beds are a fairly simple construct: first, a ditch or channel is dug and limestone containing microorganisms is laid down. Then the polluted water is run through the ditch before being distributed to end users (Berghorn and Hunzeker 2001). These beds raise the pH of the treated water in order to allow microbes to remove the manganese (Berghorn and Hunzeker 2001). Overall this method is a cost effective, low maintenance, and successful process for remediating manganese and other heavy metal pollutants in groundwater.

Another more unique biological process is using a flower called the *Rosa Centifolia* (R. *Centifolia*) as a bioremediation technique. Researchers biologically treated R. *Centifolia* before using it as an adsorbent to uptake manganese as well as other heavy metals from contaminated groundwater (Abdul Kadir et al. 2012). The researchers found that by leaving R. *Centifolia* in the contaminated ground water for 240 minutes at a pH of 5, the treated flower absorbed 77.3% of the manganese in the water - dropping manganese concentrations from 772 μg/L to 110 μg/L (Abdul Kadir et al. 2012). R. *Centifolia* does not grow in the wild but is easily cultivated, which would make obtaining the flower relatively easy and most likely cost effective (Plants for a Future). This method appears promising, however requires further research as there is very little other research or experiments done with R. *Centifolia* as a biological absorbent, or any other biological absorbent.

1.6.3 Physical-Chemical Processes for Remediation

Physical-chemical methods of ground water remediation are processes that physically block or immobilize pollutants in groundwater. Many of these processes have overlapping features with the chemical processes for remediation, but are different in that these methods of remediation interact physically with the water. This section will outline the following physical-chemical methods for groundwater remediation of manganese: soil washing, reverse osmosis, and electrokinetic remediation.

One type of physical-chemical reaction that remediates groundwater pollution is soil washing, also sometimes referred to as soil flushing. Soil flushing uses copious amount of water, with or without additives, to dilute pollutants in the contaminated soil and groundwater (Villa, Trovó, and Nogueira 2010; Mulligan et al. 2001). Additives, such as organic or inorganic acid, methanol, or non-toxic cations, are generally introduced to the water solution to increase the effectiveness of the technique (Mulligan et al. 2001). Soil flushing works best when the water solution can easily penetrate the groundwater aquifer around the soil. Without at least moderate permeability, the use of soil washing is much less effective. Little research has been conducted on this technique for remediation of heavy metal contamination, and additional study would be necessary given the potential for adverse impact that could be caused by additives commonly used for this process (Mulligan et al. 2001).

Finally, in electrokinetic remediation, at least two iron cathodes are placed into the soil, and a direct current (DC) is run between them (Agnew et al. 2011). This is an effective remediation method because it causes manganese as well as many other types of heavy metals to precipitate out of groundwater and surrounding soil at the site of the cathode (Agnew et al. 2011). The contaminant can be easily removed from the soil and disposed of properly. By using this technique, the iron cathodes also act as a physical barrier that slows down and immobilizes the manganese in the groundwater (Agnew et al. 2011). This technique has been especially effective at removing manganese, with up to 95% efficiency in types of soil ranging from very porous to near impermeable (Virkutyte, Sillanpää, and Latostenmaa 2012). To have the manganese precipitate out of the soil, the area close to the electrodes needs to have a very high pH (Laurence and Andrew 2009). Also, while this method has proven to be effective, there are other considerations including the cost and amount of electricity used; a typical remediation setup uses power at a rate of about 500 KW/ (h(m^3)). Also, the effectiveness of this technique is highly dependent on the pH and temperature of the soil, as the process becomes much less efficient with increasing soil temperature, and running electrical current through the soil can cause it to heat significantly (Virkutyte et al. 2012). Electrokinetic treatment is an effective remediation method under the right conditions, however without the right conditions this method becomes much more challenging.

1.7 Current Status of Treatment in Maywood

Obtaining current information on the status of treatment in Maywood has been alarmingly difficult, raising serious concerns over agency transparency or whether the average Maywood resident has any option available to them to obtain clear, current information on the status and safety of their water supply system. We were able to contact Roger Kintz, the Environmental Justice Coordinator for DTSC. According to Mr. Kintz, the treatment system installed by Maywood Mutual Water Company #2 has been effective in lowering manganese concentrations below the SMCL (Kintz 2016). The treatment system in place utilizes a membrane filtration process and works to remove metals from drinking water, but not industrial solvents such as PCE and TCE (Kintz 2016). The treatment system requires an infrastructure update which will be performed by the Army Corps of Engineers, but the update is seen as an immediate fix (Kintz 2016). Maywood Mutual Water Company #1 is still awaiting funding for a treatment system (Kintz 2016). Maywood Mutual Water Company #3 has been placed under the authority of EPA Region 9's Superfund Office because of their exceedances of TCE at wells (Kintz 2016). According to the correspondence with Kintz, DTSC has allegedly closed their project on Maywood around 2013, after it was established that the treatment system at Mutual Water Company #2 was working effectively (Kintz 2016). To obtain information regarding the status of treatment at Mutual Water Company #3, Kintz referred us to EPA Region 9's superfund office where we spoke to a toxicologist who referred us back to DTSC. To obtain information regarding the status of treatment at Mutual Water Company #1, Kintz stated that there was a contact at SWRCB that we should be contacted to but never provided a name or number and Kintz became unreachable. For future direction, Kintz should be recontacted for information regarding this matter.

Methods

1.8 Data Collection

1.8.1 Drinking Water Well Data Collection

To begin compiling information for our database, we obtained the "Water System Number" or code of each of the three Maywood Mutual Water Companies from State Water Resources Control Board Division of Drinking Water (DDW 2016). Using the codes: Maywood Mutual Water Company #1 (1910084), Maywood Mutual Water Company #2 (1910085), and Maywood Mutual Water Company #3 (1910086), we searched DDW's Public Water Supply database. For each company, we were able to view and download results for each drinking water well. After exporting to Excel, we searched the data sheet of each well for the following constituents of interest:

1. Alkalinity
2. Arsenic
3. Calcium
4. Dissolved oxygen (DO)
5. Iron
6. Lead
7. Manganese
8. Nickel
9. pH
10. Tetrachloroethylene (PCE)
11. Trichloroethylene (TCE) and,
12. Total Dissolved Solids (TDS)

These constituents were chosen for analysis purposes, as well as to compile general water quality parameters for future potential organizations working with Maywood's water quality. We compiled data on well identification number, analyte, concentration result, units, sample date, and source of information for each of the 6 drinking water wells operated by the Maywood Mutual Water Companies.

Locations of public drinking water supply wells have historically been held confidential in California. This rule is still strictly adhered to by many major water agencies and suppliers, including those in Maywood. While, as discussed below in our challenges section, we were unable to obtain the location of the wells from either the State Water Board or, for several of the wells, from the Department of Water Resources (DWR). However, we were able to determine the approximate addresses of the water supply wells from a report by WRD (WRD 2015; Figure 1). Using the approximate addresses, we used Google Earth to obtain approximate latitude and longitude information for each well (see Figure 6). We were able to check our approximate location information for 3 of the 6 drinking water wells against Well Completion Reports (WCRs) ultimately obtained from DWR, and concluded that our approximate locations were sufficiently accurate for further analysis.

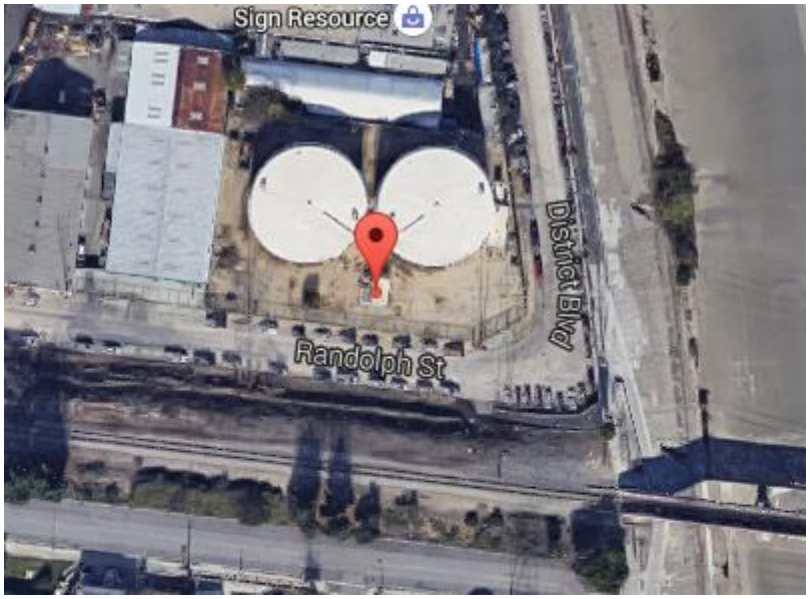
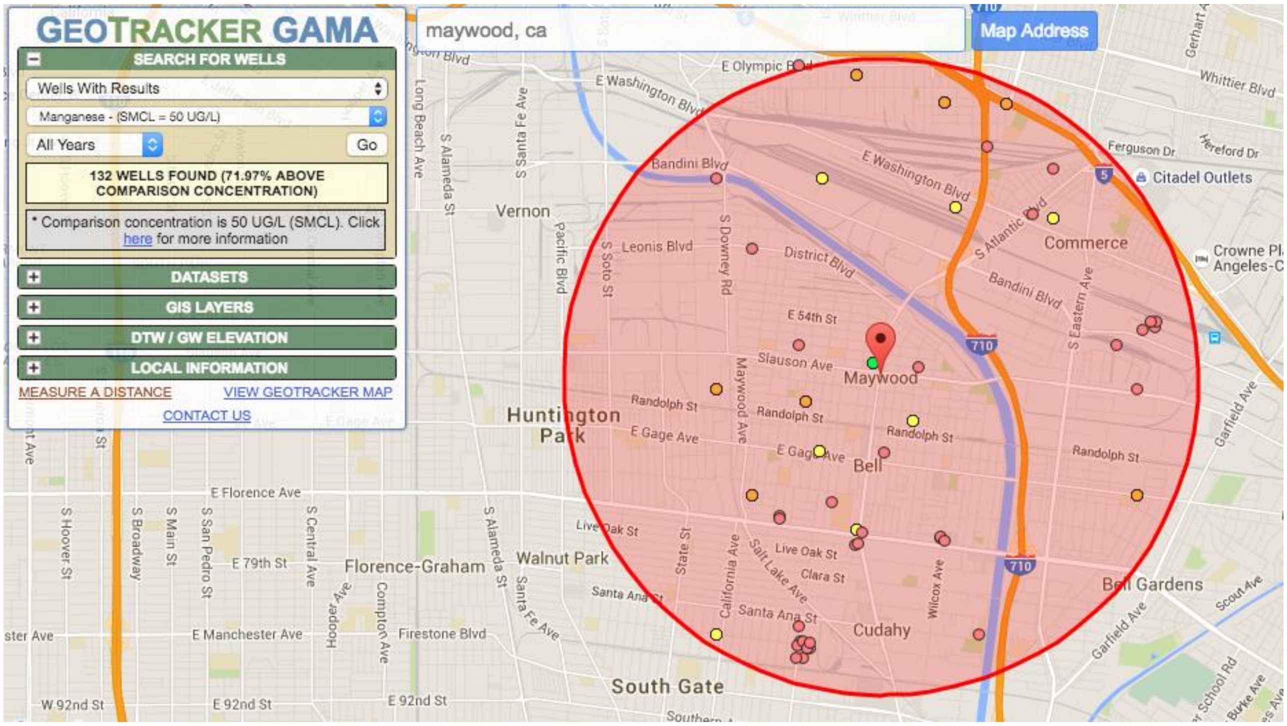


Figure 5. Google Earth image of Well no. 4 operated by Maywood Mutual Water Company # 3.

1.8.2 Environmental Monitoring Well Data Collection

For monitoring wells in the area, we used the GAMA groundwater information system to search for well data in a 2.3 mile (12,000 foot) radius of the center point (Figure 7) of Maywood, CA (33.986676, -118.185360) (GAMA 2016). This 2.3 mile radius was chosen for analysis to incorporate the entirety of Maywood as well as the surrounding cities of Huntington Park, Bell, Bell Gardens, and Commerce; environmental issues associated with these cities are similar to situations in Maywood largely due to exposure to major industrial sites such as former Exide and Pemaco plants (Barboza 2015).


maywood, ca

Wells With Results

Manganese - (SMCL = 50 UG/L)

All Years

132 WELLS FOUND (71.97% ABOVE COMPARISON CONCENTRATION)

* Comparison concentration is 50 UG/L (SMCL). Click here for more information

Figure 6. Geotracker GAMA screenshot showing results for wells with manganese data within the 2.3-mile search radius centered on Maywood, CA.

From Geotracker GAMA, we exported data on all of the constituents of concern (alkalinity, arsenic, calcium, DO, iron, lead, manganese, nickel, pH, PCE, TCE, and TDS). We obtained information on the latitude, longitude, and well depth for each well we collected data from. To obtain hydrologic information about our study area, we recorded minimum depth to water, maximum depth to water, and depth-top of casing to well screen.

We came across several wells with the same well identification name during the course of our investigation. For example, if we found two wells labeled MW-4, we checked to ensure they had different latitudes and longitudes, since they did have different locations, we labeled the duplicated well identification names as MW-4 and MW-4a. For the purposes of modeling, the repeated well identification names did not impact our analysis.

1.8.3 Well Comparison

Environmental groundwater monitoring wells can be set at any number of depths, depending on what type of activity the well is monitoring. Initially, this proved to be an issue for our project, as the analysis of our data relied on whether we could compare information from both drinking water and monitoring wells. Since various wells could be pulling from greatly differing depths, this could have impacted the accuracy of the analysis. The question was then if there is vertical communication between aquifers in the area, which would mean that groundwater, and therefore contaminants, can migrate down the water column vertically, passing through different aquifers. After contacting a hydrologist from the United States Geological Survey (USGS) who specializes in the hydrogeology of the area, we determined that there is likely enough vertical communication between aquifers to be able to accurately compare wells pulling from different depths and aquifers. This communication is likely due to improperly sealed well casings and convergence of aquifers to the east of our study area. Both of these factors create a situation where shallower groundwater contamination is likely influencing the contamination of deeper groundwater. Therefore, we concluded that we can compare drinking water and monitoring wells.

1.8.4 Groundwater Concentration Database Limitations

Due to our many obstacles throughout this project, our groundwater concentration database has a few important limitations. The data we retrieved from Geotracker GAMA was especially inconsistent. As mentioned above, we frequently came across the same well ID with different locations and had to manually included letters to the end of duplicates to differentiate (i.e. MW-2a, MW-2b, MW-2c). With three different members adding to and adjusting the database, there was more than enough room for error in this section.

In addition, the well depths, or depth that groundwater was sampled or extracted from, from Geotracker GAMA were unclear and sometimes missing. The GAMA database provided four columns of information involving well construction information: “min depth to water”, “max depth to water”, “depth - top of well casing to well screen” and “length of well screen”. Oftentimes, the two last columns, “depth - top of well casing to well screen” and “length of well screen”, which may have provided the clearest indication of actual well depth, were not included. The first two columns as a range of “min depth to water” to “max depth to water” and included the third column were included when possible. In order to understand which of these columns or combination of columns would describe the well depths best, we coordinated a call with contacts at the SWB GAMA program. However, we were unable to clearly identify which of these well attributes should be used. This is a large limitation for our database, because while our research indicates that there is vertical communication between aquifers in the region, well depth can nevertheless play a big role in understanding the location, movement, and overall distribution of contaminants. If this database were to be used for other modeling purposes, it should be noted that more research regarding depths of wells should be conducted.

For the data from WRD’s Drinking Water Watch, there are no well depths listed. This is due to the historical restrictions on drinking water well location and characteristics. While these laws have recently changed, the changes are not reflected in DWD database. In the interest of receiving these well depths, we contacted the Maywood Water Mutual companies. We received responses from all three of the Maywood Water Mutual companies. However, Maywood Mutual Water Company 2 was unsure of the accuracy of the values they gave us. These depths were also substantially shallower than those for 1 and 3 so we are hesitant to reply on these approximations.

In terms of the WRD’s monitoring well data, we have listed the well depths and are confident in the accuracy.

1.8.5 Industrial Source Site Data Collection

To investigate potential industrial sources of pollutants in Maywood’s groundwater, we began by retrieving data on releases of manganese, TCE, and lead from sites within a 3-mile radius centered on the

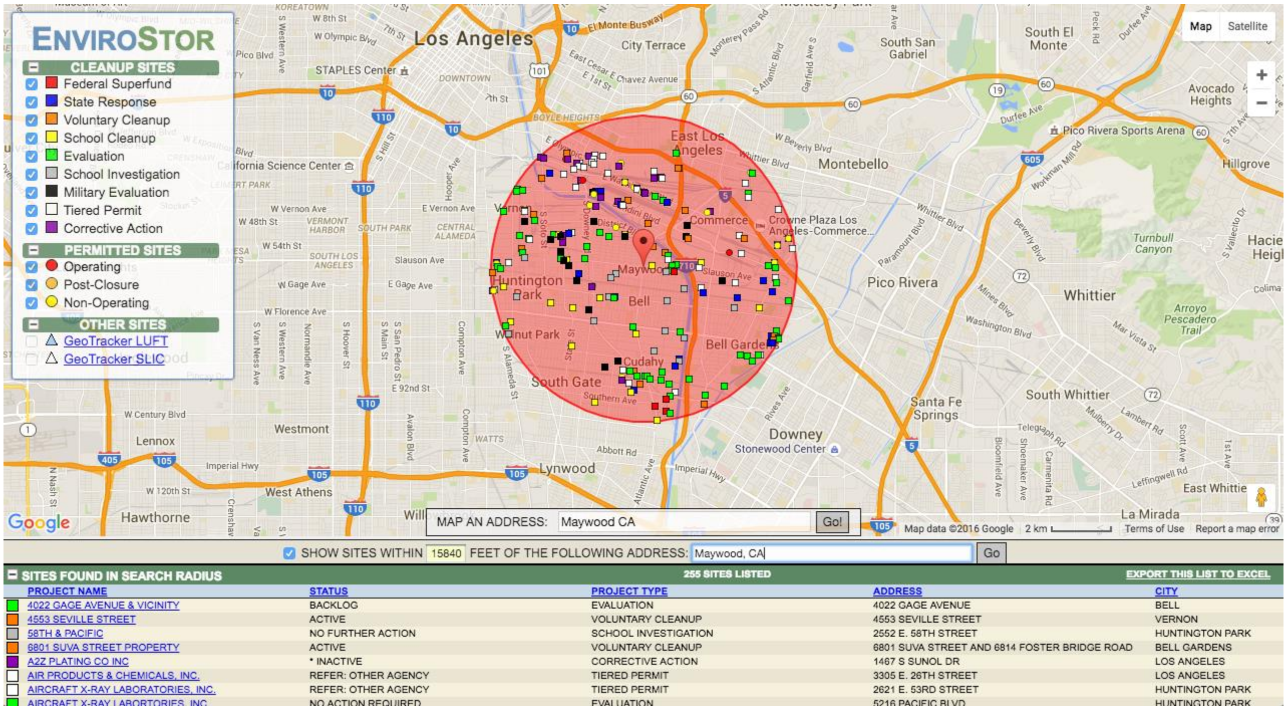
City of Maywood. These contaminants were chosen for review to allow comparison with our groundwater contamination distribution maps for the area. Similar to our groundwater quality data collection, this radius was chosen to incorporate the entirety of Maywood as well as the surrounding cities of Huntington Park, Bell, Bell Gardens, and Commerce. However, since some of the contaminants reviewed had only limited data available in the area around Maywood, we expanded the scope of our review slightly to include more industrial sites in the surrounding area.

We also identified four other contaminants of concern: PCE, solvents, metals, and fuel based sources (including gasoline and fuel). We choose to look for potential PCE sources because industries who discharge PCE are found near Maywood. We choose to look for potential sources of solvents because both PCE and TCE are types of solvents **-**while the term 'solvents' is general, PCE and TCE may have been included under the umbrella term. To ensure all possible sources of PCE and TCE were accounted for we also identified the sources of solvents. Similarly, we chose to look for potential sources of metals because manganese is a metal and the databases could be categorizing manganese under the more general term of 'metals'. We choose to look for potential sources of fuel or gasoline and fuel oxygenates because manganese oxide in the past has been used as a fuel oxygenate. As a result, manganese may be present in fuel or gasoline that is being released into groundwater or soil from sources including leaking underground storage tanks. Finally, we attempted to identify the locations of landfills and solid waste transfer facilities in the area because they are known sources of manganese pollution (Johnson 2008).

Potential sources of TCE, PCE, and lead were obtained from all three databases we reviewed, the EPA Toxic Release Inventory (TRI), DTSC's EnviroStor, and the State Water Board's GeoTracker. These databases and their limitations are discussed below. Potential sources of manganese were identified only from TRI because neither the EnviroStor nor GeoTracker databases report manganese. Potential sources of solvents, fuel or gasoline, and fuel oxygenates were obtained only from EnviroStor and GeoTracker.

1.8.5.1 EnviroStor

The first database we looked at was EnviroStor, managed by DTSC. This database keeps track of contaminated properties and cleanup sites in California. We used the search radius feature to find sites within 15840 feet (3 miles) of Maywood, CA (Figure **8**).



MAP AN ADDRESS: Maywood CA

☑ SHOW SITES WITHIN 15840 FEET OF THE FOLLOWING ADDRESS: Maywood, CA

SITES FOUND IN SEARCH RADIUS — 255 SITES LISTED — EXPORT THIS LIST TO EXCEL

	PROJECT NAME	STATUS	PROJECT TYPE	ADDRESS	CITY
🟩	4022 GAGE AVENUE & VICINITY	BACKLOG	EVALUATION	4022 GAGE AVENUE	BELL
🟧	4553 SEVILLE STREET	ACTIVE	VOLUNTARY CLEANUP	4553 SEVILLE STREET	VERNON
▨	58TH & PACIFIC	NO FURTHER ACTION	SCHOOL INVESTIGATION	2552 E. 58TH STREET	HUNTINGTON PARK
🟧	6801 SUVA STREET PROPERTY	ACTIVE	VOLUNTARY CLEANUP	6801 SUVA STREET AND 6814 FOSTER BRIDGE ROAD	BELL GARDENS
🟪	A2Z PLATING CO INC	* INACTIVE	CORRECTIVE ACTION	1467 S SUNOL DR	LOS ANGELES
☐	AIR PRODUCTS & CHEMICALS, INC.	REFER: OTHER AGENCY	TIERED PERMIT	3305 E. 26TH STREET	LOS ANGELES
☐	AIRCRAFT X-RAY LABORATORIES, INC.	REFER: OTHER AGENCY	TIERED PERMIT	2621 E. 53RD STREET	HUNTINGTON PARK
🟩	AIRCRAFT X-RAY LABORTORIES, INC	NO ACTION REQUIRED	EVALUATION	5216 PACIFIC BLVD	HUNTINGTON PARK

Figure 7. Envirostor sites within a 3 mile radius of Maywood.

Next, the exported results yielded an excel file containing project names, status of the project, address, and city. When the results are exported, there is no chemical or method of release listed. We navigated to each release site individually to obtain this information.

Once the site is clicked on individually it lists: the chemical being cleaned up, the media of concern, and the method of release. We then compiled all of the available information into our own excel sheet.

1.8.5.2 GeoTracker

The next database we used was GeoTracker, managed by the California State Water Resources Control Board. GeoTracker keeps track of the discharge of waste to land and discharge from underground storage containers. GeoTracker has a very similar interface to EnviroStor and the process of obtaining data was nearly identical. We looked at sites within 15840 feet (3 miles) of Maywood, CA (Figure **9)**.

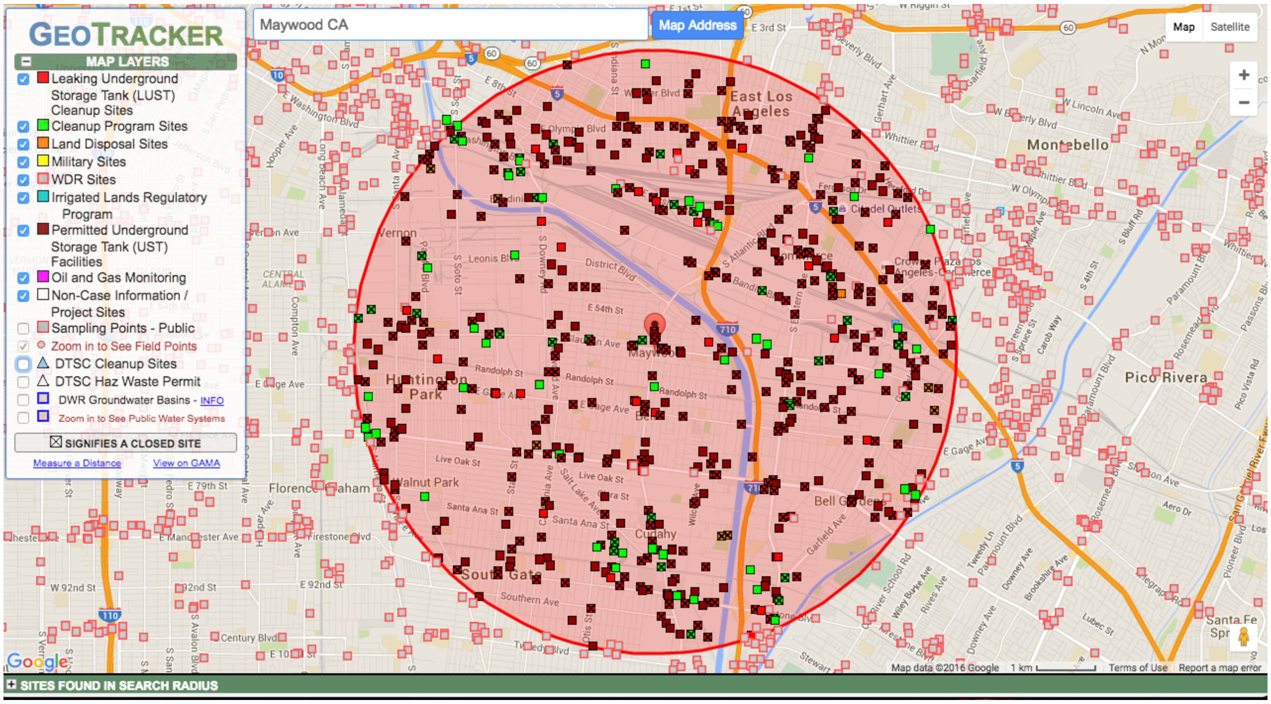


Figure 8. Geotracker sites within a 3 miles radius of Maywood, CA.

Next, the exported results yielded an excel file with project names, status of the project, address, and city. Similar to Envirostor, when the results are exported, there is no chemical or method of release listed. We navigated to each release site individually to obtain this information. Once we investigated each source individually, all information obtained was added to own excel file.

1.8.5.3 Toxic Release Inventory (TRI)

The third database we used was EPA's Toxic Release Inventory. TRI is a database that collects data voluntarily from industries that release toxic waste. TRI is a public database that lists toxic chemical releases by weight and specifies whether the releases are into air, water, or underground. TRI data is accessible on the EPA's website and every year from 1987-2014 has its own downloadable CSV spreadsheet. Each year's spreadsheet has columns for location, contaminant, and release weight. Each facility has a separate row for each type of contaminant it releases.

We analyzed the data in two separate methods: Method 1 was used to create maps that show releases of specific contaminants into air or water, while Method 2 was used to create a master list of contaminants in Maywood and Los Angeles County.

Method 1**:** We downloaded and compiled all datasets from 1987-2014 and filtered out all contaminants other than manganese, TCE, lead, and PCE. Next, we filtered all spreadsheets to include only Los Angeles County. After this step, we compiled spreadsheets from every year into one dataset so we could analyze total releases for each type of release category. While we attempted to review underground injection releases, they were very uncommon and there were none identified in our area of study for the contaminants we focused on. After compiling the datasets into one spreadsheet, we were able to plot the facilities on My Maps, a custom mapping app by Google, and manually search for facilities within a three-mile radius of Maywood. We highlighted these facilities and deleted all other facilities that fell outside the three-mile radius. This method was conducted separately for manganese into air and water, manganese into water only, lead into water only, and manganese, lead, PCE, and TCE into air and water.

Method 2: We downloaded and compiled all datasets from 1987-2014, but we did not immediately filter out irrelevant contaminants. Instead, we filtered the data to include only Los Angeles County. Next, we deleted all facilities that were not within a three-mile radius of Maywood, which we determined by plotting the facilities on My Maps. We then manipulated this data to determine the total releases of manganese and manganese compounds on-site and off-site from 1987-2014.

1.8.5.4 Landfills and Solid Waste Transfer Facilities

To find landfills and other solid waste transfer facilities sites we used the Integrated Waste Management report from 2014 and the Solid Waste Information Management System (SWIMS) both from the Los Angeles County Department of Public Works. In the report it shows that there are no landfills near Maywood, California (Figure 56). However there are many large solid waste transfer facilities and recycling transfer centers. These facilities addresses and permitted capacity (tons per day) were copied to an excel file.

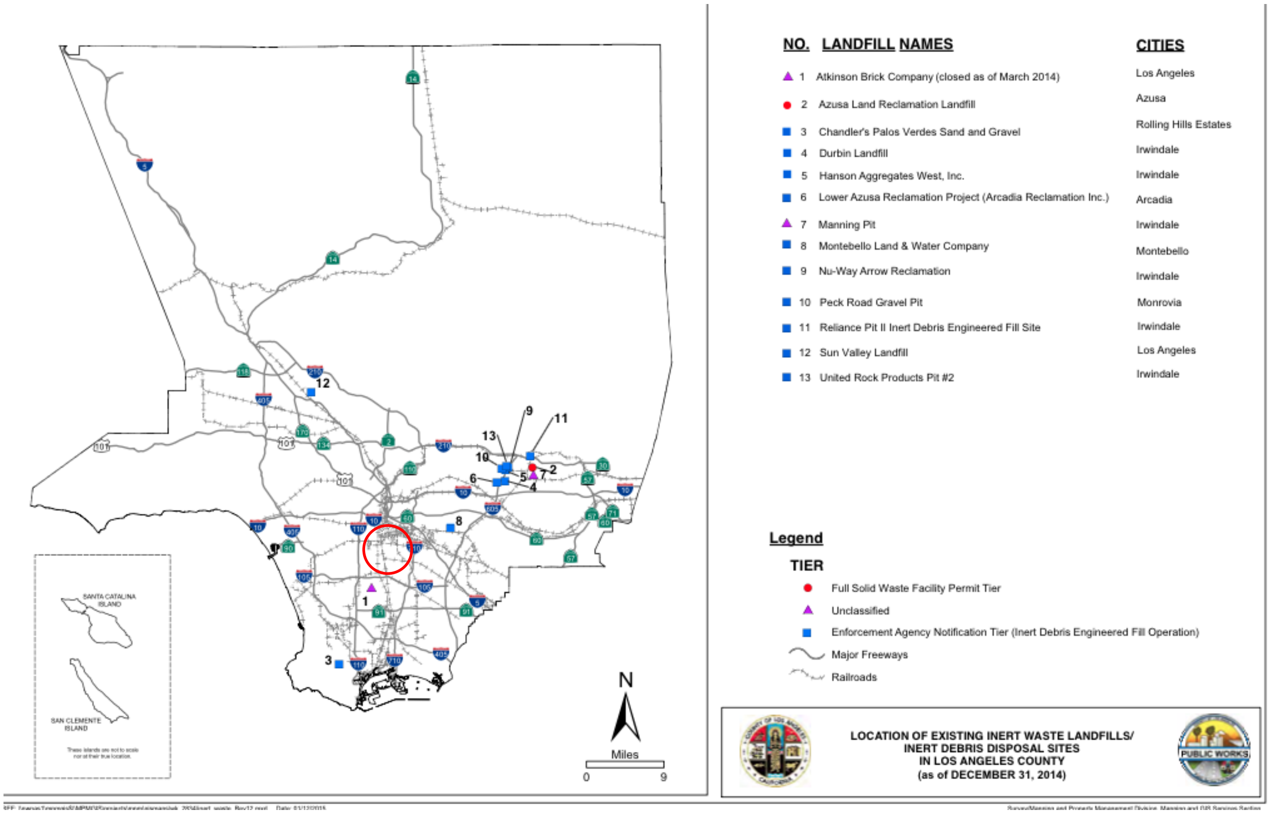


Figure 9. Map showing the distance landfills are away from Maywood, CA. Maywood lies within the red circle. (LA County 2014 Waste Management Plan, page 120).

1.8.6 Source Database Limitations

While the databases provide many potential sources each database has its own limitations. Overall, each database was only able to provide a small snapshot of what any one facility is releasing to the environment. This is huge flaw because it is nearly impossible tell what each facility is truly contributing to groundwater contamination problem in the Maywood area solely based on what chemical is being released or needs clean up. In addition, GeoTracker and EnviroStor do not have an easy way to sort by what chemical each facility is releasing, to which media (air, water, or soil) it is releasing, how much was released, and for what time period. To find this information industrial sites need to be click on each individually, this data then was recorded into our own excel file. This was a tedious process and sometimes this data is not available at all, forcing us to exclude facilities based on lack of information. In addition, no facilities in the study area, from either GeoTracker or EnviroStor, had manganese as a chemical release or a clean-up site, leading us to believe it likely that sites were not required to be test for manganese. If this is true then there may be more facilities polluting manganese with no record of the facilities doing so.

The data from TRI was much easier to navigate. However, TRI did not come without its own limitations the database is entirely self-report by the facility and thus releases of hazardous materials are probably significantly under-reported. Another limitation of the databases is when chemicals are listed vaguely. For example, many times ‘MTBE or other fuel oxygenate’ is listed as the chemical. Manganese is a fuel oxygenate but there is no way to determine whether it is the specific fuel oxygenate being leaked from any specific underground storage tank. Additional examples are ‘VOCs’ and ‘metals’, TCE is a type of VOC and manganese is a type of metal, but again there is no way to tell if these facilities are polluting these specific chemicals or something else.

Another limitation is that the data is not consistent across or even within databases. TRI, EnviroStor and GeoTracker all note different parameters about each facility, making it hard to draw comparisons from the three to make one cohesive database of all gathered potential sources. Additionally since the pollution problem in Maywood has persisted for many years, we presume that the responsible parties, if any, would have to have either been releasing contaminants over a long period of time, or would have had to have been responsible for a very large release. Finally, we note that the complex groundwater hydrology of the area may make pinpointing potential sources more difficult see section 7.1 for further discussion.

1.9 Groundwater Data Preparation

1.9.1 Geostatistical Analysis

Our ultimate goal was to gain a better understanding of various contaminants and their distribution in of groundwater in Maywood, CA, and identify their potential sources if feasible. Our focus was to shed light on the distribution of manganese, TCE, and lead. These contaminants were chosen based on the Maywood Water Quality Action Plan Assembly Bill No. 240 results that determined TCE and manganese as contaminants of concern. In addition, lead was examined due to quantifiable results of contamination observed from compilation of the water quality database from Geotracker GAMA and WRD.

Creating complex hydrogeological modeling efforts using geochemical properties of the water and sophisticated software is costly, time-consuming, and above the scope of work for this project (Rohazaini et al. 2011). As such, we undertook a geostatistical based approach to modeling contaminant distribution, particularly due to the variety of open-source and streamlined resources available and thus the potential to benefit multiple parties and future projects (Hengl 2007). To understand contaminant distribution across the City of Maywood as well as small areas of neighboring industrial cities, we used kriging analysis. Kriging, or Gaussian process regression, is a widely used method in applied geostatistics that involves interpolating values through a linear prediction based on the data of the nearest neighboring points. Kriging foundations are based on predicting the value of a parameter at an unknown, specific point by computing a weighted average of known values in the spatial proximity of the target point. There are multiple types of kriging analyses, however, we used ordinary kriging (OK) as it renders highly reliable results (Yamamoto 2000), and is one of the most common kriging subtypes used in environmental research (Giraldo 2011).

In addition to ordinary kriging, inverse distance interpolation was utilized to serve as a comparison mechanism and further cross validate results obtained from OK. Inverse distance interpolation, or inverse-distance weighting (IDW), involves assuming the value of an unsampled point (in this case, the contaminant concentration), and calculating the weighted average of sampled points within the area. There is an inverse relationship between distances and prediction location as well as sampled locations (Lu 2008). This method does not produce cross-validation or error results, and was not used as the main statistical approach as a result. However, utilizing comparisons between IDW and OK results renders a more accurate approach to determining potential, if any, sources that could contribute to maximum contaminant loading.

The two geostatistical platforms utilized in study were R version 3.2.3 and ArcGIS 10.1. Both platforms offer several benefits, return powerful results, and can be used simultaneously. To further validate our results, we compared results from R and assured that similar parameters were used in ArcGIS, paying particular attention to semivariogram fitting. For purposes of final contaminant source assessment, we used ArcGIS to better understand the locational qualities of data. Thus, the R platform was used for data preparation and as a validational step that would further aid in accuracy of the results in ArcGIS.

1.9.2 Dataset Preparation

Preparation of the dataset for modeling purposes involved several, complicated steps, which were programmed through R through over 500 lines of code. For each constituent, we had to determine the most representative years of contamination that would be used for kriging assessment. Because ordinary kriging requires a relatively even distribution over grid space and targeted area as well as no duplicate values, datasets were prepared to include several qualifications:

1. Accurate years of analysis that included years with the worst contamination over a decadal timescale.
2. Accurate years of analysis that included a quantifiable number of wells that would aid the modeling process in ensuring a more even distribution of known sampled points.
3. Dataset that would include all drinking water wells in Maywood.
4. Dataset that would incorporate wells within and up to a 2.3-mile radius to incorporate Commerce, Bell, and Huntington Park.
5. Additional dataset that would demonstrate recent conditions in Maywood, which includes 2014-2015 concentrations.
6. Removal of all duplicate values, which involved removal of points sampled on the same day, or for multiple sampled points for one unique value (Well ID)
7. Normalization of data.

Preparation of this dataset involved complex looping and extraction. Date information was separated into another column to aid the extraction process. Then, a thorough analysis of the 1) number of counts per year and 2) years with high contamination values in comparison to other years was run, and these two qualifications were merged to create a comprehensive dataset that would span the grid target study area appropriately. As such, the chosen years of evaluation were as followed:

1. Manganese: 2007-2010, 2014-2015
2. TCE: 2009-2012
3. Lead: 2008-2010

These years were consistent with the worst water quality according to the results of the Phase I and II assessments from DTSC according to the January 2015 Maywood Executive Summary.

Several grids were created that were a compilation of these results seen in Figures X-X. Note that TCE is the only contaminant with a relatively even spread of wells, indicating more of an accuracy from an OK perspective. Manganese and Lead involved highly clustered data, which is less preferable.

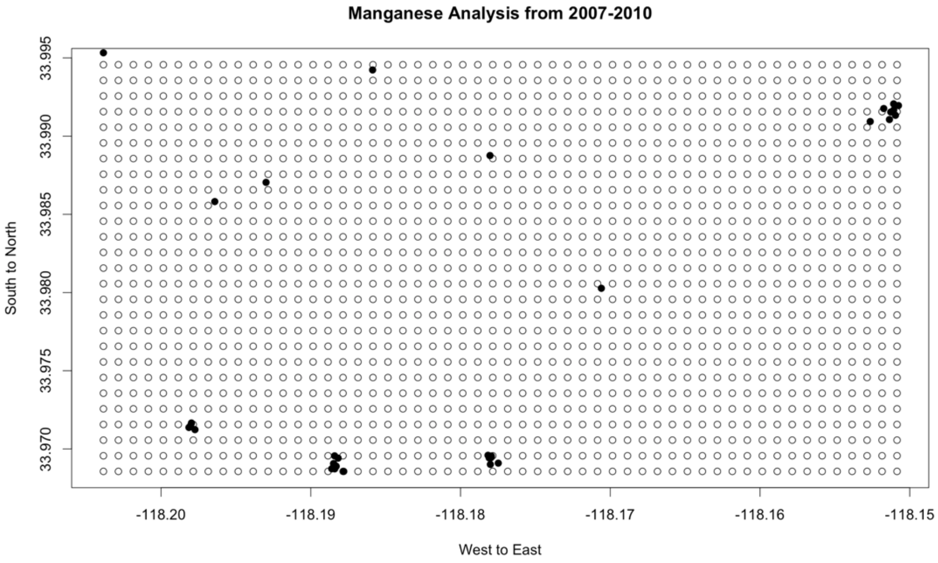


Figure 10. Manganese study area coded from final dataset preparation. Each black dot represents either a drinking water well or a monitoring well.

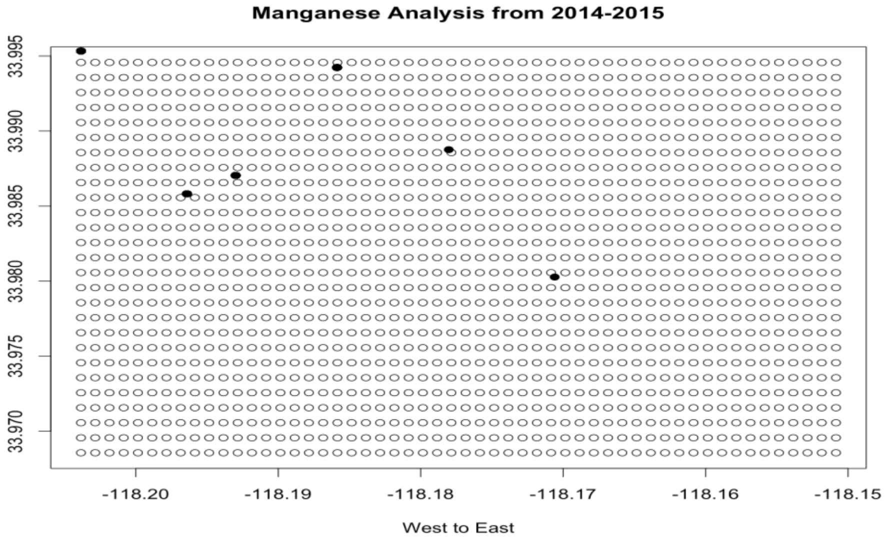


Figure 11. Manganese study area coded from final dataset preparation. Each black dot represents either a drinking water well.

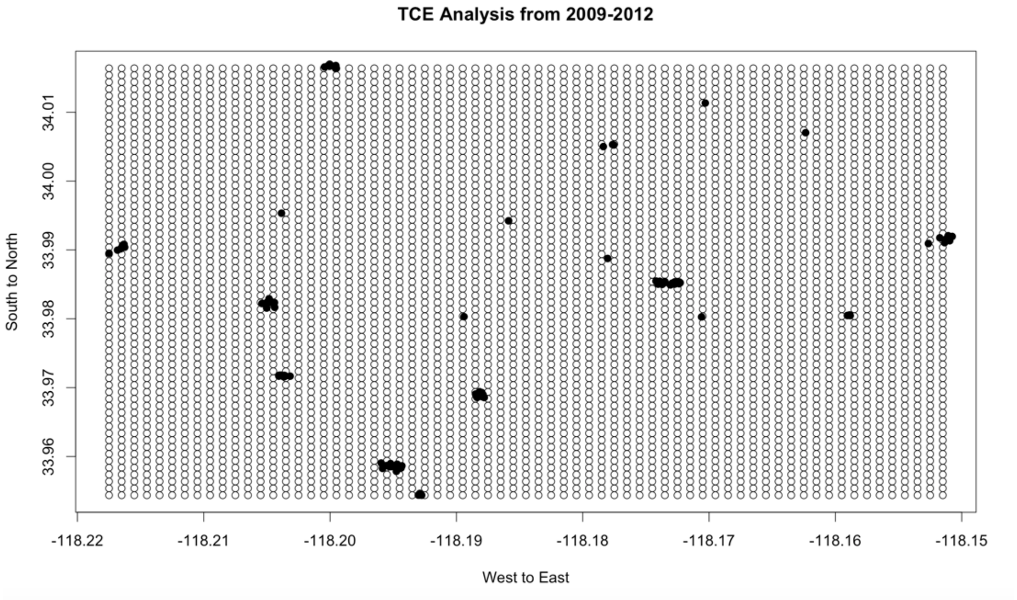


Figure 12. TCE study area coded from final dataset preparation. Each black dot represents either a drinking water well or a monitoring well.

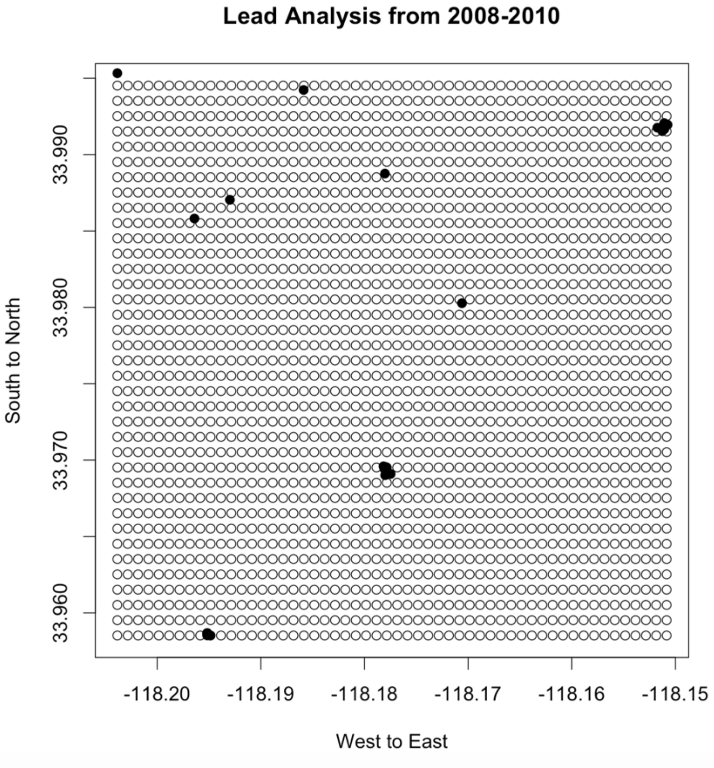


Figure 13. Lead study area coded from final dataset preparation. Each black dot represents either a drinking water well or a monitoring well.

Subsequent to grid formation, the data was further manipulated to remove duplicate values. Because the grid results rendered values over multiple years to include more wells, the original dataset resulted in a given well sampled multiple times over the years in study. For example, a drinking water well in Maywood during the years 2007-2010 for manganese would be noted several times over the course of three years, providing multiple sample points for one unique value. As such, kriging would not run for this data, because the unique value of a Well ID would be interpreted as duplicated with sample points over the three-year period in the case of manganese. To circumvent this problem, two methods were approached: extraction of the maximum concentration of a given well over the time period, and extraction of the median of a well over the given time period. Both the maximum value and median values were kriged and compared. If the median dataset bore similar results to the maximum value dataset, it indicated accuracy with the methodology. However, if the median results differed from maximum results, we analyzed the contaminant in a different way altogether, as discussed in Section X. Extraction of maximum or median values resulted in a significantly reduced dataset in regards to number of working wells. The number of resulting wells from this effort includes:

1. 38 wells for manganese.
2. 113 wells for TCE.
3. 26 wells for lead.

One of the last steps of dataset preparation included transformation of data to enable a more normalized distribution of data, which were further validated through QQplot analysis. All datasets could not be transformed with a log function because of the presence of “0” sampled values. Multiple scenarios were run, and the best normalization parameters for 2007-2012 data were as followed and were deemed as appropriate for modeling based on the QQplot and histogram analysis:

1. Manganese raised to the power 0.1.
2. Recent Manganese (2014-2015) transformed logarithmically.
3. TCE raised to the power 0.1.
4. Lead raised to the power 0.2.

For manganese, the transformed data and its distribution can be seen in Figures 15-16 below.

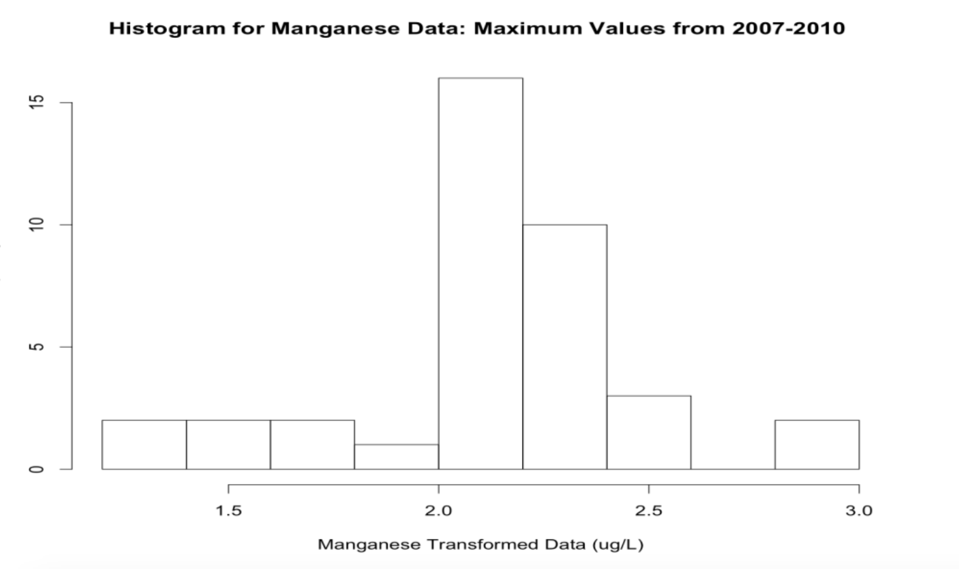


Figure 14. Histogram of manganese transformed concentrations.

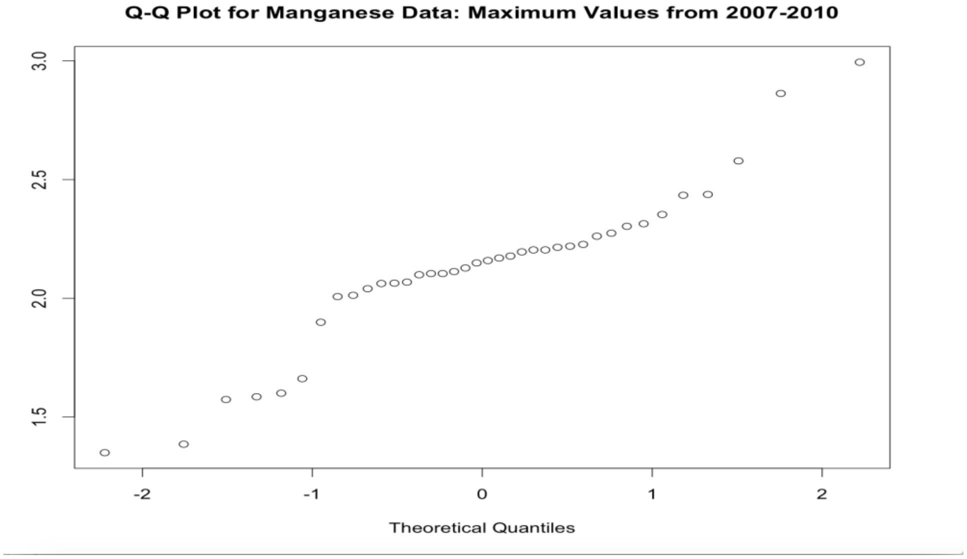


Figure 15. QQplot of manganese data indicating a relatively normal distribution post transformation.

Similarly, for TCE, the transformed data and its distribution can be seen in Figures 17-18 below.

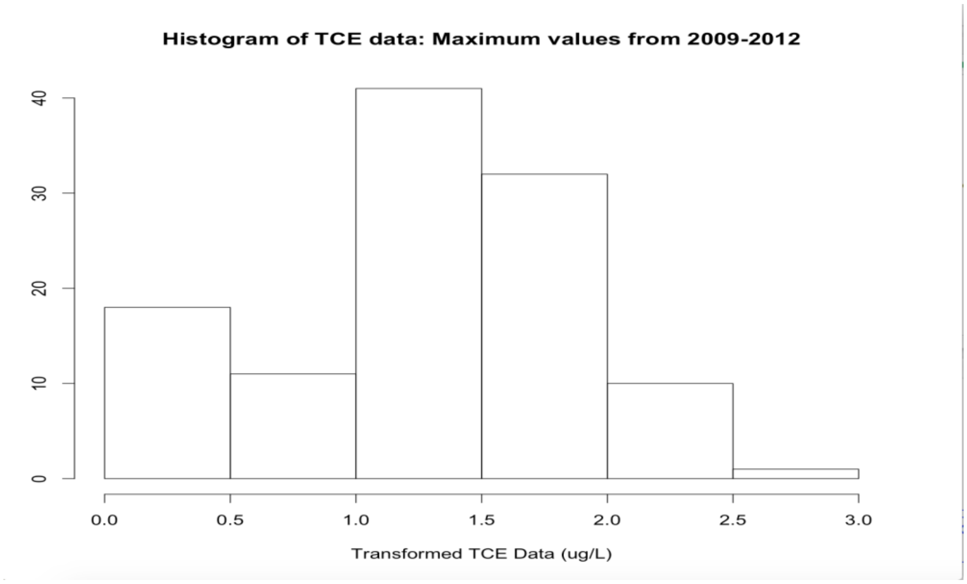


Figure 16. Histogram of TCE transformed concentrations.

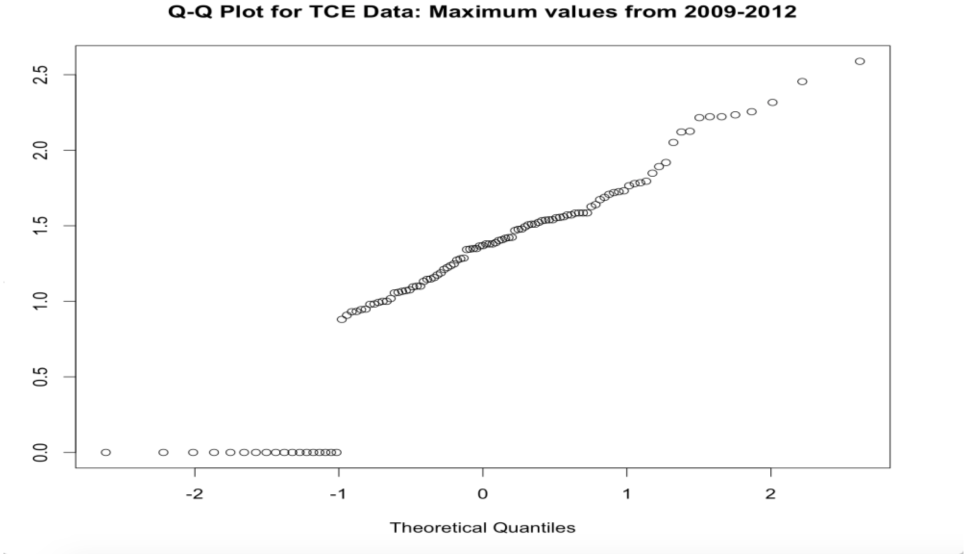


Figure 17. QQplot of TCE data indicating a relatively normal distribution post transformation.

Finally, for lead, the transformed data and its distribution can be seen in Figures 19-20 below.

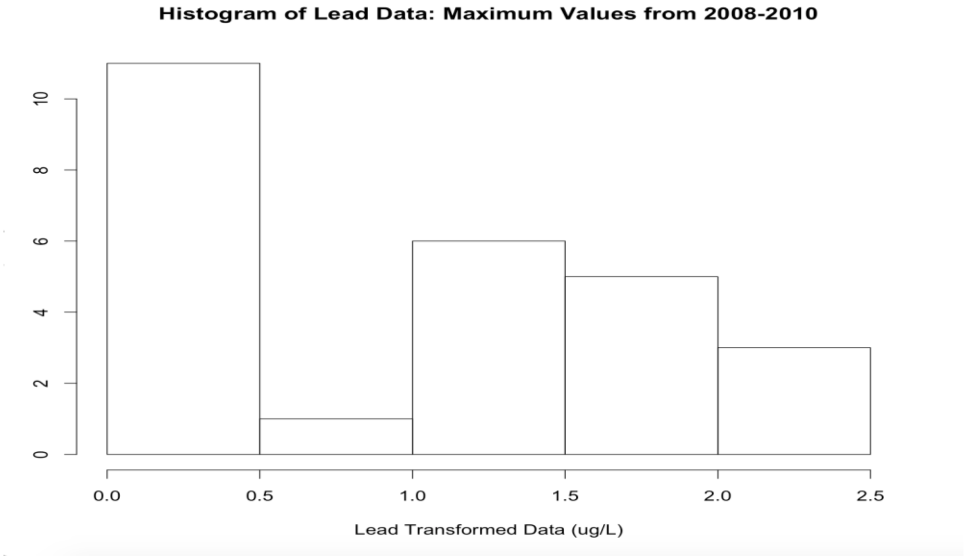


Figure 18. Histogram of lead transformed concentrations.

Note this distribution does not ideally fit the normalization curve, because there are limited number of wells (26) compared to the other contaminants. The lack of true normalization can be seen through the QQplot below.

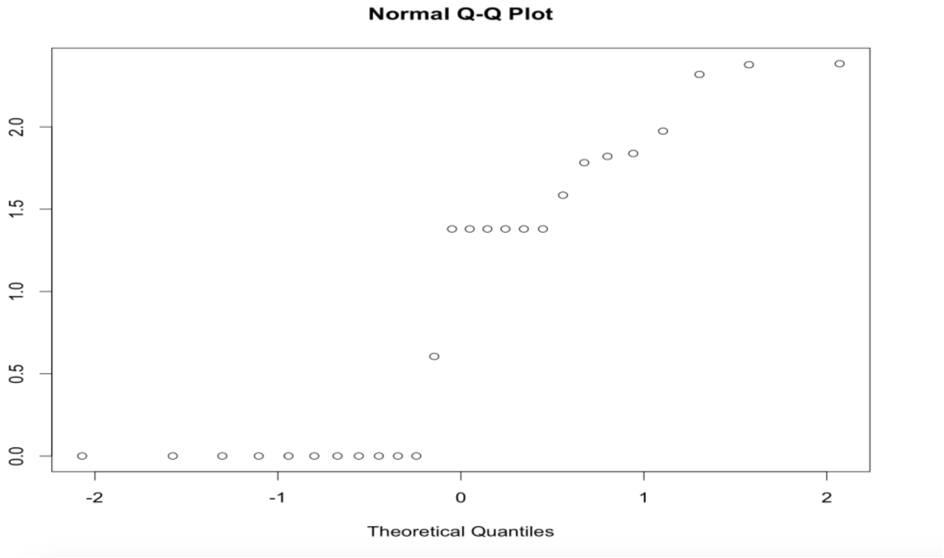


Figure 19. QQplot of lead data post transformation.

Limitations to modeling lead will be described in Section 1.9.7.

Preparation of median data was determined in a similar fashion to the methodology undertaken above. Transformations of data remained similar to values expressed used for the maximum value datasets, with exception to lead and manganese, which took a transform to the power of 0.3. The number of wells for median values were the same compared to maximum values, thus any limitations with the data, especially ones found with lead, appeared for median modeling efforts. Figures 21-25 represent the results of these efforts.

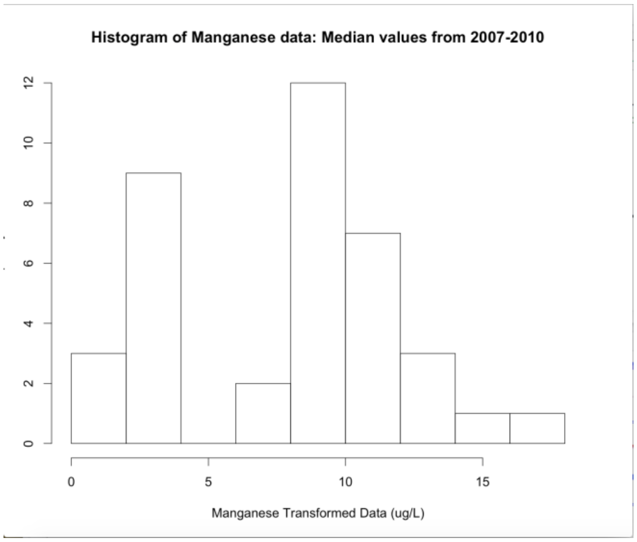


Figure 20. Histogram of manganese transformed concentrations for the median dataset.

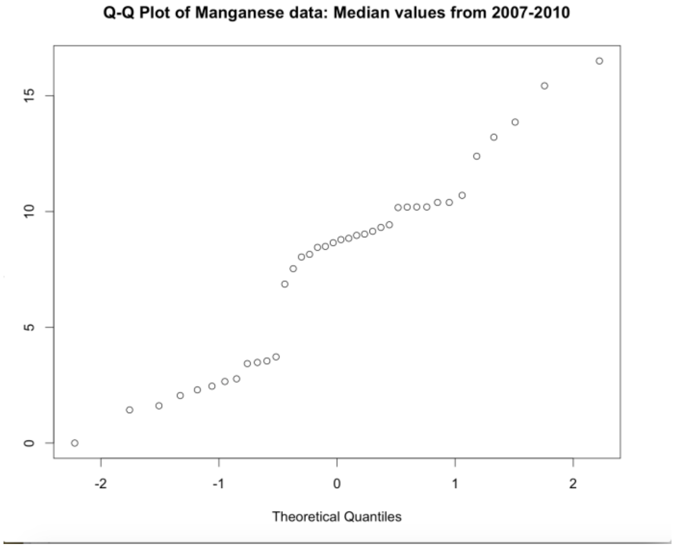


Figure 21. QQplot of manganese transformed concentrations for the median dataset.

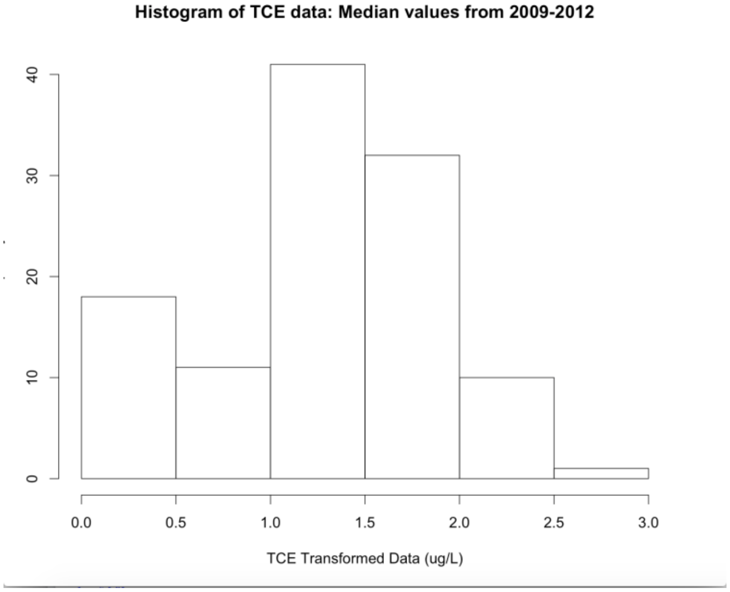


Figure 22. Histogram of TCE transformed concentrations for the median dataset.

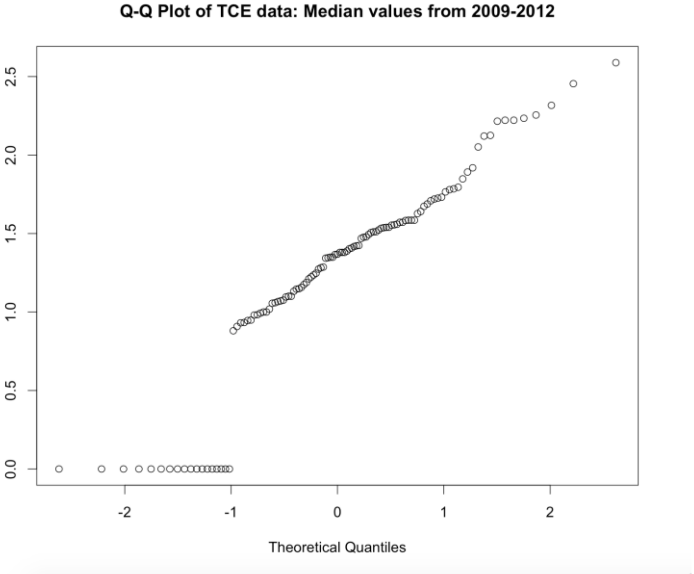


Figure 23. QQplot of TCE transformed concentrations for the median dataset.

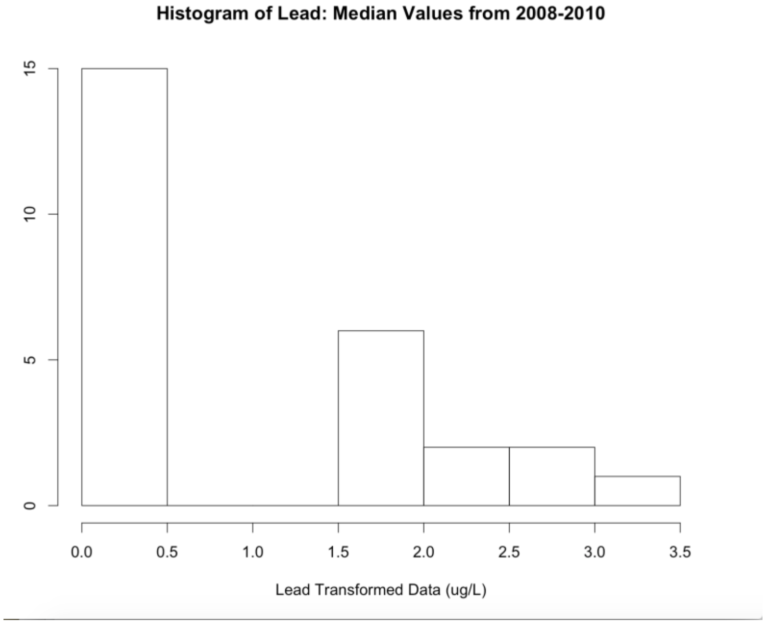


Figure 24. Histogram of lead transformed concentrations for the median dataset. Note the non-normal distribution.

1.9.3 Ordinary Kriging and Inverse Distance Weighting in R

After data preparation, several scenarios were modeled in R for each constituent, for both maximum and median values. OK was run through both geoR and gstat packages. Because kriging weights are determined by semivariance (average of the squared difference of values below the mean), a semivariance (variogram) model had to be fitted to the data. A standard semivariance includes various constants, namely the nugget, partial sill, and range that model a best-fit line. Many of these were determined through "fitting by eye" from the original variogram. Table 9 below describes the various kriging parameters used.

Semivariance Parameters				
	Nugget	**Partial Sill**	**Range**	**Fitting**
Maximum Values				
Manganese	0	0.001	0.05	Spherical
TCE	0.2	0.04	0.03	Gaussian
Lead	0	0.001	0.05	Exponential
Median Values				
Manganese	0	0.001	0.05	Spherical
TCE	0.02	0.03	0.02	Gaussian
Lead	0	0.001	0.05	Exponential

Table 9. Kriging parameters determined from "fitting by eye."

IDW does not include any semivariance, and thus these parameters were not necessary. Figures 26-28 demonstrate the various variograms for each constituent.

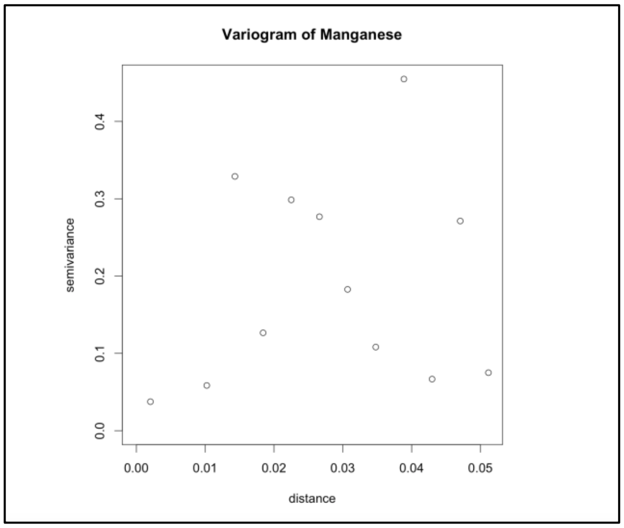


Figure 25. Variogram of Manganese, maximum values from 2007-2010.

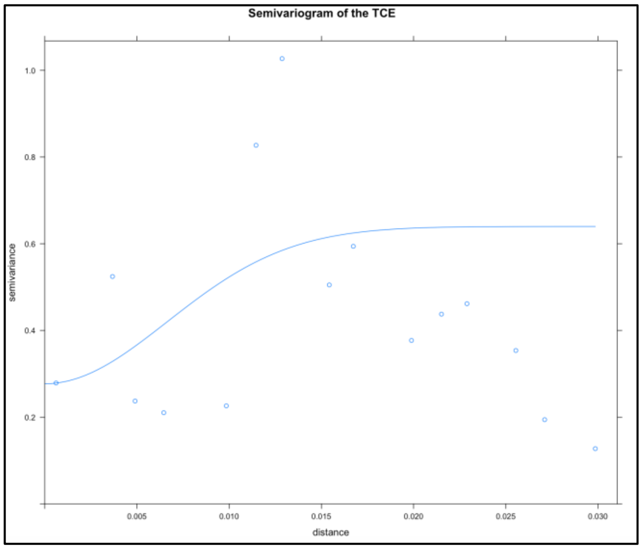


Figure 26. Semivariogram with the fitted line of TCE for maximum values.

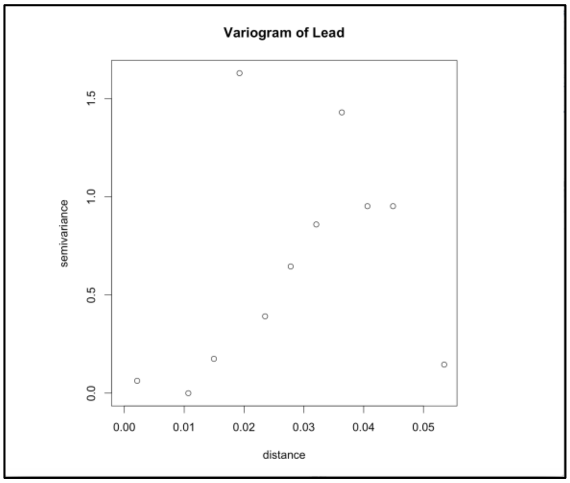


Figure 27. Variogram of lead, maximum values from 2008-2010.

1.9.4 Ordinary Kriging Results from R

Ordinary Kriging results were obtained after running several models. In addition to comparing historic data (2007-2012), recent manganese contamination (2014-2015) was also modeled. Recent data for manganese, however, consisted only of 6 drinking water wells that contained recent data, as monitoring well data was unavailable. The lack of wells causes some concern for analysis. These concerns are discussed in Subsection viii.

Cumulatively, these results were compared to IDW results in subsection 1.9.5 below. Furthermore, for each OK result, variances were generated. Figures 29-36 demonstrate the variances. Note that the colors are a heat map ramp, where lighter colors indicate the increased variability in results. This should not be confused with the color scheme introduced in Results, that is inversed to the ones described in this section. Results were consistent across all scenarios indicating high concentration estimations (brighter yellow) had decreased variance, providing more accuracy at these locations.

1.9.4.1 Variance of Maximum Value Datasets per Constituent

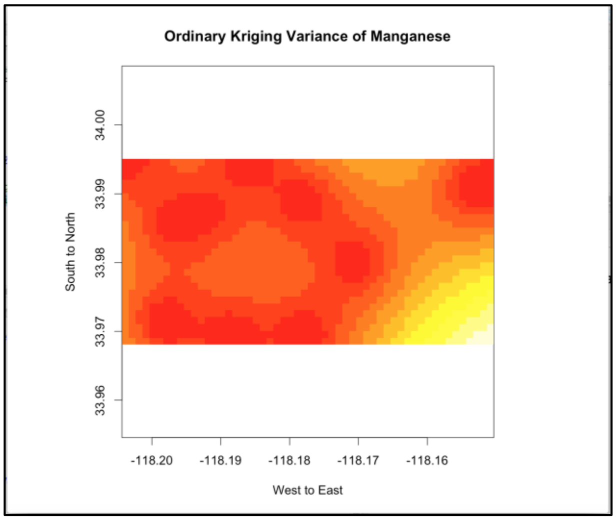


Figure 28. Ordinary Kriging Variance of Manganese, from 2007-2010 using maximum values.

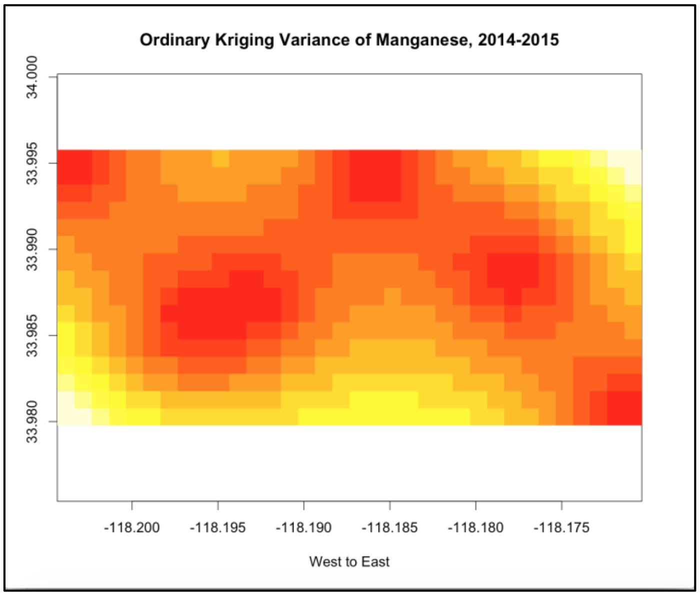


Figure 29. Ordinary Kriging Variance of Manganese, from 2014-2015 using maximum values.

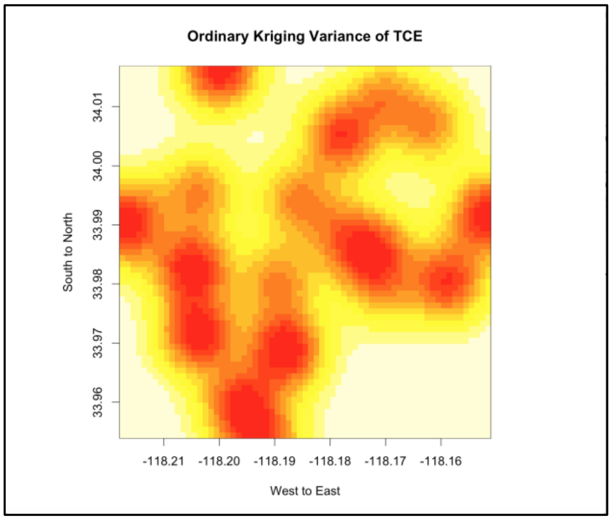


Figure 30. Ordinary Kriging Variance of TCE, from 2009-2012 using maximum values.

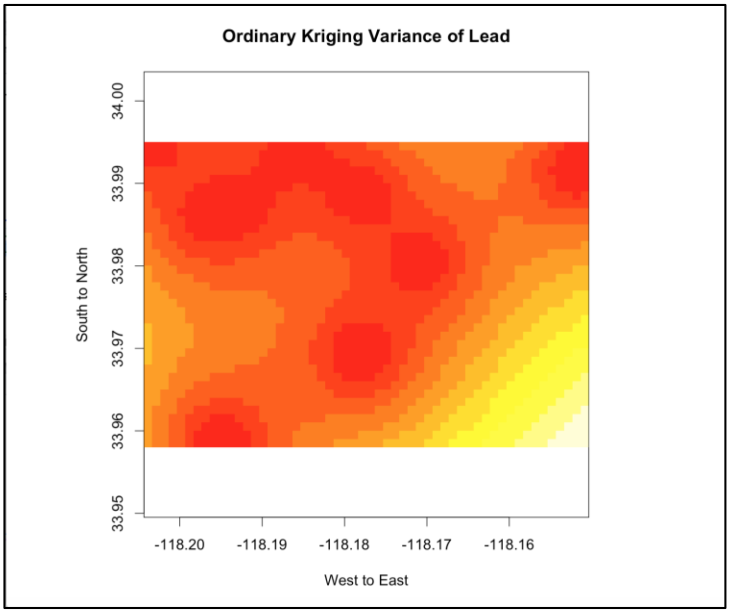


Figure 31. Ordinary Kriging Variance of lead, from 2008-2010 using maximum values.

1.9.4.2 Variance of Median Value Dataset per Constituent

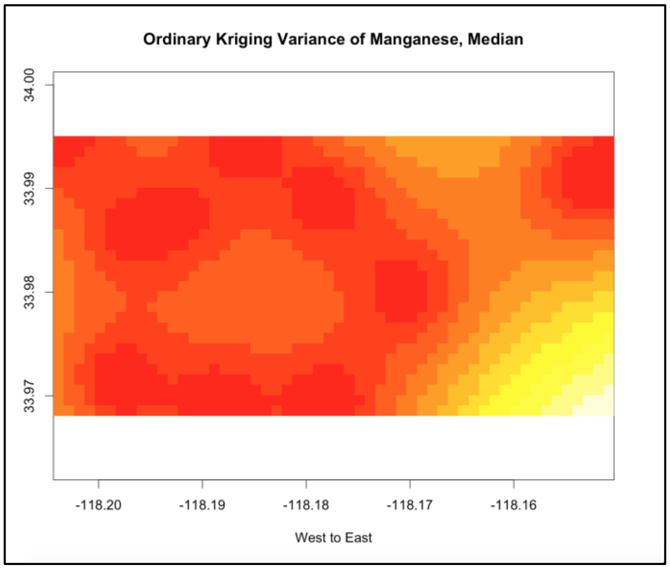


Figure 32. Ordinary Kriging Variance of manganese from 2007-2010 using median values.

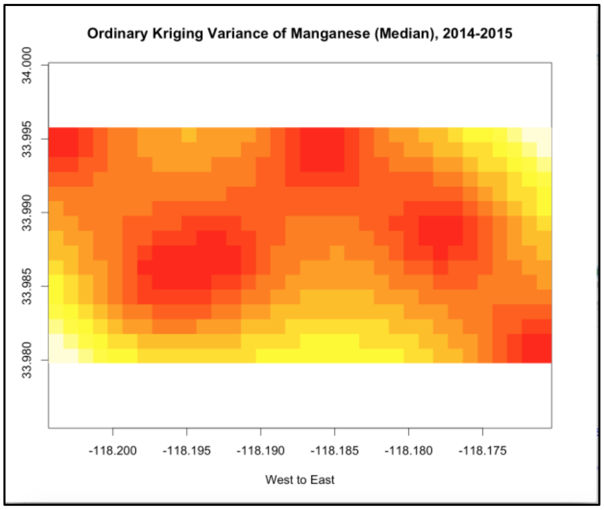


Figure 33. Ordinary Kriging Variance of manganese from 2014-2015 using median values.

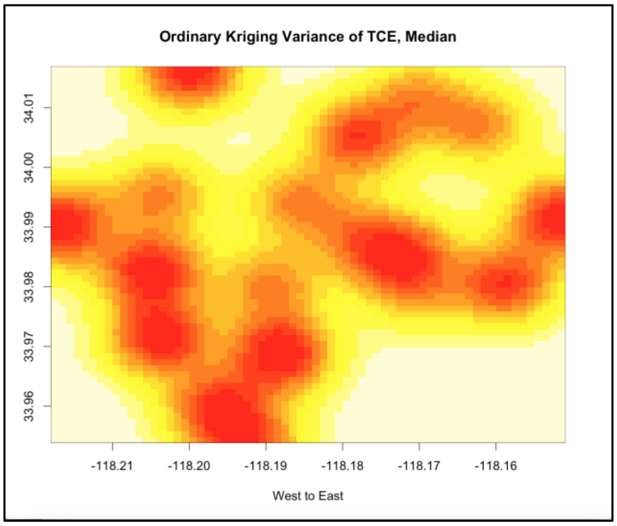


Figure 34. Ordinary Kriging Variance of TCE from 2009-2012 using median values.

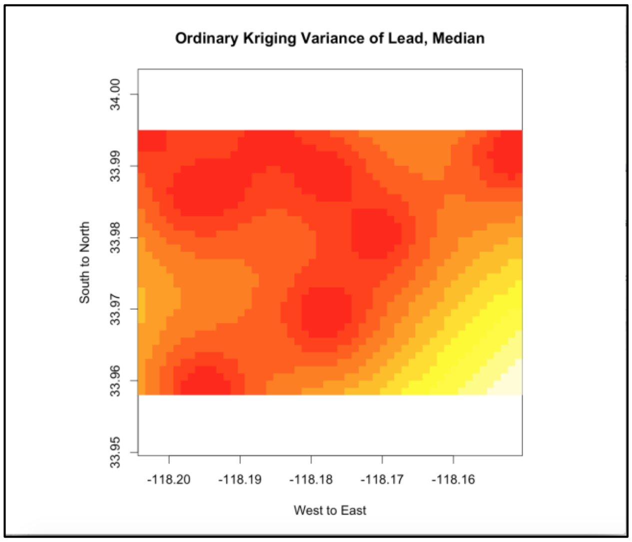


Figure 35. Ordinary Kriging Variance lead from 2008-2010 using median values.

1.9.5 Ordinary Kriging and Inverse Distance Weighting Comparisons

Finally, once models for both IDW and OK were run and generated, the two were compared side by side to determine accuracy in results and patterns across methods. Assessment of accuracy between models was determined by eye. Particular attention was given to areas of high concentrations (brighter yellow), which demonstrated the least variability according to subsection 1.9.4. Figures 37-41 demonstrate these comparisons. For all scenarios, there was a consistent trend in that maximum values (brighter yellow) were estimated correspondingly between IDW and OK. This indicated that maximum values were the most accurate in analysis. For purposes of time and scope, IDW results were only computed for maximum value scenarios for manganese, TCE, and lead for the time period 2007-2012.

IDW and OK comparisons were also computed on recent manganese contamination from 2014-2015 for both median and maximum value datasets. OK results are available for median values for all contaminants (Figure 39).

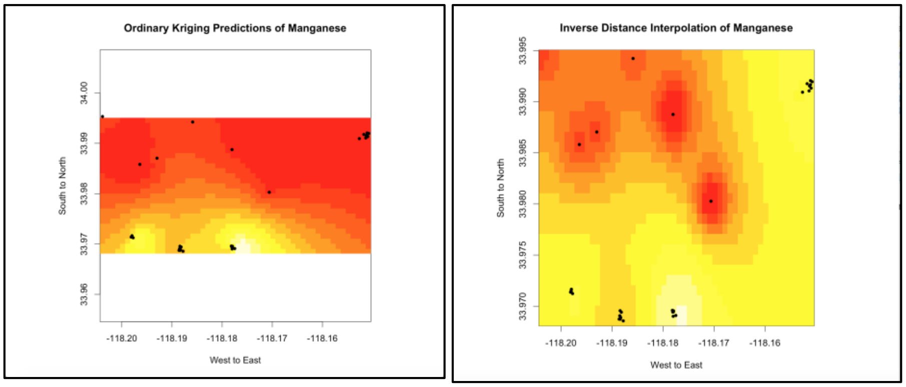


Figure 36. Ordinary Kriging vs. Inverse Distance Weighting comparison of Manganese, Maximum values, from 2007-2010.

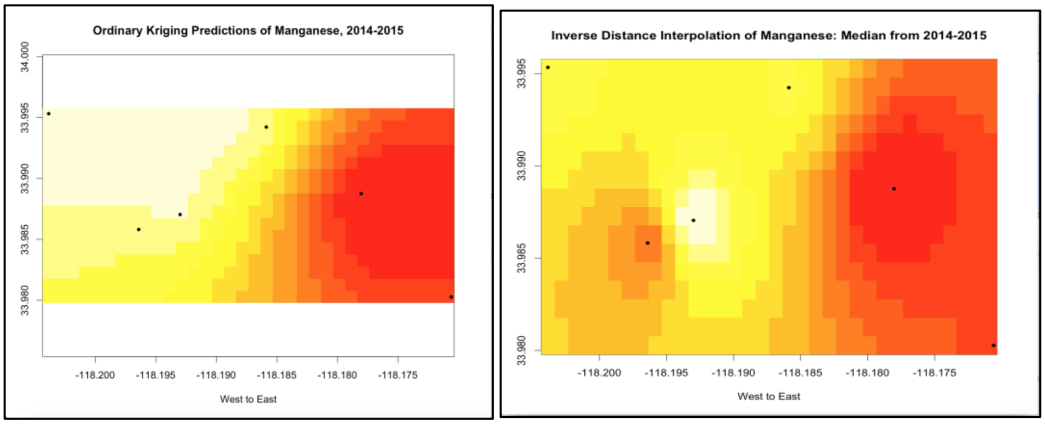


Figure 37. Ordinary Kriging vs. Inverse Distance Weighting comparison of Manganese, Maximum values from 2014-2015.

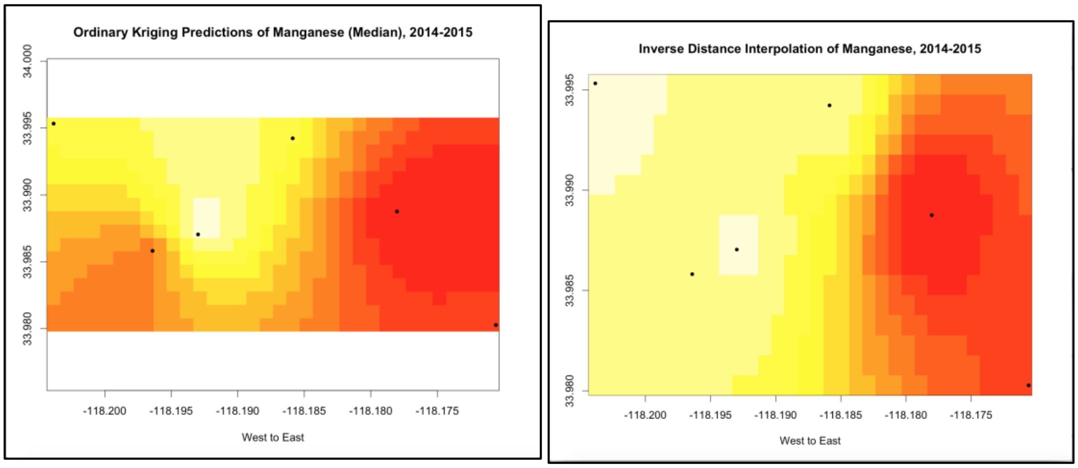


Figure 38. Ordinary Kriging vs. Inverse Distance Weighting comparison of Manganese, Median Values from 2014-2015.

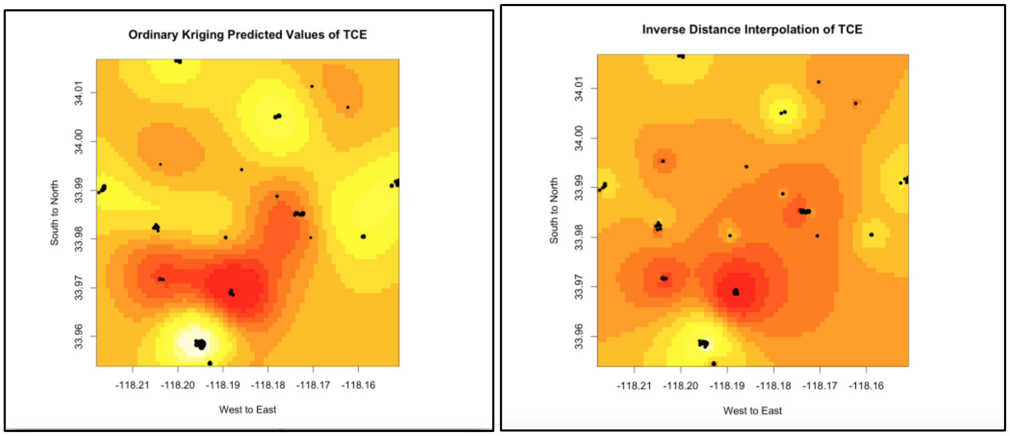


Figure 39. Ordinary Kriging vs. Inverse Distance Weighting comparison of TCE Maximum values from 2009-2012.

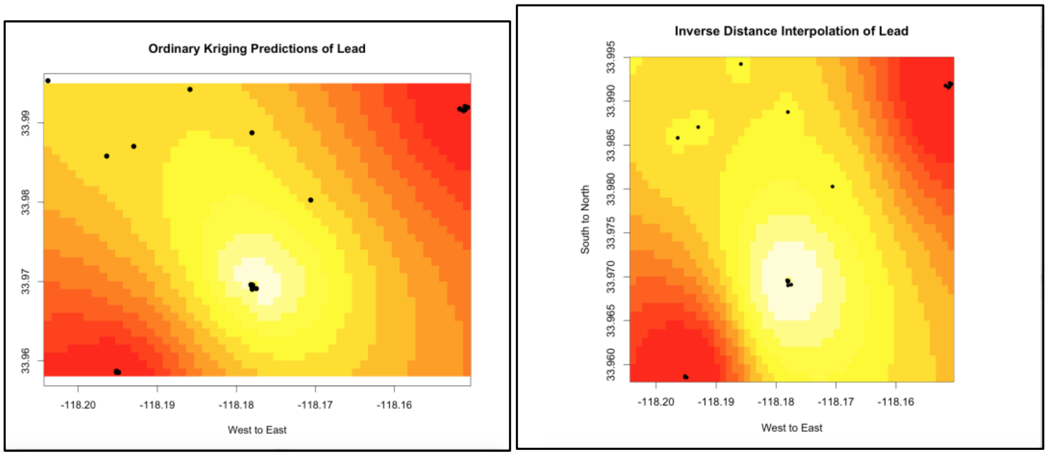


Figure 40. Ordinary Kriging vs. Inverse Distance Weighting comparison of Lead Maximum values from 2008-2010.

1.9.5.1 Median Ordinary Kriging Results

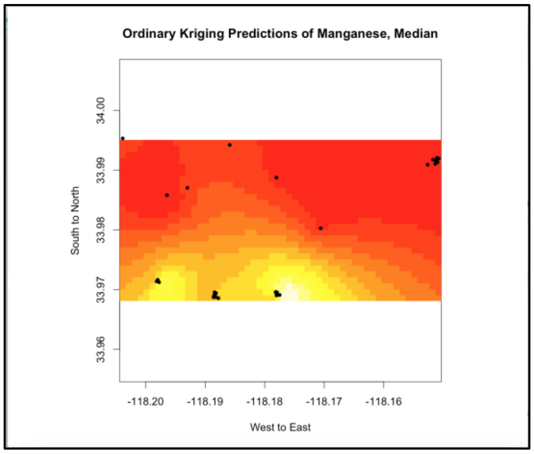


Figure 41. Ordinary Kriging Result of Median Manganese values from 2008-2010.

Compared to maximum values in the same time frame, this distribution is almost 100% similar, indicating analysis can be undertaken for maximum or median values.

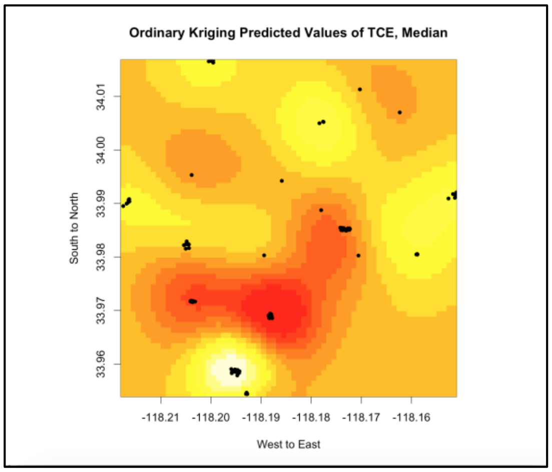


Figure 42. Ordinary Kriging Result of Median TCE values from 2009-2012.

Compared to maximum values in the same time frame, this distribution is almost 100% similar, indicating analysis can be undertaken for maximum or median values.

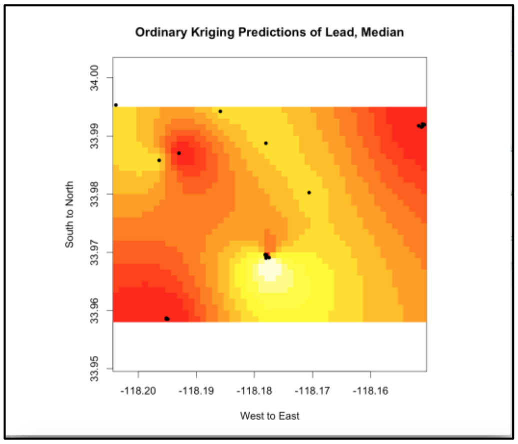


Figure 43. Ordinary Kriging Result of Median Lead values from 2008-2010.

Compared to maximum values in the same time frame, this distribution is not similar, indicating a limitation of using solely maximum or median values for analysis.

1.9.6 Conclusions from R Data Preparation and Modeling Efforts

Despite the fact that lead was a concern regarding lack of normality, and that the median ordinary kriging results compared to maximum value ordinary kriging results were dissimilar, we decided to use maximum values for modeling as a more conservative estimate approach. Thus, all datasets used for OK in ArcGIS were maximum value datasets. In order for importation to ArcGIS, we applied exactly similar transformations and fitting parameters to generate similar results. To cross validate our ArcGIS efforts, we assured that a similar distribution was apparent between ArcGIS OK, OK results from R, as well as IDW results from R. We paid particular attention to similarities between all assumed maximum values throughout the models. This is because the variance was the least prominent in these areas and there was the most correspondence between these values across all model approaches.

1.9.7 Modeling Limitations

Understandably, there are several limitations to modeling in R as well as using ordinary kriging in general. To approximate concentration distributions in the most precise manner, multiple approaches were undertaken to assure sound methodology. However, it is important to note that our approach to modeling is purely through geostatistical methods. More exact modeling in the future must be approached through geochemical reactions, aquifer porosity constraints, and other more complex transport mechanisms that are above the scope of this project.

In regards to the methodology, one of the first concerns centers around the non-normality of the lead data. The number of wells that resulted from the maximum and medium value mining process (26 wells) was ultimately not as preferable in terms of modeling. This could have negative effects on OK analysis as modeling is less robust with increasingly sparse data (Adhikary et al. 2011). Additionally, a large portion of cross-validation efforts was not undertaken due to time constraints on the project. Inadequate estimations of "fitting by eye" parameters for OK analysis such as the range, partial sill, and nugget could also affect subsequent fitting parameters involved in the model. While they are a better effort in comparison to default kriging, further cross validation results must be undertaken to truly understand the improved modeling mechanisms.

1.10 Groundwater Contamination Distribution Maps

We added the transformed datasets for manganese, TCE, and lead into ArcGIS 10.1. We also imported the United States street map basemap into ArcGIS.

Since we collected our data within a 2.3-mile radius of Maywood, CA, we needed to create a buffer with this same radius. Using the buffer function, we created a 2.3-mile radius from the center point of our study area (33.986630, -118.185334).

Using the geostatistical analysis toolbar in ArcGIS, we utilized the geostatistical wizard function. To model contamination distribution, we used Ordinary Kriging. Based on recommendations from a statistics expert and results from R, we did not take directionality, anisotropy, or trend removals into account for our models. For all contaminants, we used the default settings for Ordinary Kriging to create our maps. To determine the accuracy of our maps, we cross-referenced areas of highest concentrations back to the mapped results of inverse distance interpolation and Ordinary Kriging from R. Initially, the results from Ordinary Kriging show up as a square, to clip the results to our buffer radius of 2.3 miles, we displayed the results to the extent of our buffer.

Next, we downloaded a Los Angeles city boundaries shapefile from the LA County GIS Data Portal and imported it into ArcGIS (LA County GIS Data 2016). To show the Maywood city boundary, we deleted the data for all cities other than Maywood. This gave us a map with the outline of Maywood shown over our Ordinary Kriging map.

Since we transformed our data for Ordinary Kriging purposes, we had to back-transform the values in the legend to show the ranges in meaningful, normal values.

For manganese, we used 10 classes to show the best distribution of contamination from 2007-2010 (Figure 45). We manually changed the class breaks to show the concentration distribution with respect to the detection limit of 20 μg/L and the SMCL of 50 μg/L.

To map the most recent manganese concentration distribution, we took the maximum result from each of the six drinking water wells operated by the three Maywood Mutual Water companies. Next, we imported the data into ArcGIS, along with the US street maps. We used Ordinary Kriging, to map the most recent distribution. We set the transformation to log, and used the default for every other setting. We used the same class breaks as the 2007-2010 map for manganese.

For TCE, we used 7 classes to show the contamination distribution for 2009-2012 (Figure 47). We manually changed the class breaks to show the contamination with respect to the detection limit of 0.5 μg/L and the MCL of 5 μg/L.

For lead, we used 5 classes to show the contamination distribution for 2008-2010 (Figure 48). We manually changed the class breaks to show the concentration distribution with respect to the detection limit of 5 μg/L, the regulatory action level of 15 μg/L, and the rescinded MCL of 50 μg/L.

1.11 Potential Industrial Source Maps

To make the contaminant maps first the data needed to be saved into a CSV file. A CSV file was created for each contaminant. For example, all of the TCE sources across all databases were compiled into a single CSV file. The same method was used for all other contaminants. Once we had a single file for each contaminant, the files were imported into the ArcGIS map. A layer was created for each contaminant. Maps were made for groups of similar contaminants; metals (lead, manganese, and metals), solvents (PCE, TCE, VOCs, 'solvents', and 'other solvents or non-chlorinated hydrocarbons'), and fuel based contaminants (fuel, aviation fuel, motor oil, petroleum, diesel, gasoline, and fuel oxygenates). Next a map was made for manganese identifying the number of years each of the potential sources had a release. We were not able to create this type of map for other pollutants because the number of years released was not available for potential sources from GeoTracker and EnviroStor. For the last map we determined the top 11 polluters in the study area. For TRI the top polluters were considered to be a part of the top 11 if they had at least 24 'points.' Points were given to polluters by the number of contaminants (lead, PCE, TCE, and manganese) and number of years. For example, if Polluter Z released lead for 3 years and manganese for 2 years they would have 5 points. For GeoTracker and EnviroStor, the top polluters were determined by a different process because of the available data. Polluters were determined to a part of the top 11 if they polluted at least 3 of the following contaminants: lead, PCE, TCE, manganese.

1.11.1 Limitations of Industrial Source Databases

Identifying industrial sources was complicated by the lack of comprehensive data sources. While we did extract data from three known sources, each source only provides a brief snapshot containing very limited information of what a facility is doing at any given time. It is very difficult to determine the full scale of potential releases from any specific industrial source from the limited amount of data available from these databases. Another limitation is that older pollution sources may not be recorded in any database or may predate modern reporting requirements. This makes it much harder to identify potential sources that may have contributed pollution, but that are not currently operational. Additional data outside of the sources we reviewed may be available and further research should be done on the possibility of pollution from historical sites. This could include a review of building permits or business licenses in Maywood and neighboring cities. From the Integrated Waste Management report from 2014 and the Solid Waste Information Management System (SWIMS) databases we were able to identifying solid waste and transfer processing facilities. These types of facilities are known to produce manganese (Johnson 2008). However, similarly to the other databases very limited information was available on each site and more information may be available from other databases. Since the pollution in Maywood has persisted historically, it is also possible the source of pollution may be coming from well outside of the three-mile radius we investigated. Section 1.30.3 further discusses improvements to source identification. A detailed explanation of the limitations of the TRI database is discussed below.

1.11.1.1 TRI Database

Upon first glance, the TRI database appears to be comprehensive, with columns for facility, year, location, chemical type, release amount and type (air, water, or underground injection), and recycling. However, after analyzing this data it is apparent that there may be missing data entries. TRI has been criticized by environmentalists for its self-reporting method, which may give facilities too much leeway to report inaccurate results.[1] Additionally, TRI does not require facilities to use a monitoring device. Instead, TRI allows facilities to estimate their emissions through modeling. This method is a less expensive, but introduces significant uncertainties.[1] A study conducted by the Environmental Integrity Project estimates that companies may not be reporting 15% of their total toxic air emissions to TRI. Additionally, TRI only requires facilities to report releases for 689 chemicals, yet there are over 3,300 chemicals on the “Right to Know Hazardous Substance List” (EPA 2016, Department of Health 2016). This means that there is no data available for roughly 80% of hazardous chemicals that may be inducing health risks on people. In addition to chemicals that are known to be hazardous, the U.S. manufactures roughly 75,000 chemicals in total, so TRI represents less than 1% of all chemicals produced in the U.S. Although the EPA selects chemicals to be monitored for based on TRI requirements, they have never systematically reviewed available environmental health data to find all the chemicals that meet these requirements. Furthermore, TRI only require three types of pollution sources to file their release reports. Many major pollution sources are exempt from reporting to TRI, such as superfund sites, landfills, service businesses (like dry cleaners), sewage treatment plants, and agricultural application of pesticides (The Pollution Information Site 2011). TRI has also been criticized by environmentalists for only reporting on “end-of-the-pipe” chemical releases instead of requiring a total life cycle report for each chemical, including chemical production, use, and disposal (The Pollution Information Site 2011).

Due to these limitations it was not possible to directly connect any sources to the contamination of the groundwater based on the TRI, EnviroStor or GeoTracker data and the continuation distribution map. These concerns will further be discussed in Section 1.1.8.

1.12 ArcGIS: Map Compilation

To produce a single map for each contaminant, we chose to overlay the potential industrial source data onto each of our contaminant distribution maps. For manganese, TCE, and lead, we overlaid the top 11 polluters and sources known to release the respective constituent on top of our contaminant distribution maps. Results can be seen in Section 1.16.

1.13 Water Sampling

Our team wanted to go into Maywood to collect and test water samples and compare the results with what was being reported. From a small number of samples, we also hoped to detect any other trends such as how concentrations of contaminants changes with distance from the water utilities or how much variation there is between buildings with old and new infrastructure. We took samples mostly from public locations such as parks, government offices, and schools, as well as the houses of a few residents. We collected 18 samples in total and sampled for manganese, lead, arsenic, TCE, and PCE depending on the location. Manganese was tested for at all but 3 locations because it was the primary contaminant of concern. Given Maywood and the surrounding area's highly industrialized environment, we were concerned about the presence of lead and arsenic in drinking water so these contaminants were sampled for as well. Lastly, because of the known exceedances of TCE at wells owned by Water Mutual Company #3, TCE and PCE were also sampled for at selected locations.

Sampling for metals and sampling for industrial solvents require different preservatives and different sampling protocols. The bottles used to sample for metals contained citric acid while the bottles used to sample for industrial solvents contained hydrochloric acid. Faucet taps and water fountains were run for 2-3 minutes before collecting water samples. For metals, bottles were filled at least ¾ of the way while industrial solvent bottles were filled to maximum capacity in order to prevent headspace or any air from altering the sample. Sample bottles for both contaminants were kept on ice until they were transported to Weck Laboratories for analysis. Results from this effort are noted in Section 1.17.

Results

1.14 Groundwater Data

1.14.1 Results from ArcGIS: Ordinary Kriging

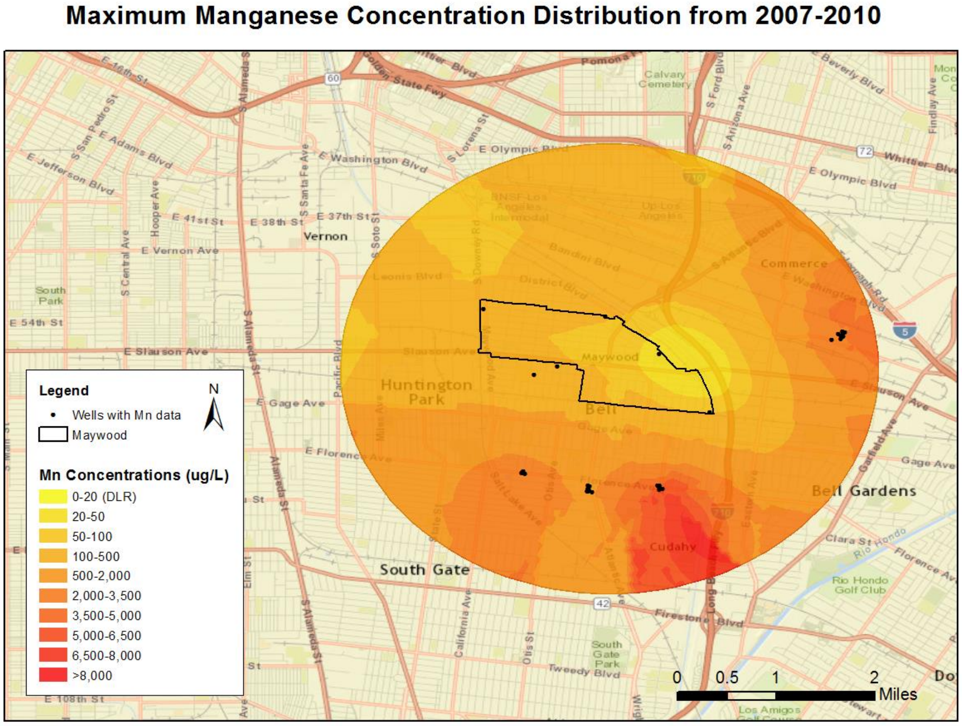


Figure 44. : Maximum manganese concentration distribution (using 10 classes) from 2007-2010 within a 2.3 mile radius of Maywood, CA.

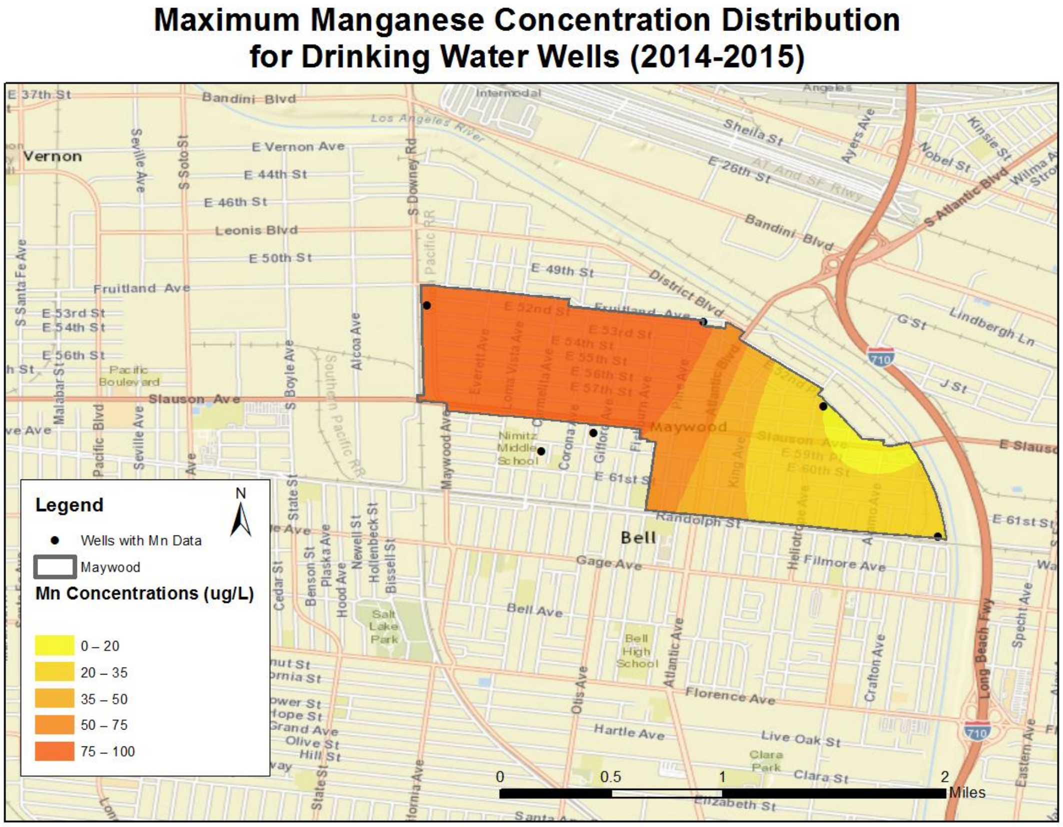


Figure 45. Maximum manganese concentration distribution for drinking water wells from 2014-2015.

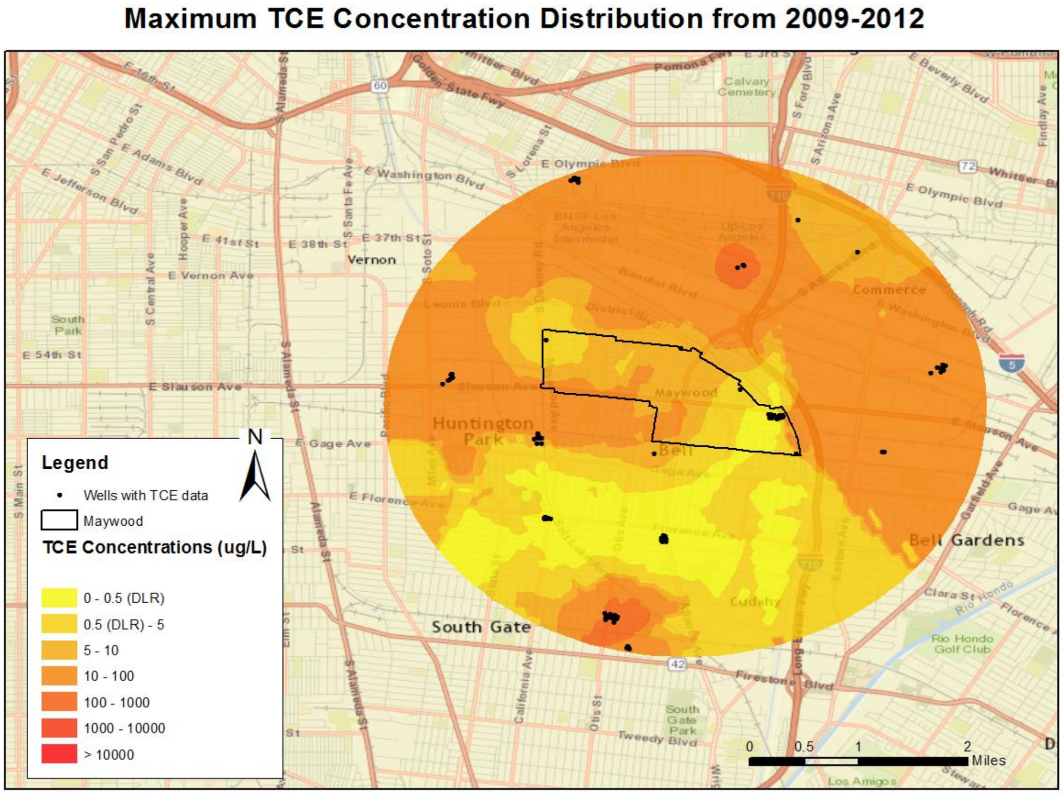


Figure 46. Maximum TCE concentration distribution (using 7 classes) from 2009-2012 within a 2.3 mile radius of Maywood, CA.

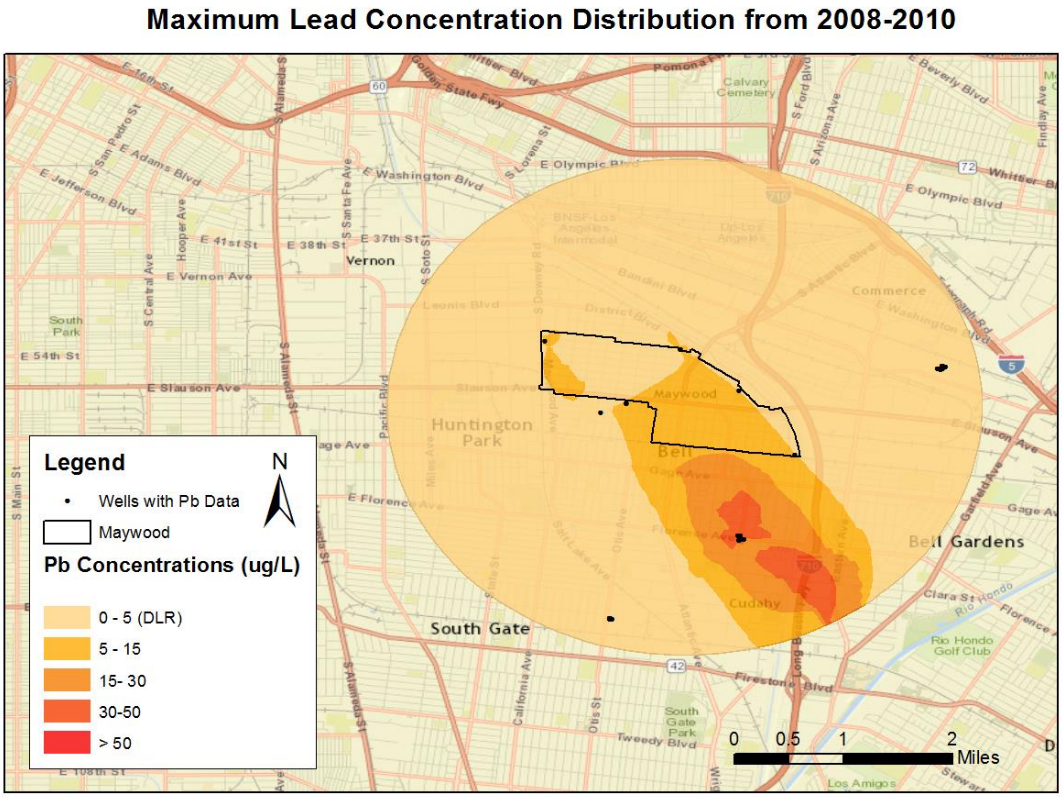


Figure 47. Maximum lead concentration distribution (using 5 classes) from 2008-2010 within a 2.3-mile radius of Maywood, CA.

1.15 Potential Industrial Sources

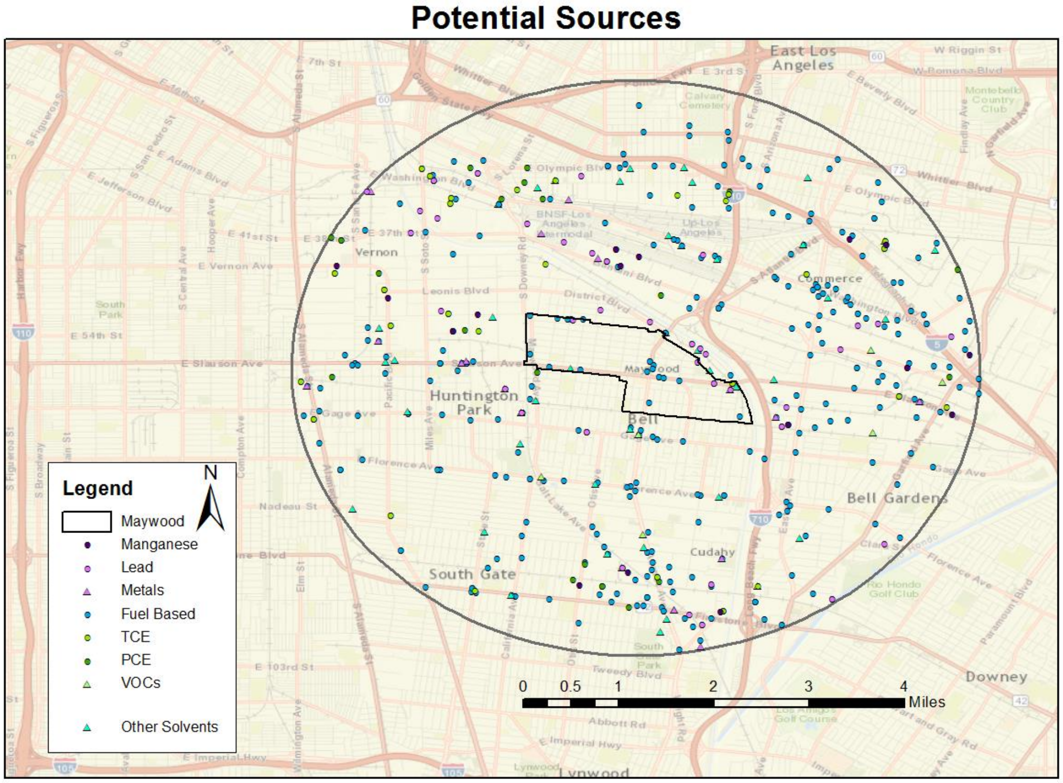


Figure 48. All potential industrial sources of the contaminants of concern in and around Maywood, California.

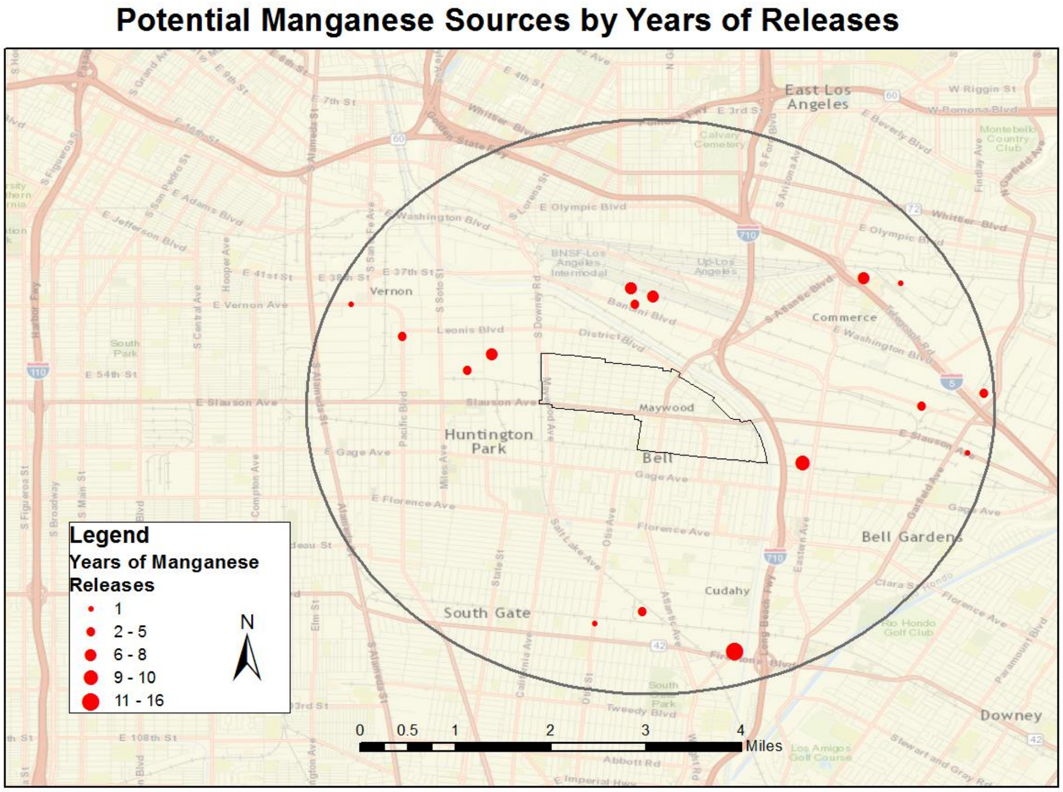


Figure 49. Potential industrial manganese sources, based on the number years of releases.

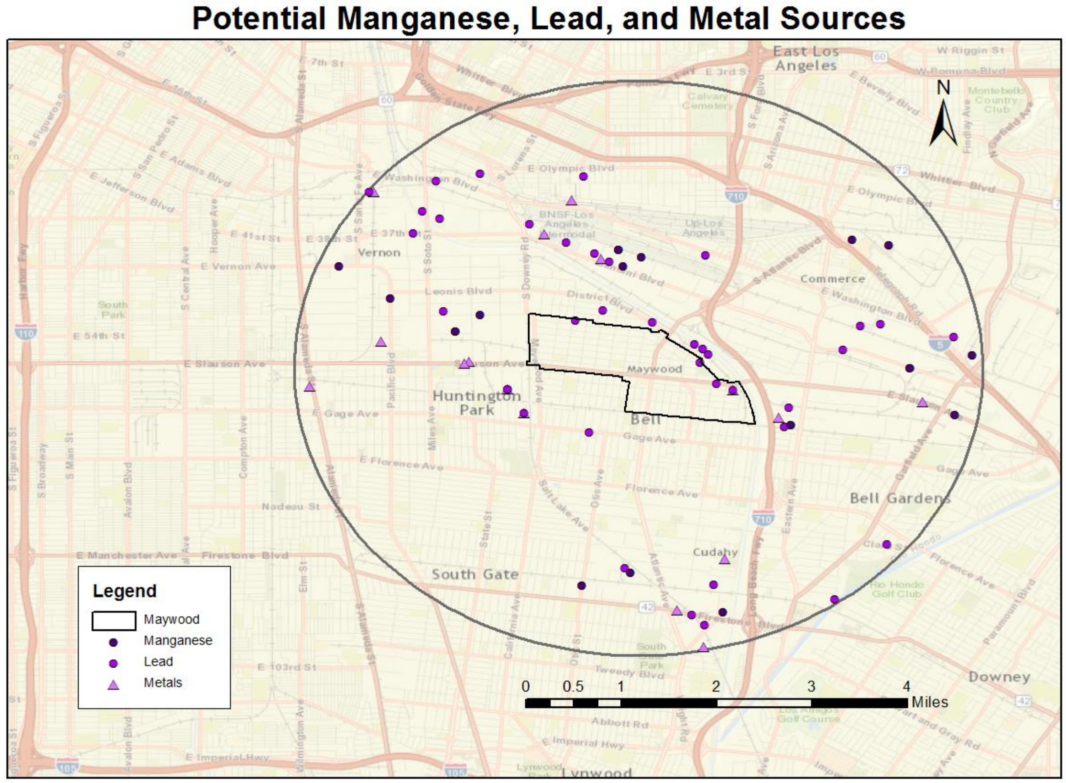


Figure 50. Potential industrial manganese, lead and metal sources in around Maywood, California.

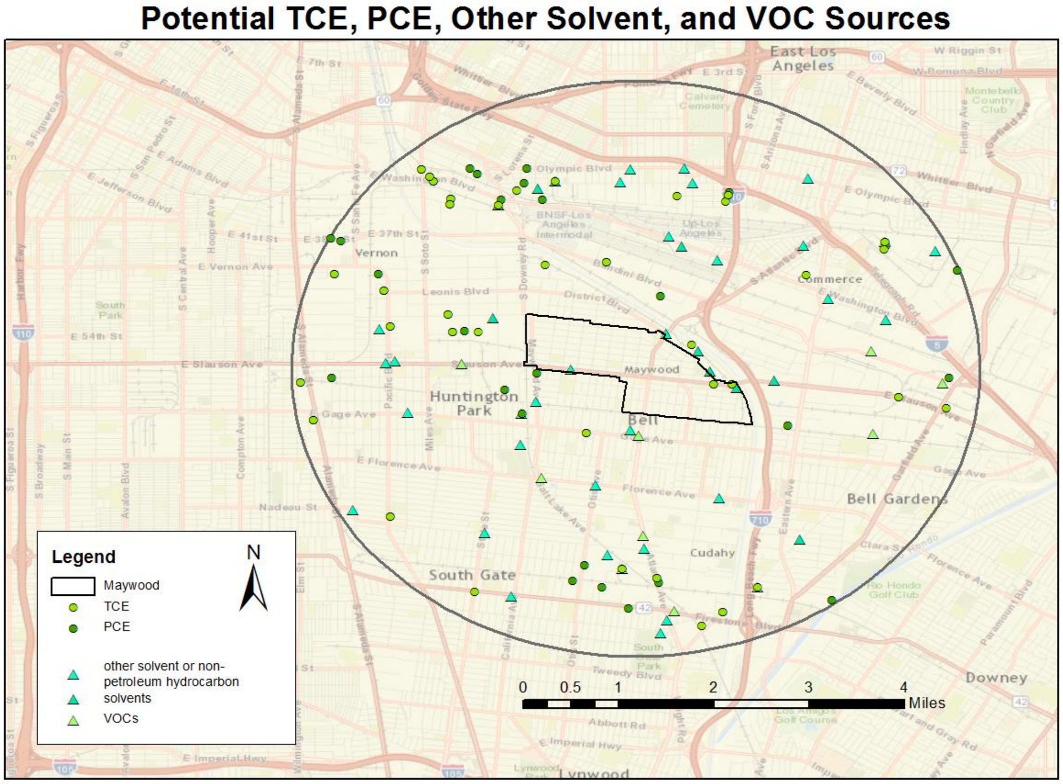


Figure 51. Potential TCE, PCE, solvents, and VOC sources in and around Maywood, California.

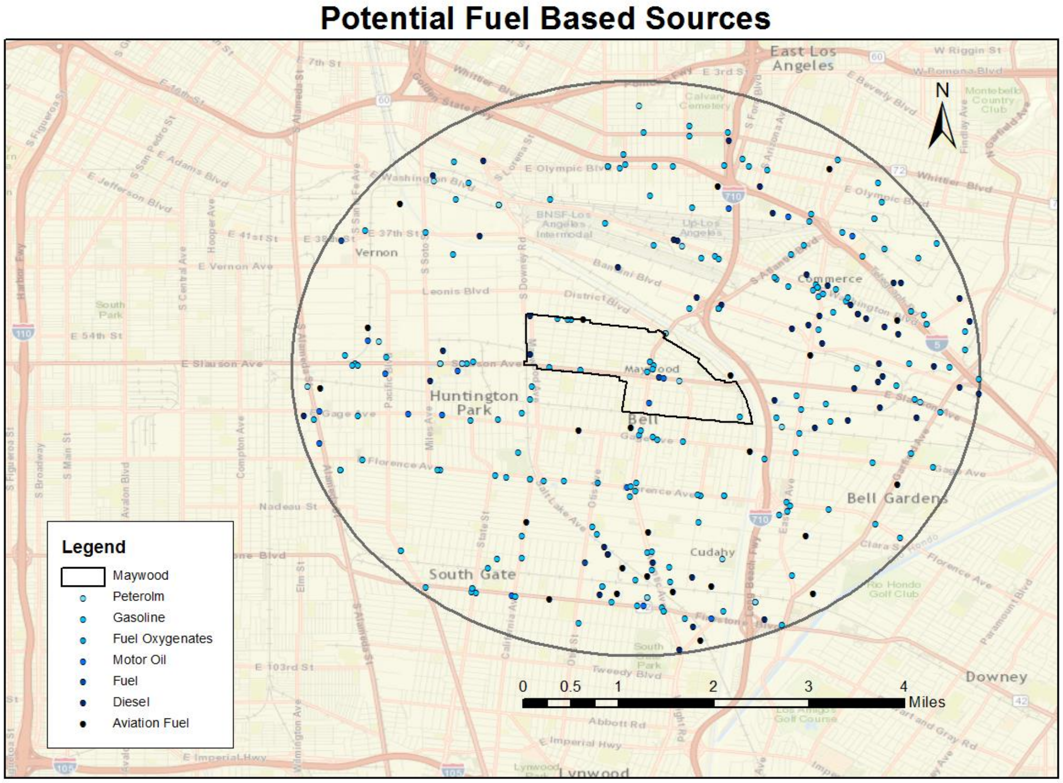


Figure 52. Potential fuel based sources in and around Maywood, CA.

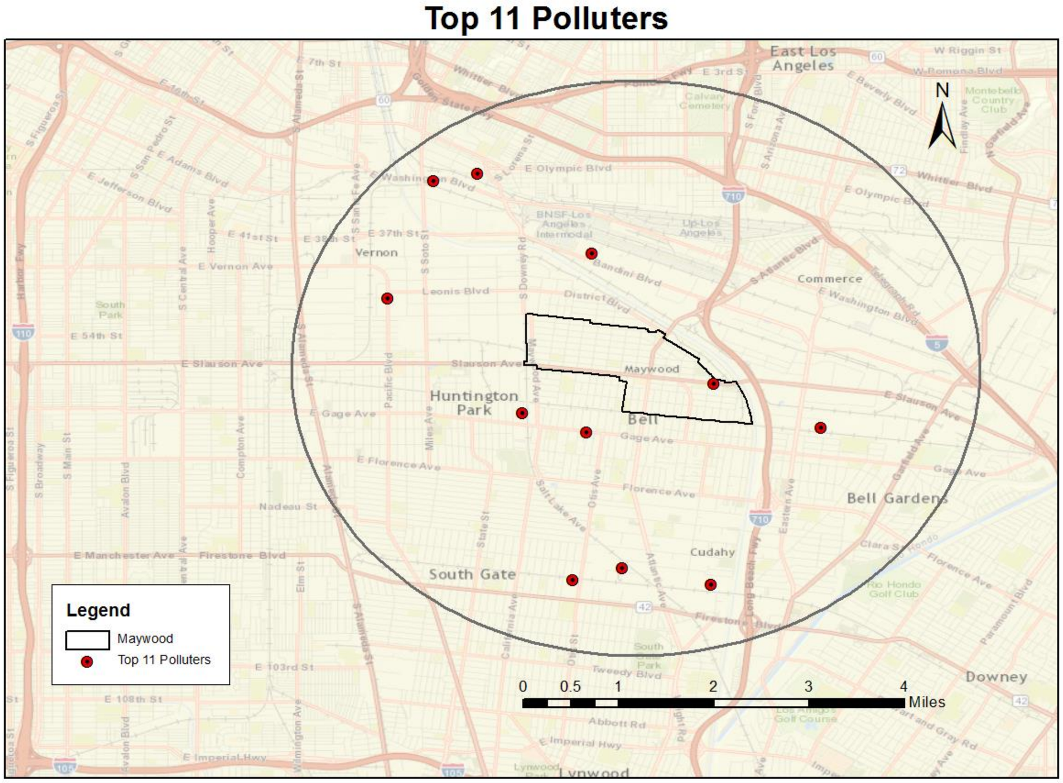


Figure 53. Map of top 11 polluters in and around Maywood, California. The top 11 polluters were determined by the processes outlined in section 1.11

Name	Address	Points (TRI only)	Number of Chemicals	Source
Former D.L. Gin Cleaners & Laundry	4032 Gage Ave, Bell		3	envirostor
Los Angeles Chemical Company	4545 Ardine St, South Gate		3	envirostor
Cook Induction Heat Treating	4925 Slauson Ave, Maywood		3	envirostor
EXIDE TECHNOLOGIES	5909 Randolph St, Commerce	25	1	tri
EXIDE TECHNOLOGIES	2717 S Indiana St, Vernon	24	1	tri
RAMCAR BATTERIES INC	4898 Pacific Blvd, Vernon	25	1	tri
BERG LACQUER CO	5037 Patata St, South Gate	24	2	tri
EVOQUA WATER TECHNOLOGIES LLC	4110 Ardmore Ave, South Gate	22	4	tri
EXXONMOBIL OIL CORP	3150 E Pico Blvd, Los Angeles	24	1	tri
KAISER ALUMINUM FABRICATED PRODUCTS LLC	3370 Benedict Way, Huntington Park	24	2	tri
Cal Doran	2830 E Washington, Los Angeles			

Table 10. Top 11 potential industrial polluters in and around Maywood, chosen as described by the methods in section 1.11.

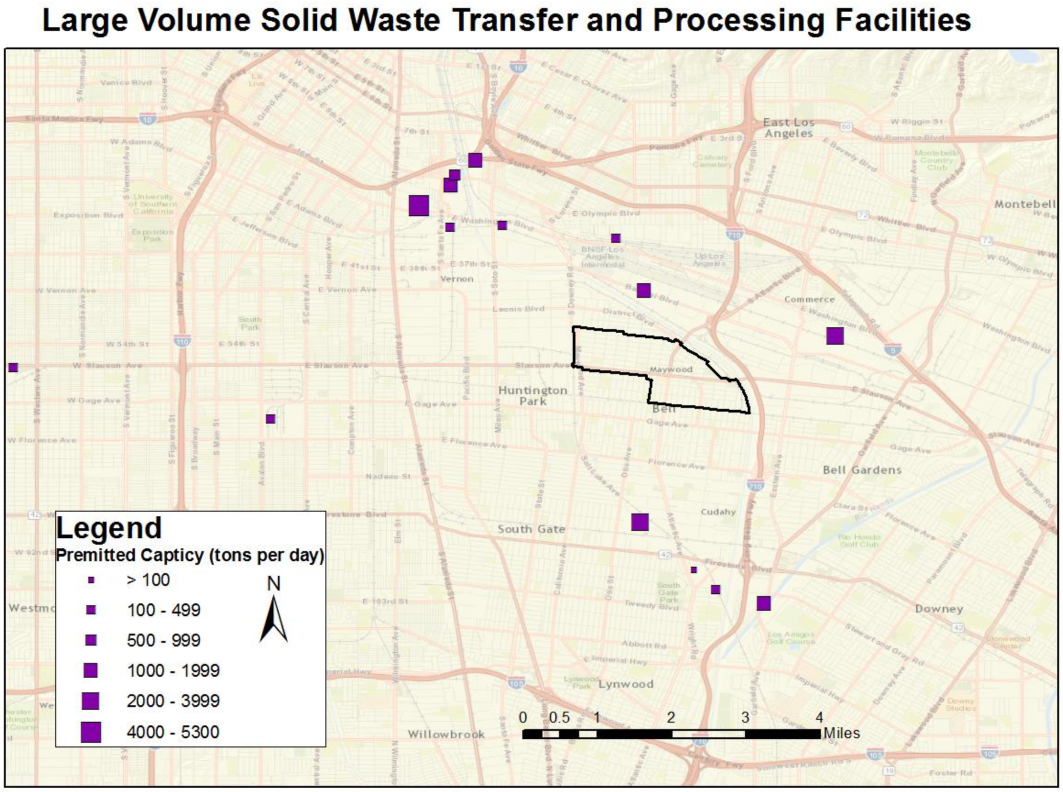
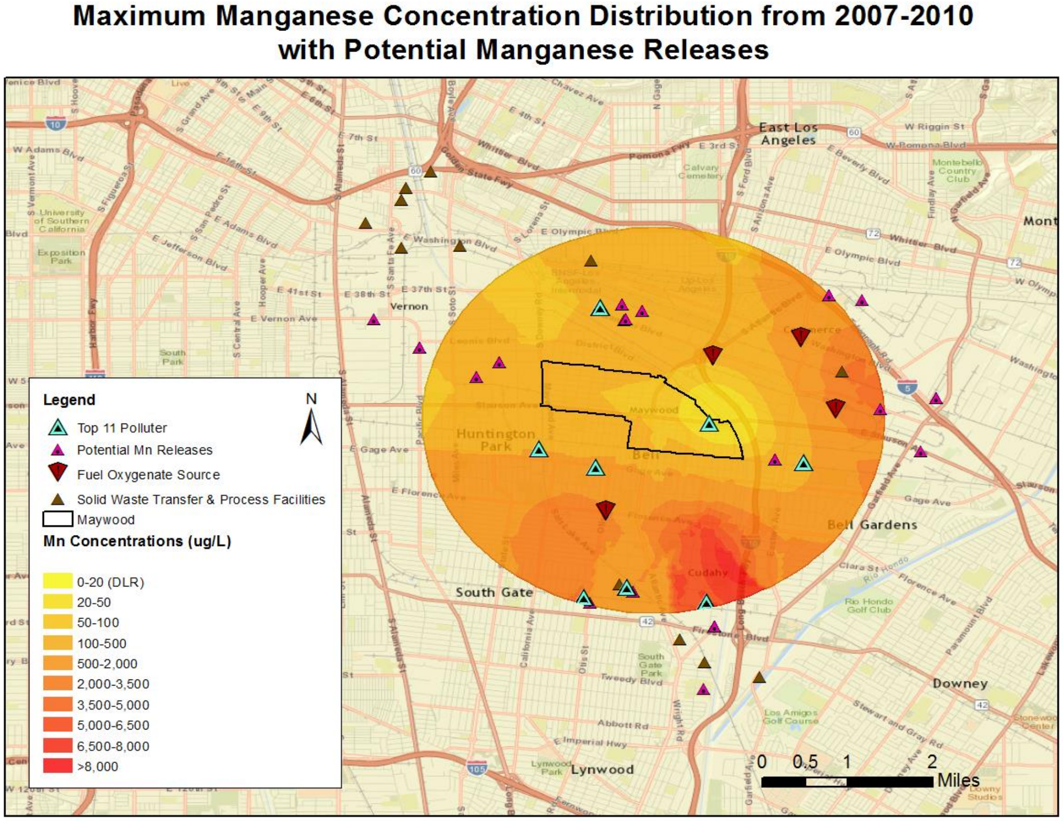

Large Volume Solid Waste Transfer and Processing Facilities

Figure 54. Large volume solid waste transfer and processing facilities near Maywood, California.

1.16 Overlay: Groundwater Data and Source Data



Maximum Manganese Concentration Distribution from 2007-2010
with Potential Manganese Releases

Figure 55. Maximum manganese concentration distribution (separated into 10 classes) from 2007-2010 overlaid with manganese releases into water and air.

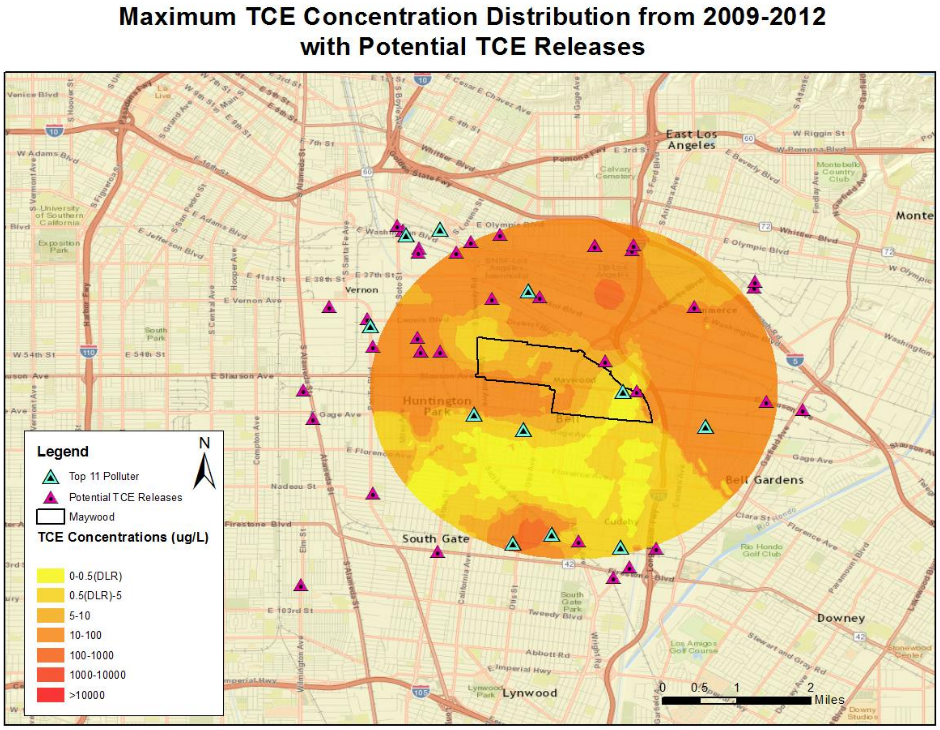


Figure 56. Maximum TCE concentration distribution (separated into 5 classes) from 2008-2010 overlaid with lead releases into water and air.

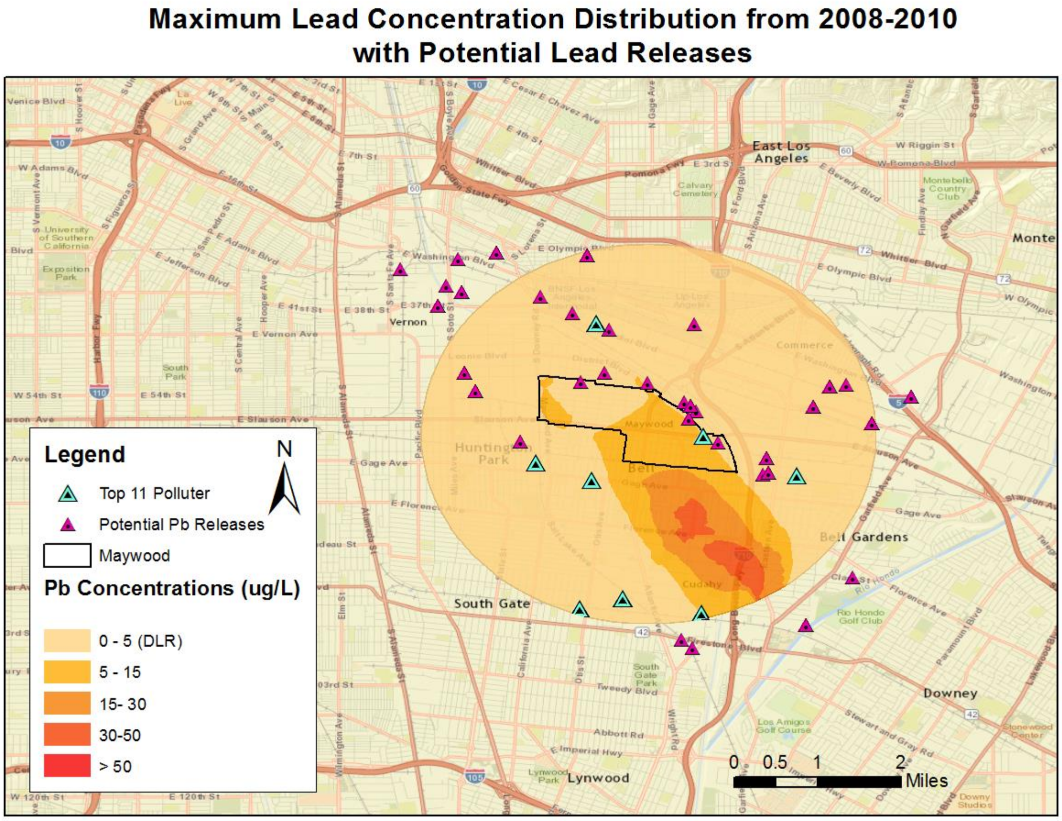


Figure 57. Maximum lead concentration distribution (separated into 5 classes) from 2008-2010 overlaid with lead releases into water and air.

1.17 Water Sampling

Our aim was to compare our results with what has been reported by state agencies.

For all of the contaminants we sampled for, none were found at concentrations above their respective MCL or SMCL (Figure 59). It is worth noting that manganese was detected in almost every water sample, at values ranging from 1.1-16 µg/L. Additionally, TCE was detected at a level of 1.8 µg/L at Maywood Riverfront Park, which was built over land from former Pemaco Chemical Corporation Superfund site. If they were detectable at all, lead, arsenic, and PCE were present at very low concentrations. It is possible that the treatment system installed at Mutual Company #2 could be working effectively. However, the results of our fieldwork are inconclusive given the small number of samples taken.

Location	Manganese (µg/l)	Lead (µg/l)	Arsenic (µg/l)	PCE (µg/l)	TCE (µg/l)
Maywood Park	7.7				
Resident 1, control	6.4				
Resident 1	6.1	ND	1.7		
Fitness 19	1.6				
School 1	5.1	ND	0.47		
Maywood City Hall	4.4	ND	0.88		
Maywood Public Library	1.1				
School 2	1.3	0.73	0.66	ND	ND
School 3	ND	ND	0.43		
School 4	11	ND	0.79		
Maywood Riverfront Park	16	0.21	0.76	ND	1.8
Maywood Public Library	16			ND	ND
Resident 2	13				
Maywood Park YMCA	11	ND	1.5		
Resident 3	7.1				

Figure 58. Table showing results of sampling fieldwork where ND means NOT DETECTED at or above the Method Reporting Limit (MRL). Resident and school names have been omitted for privacy. Water samples were analyzed by Weck Laboratories, Inc.

Discussions and Implications

1.18 Contamination Distribution and Potential Sources

Several sections (Section 1.2.6, Section 1.8.4 and 1.8.6, Section 1.24) discuss notable limitations to our approach with accurately understanding the true sources for groundwater contamination. While these limitations have a large impact on final conclusions, our analysis is a step forward in understanding groundwater issues in Maywood.

While we had hoped our initial review of potential industrial sources of pollution to groundwater in Maywood would allow us to determine a likely cause of the groundwater contamination, this process was complicated by a number of different factors. The following section will discuss individual conclusions regarding contamination of manganese, TCE, and lead sourcing in Maywood and surrounding areas.

1.19 Manganese

For the contamination distribution for manganese from 2007-2010, the worst levels of manganese occur in Cudahy, CA, with many values well over 2,000 µg/L. Table 11 shows three of the maximum values of manganese that were incorporated into the 2007-2010 map. The highest value recorded in our water quality data base was in 2008, sampling at 58,000 µg/L, which is nearly 1,200 times the SMCL of 50 µg/L. While our water quality database details the untreated, raw groundwater being used by Maywood, it is imperative to note this contamination; if the treatment systems in place fail, residents will continue to face unusable drinking water. This map is important in showcasing the contamination distribution and providing important information regarding the historical state of the groundwater.

Maximum Concentrations		
Well ID	**Sample Date**	**Mn (µg/L)**
MW-2	12/11/08	37000
MW-24	2/2/09	13000
MW-24	8/20/08	58000

Table 11. Maximum concentrations of manganese present in the database and represented in kriging efforts. These concentrations all derived from monitoring wells, for which depth data is not available.

The more recent map of manganese distribution (2014-2015) shows Maywood's raw groundwater still spiking above the SMCL for approximately half the city. To create this map, we used exclusively drinking water wells, instead of both types of wells. This is important to note, because the depths at which these wells are pulling from are better understood than the monitoring wells. Taking into account the limitations in methodology for these maps, we can conclude that the maximum values for manganese shown, in both the 2007-2010 and the 2014-2015 maps, are likely the most accurate. Visually, we did not identify any patterns in the overlay map with manganese and potential industrial sources. Maywood is surrounded by an extremely complex, industrialized area, so drawing any concrete conclusions about the industrial sources of manganese with the information we collected was not possible at this time.

1.19.1 Dissolved Oxygen and Groundwater Conditions as a Potential Source for Manganese

Our research has indicated a potential correlation between dissolved oxygen and soil conditions as a source for manganese. Several case studies have aided in this hypothesis. For instance, the Rhone Valley in France has similarly experienced a problem with manganese pollution and blackish drinking water (Jaudon et al. 1989). Researchers attributed the extremely high levels of manganese (1.2 million-2.8 million μg/L) to the low concentrations of dissolved oxygen in the groundwater (Jaudon et al. 1989). The average DO for the groundwater of concern was 2.6 mg/L (Jaudon et al. 1989). This case study showed that the highest concentrations of manganese were found in aquifers with the deepest depths (Jaudon et al. 1989).

It is a possibility that the manganese contamination seen in Maywood is attributable, in part or in whole, to a deficiency in DO, though much more research would need to be done on this topic to assess the specific conditions present in Maywood. The lack of dissolved oxygen is a possible explanation for the excessive presence of manganese in groundwater. Particularly given that Maywood wells use deep aquifers for drinking water (800ft -1400ft), the lack of dissolved oxygen at increasing depths below the surface is very likely. Dissolved oxygen values from 2008-2012 were retrieved from Geotracker GAMA and displayed on the manganese contamination distribution map to determine if there were any visual correlations between DO and manganese values. Because the number of monitoring wells measuring DO monitoring is very low, any correlation was difficult to assess. Figure 60 shows the location and median DO levels from wells in the Maywood area overlaid on our manganese concentration map of Maywood for the period of 2007-2010. Note that all values are below the concentration comparison given by Geotracker GAMA, at 8.4 mg/L. These numbers are likely not fully representative of potentially lower values for DO concentrations, because many monitoring well depths are shallower than the aquifers used by the Maywood Mutual Companies.

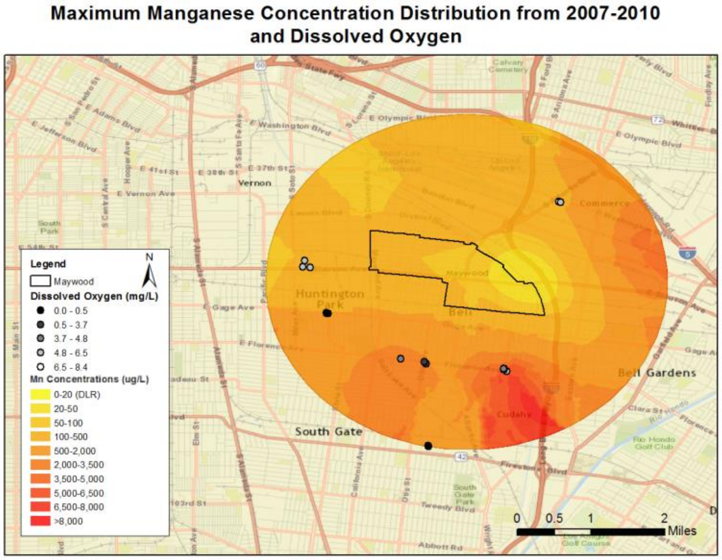


Figure 59. DO levels overlaid on manganese concentration distribution map from 2007-2010 in the Maywood area of the Central Basin.

According to Figure 60 and Figure 61, several regions across the Central basin have a high levels of manganese infiltrating groundwater aquifers and thus, groundwater drinking supply sources. To find any patterns between anoxic conditions and manganese concentrations in groundwater from other cities in the Central Basin with similar characteristics to Maywood, we extracted DO data from GAMA and provided a few summary statistics for the DO monitoring wells available in a 2.3-mile radius with each city. According to the Regional Groundwater Monitoring Report by WRD in 2016 (Figure 61-62) the City of Lomita's groundwater is heavily contained by manganese, while Bell Gardens contained little to no manganese in its groundwater. These two cities were used for a comparison.

A deficit in DO values is possibly seen deeper into the aquifers. DO data is not available for Maywood drinking water supply wells, as such, several assumptions must be made regarding these values. The values represented on the map as well as Table 12 below may be an overestimation of actual DO values corresponding to the depth of Maywood drinking water supply wells, particularly if the monitoring wells used for the study pulled groundwater from shallower depths. Table 11 demonstrates a comparison between the cities. Note that the median value for Bell Gardens is significantly higher than the median values of both Maywood and Lomita. The highest recorded manganese concentration in our database was reported at 58,000 µg/L. At this location, some concentrations of DO were ND, which potentially suggests areas of hypoxic groundwater conditions.

	Maywood	Lomita	Bell Gardens
Average	3.9	4.5	6.2
Max	8.9	12.0	8.3
Min	0.0	0.4	4.1

Median	3.7	4.1	6.2

Table 12: Comparison of DO (mg/L) values across cities in the Central Basin.

According to Figure 60 below, portions of the northern and western basin have manganese contamination in production wells. Maywood is located in the area with the cluster of darker brown wells in the North basin, near the 710 freeway and LA River.

In particular, Lomita has significant manganese contamination throughout aquifers in the subsurface. As such, understanding relationships between subsurface geochemical properties and manganese could merit investigation, particularly in localities like Lomita where manganese has infiltrated water production wells and monitoring wells.

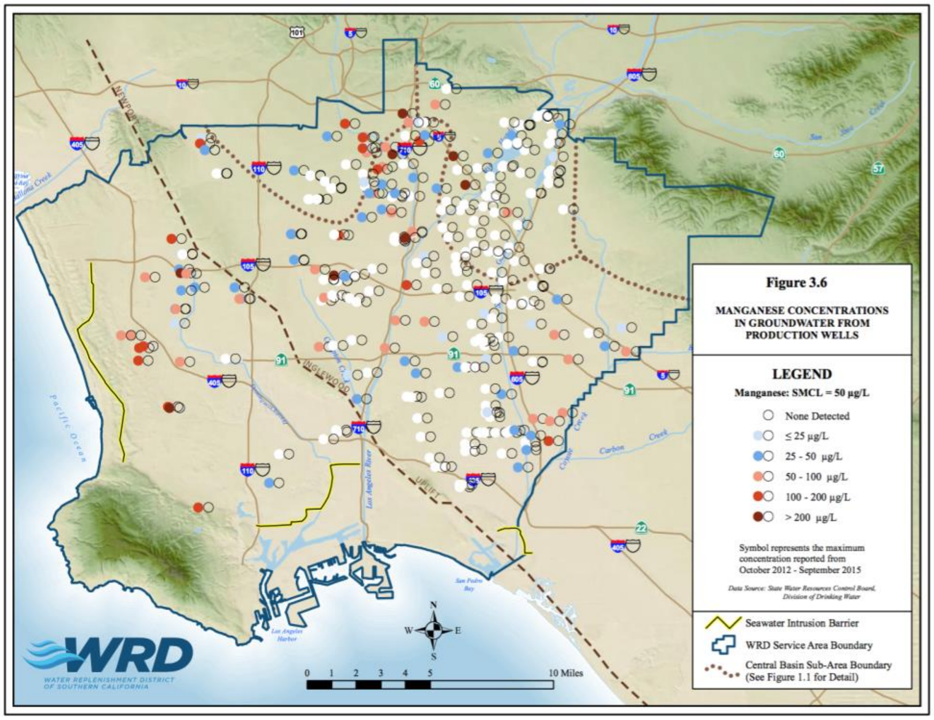


Figure 60. Manganese concentrations in groundwater wells in 2016. WRD Regional Groundwater Monitoring Report, 2016.

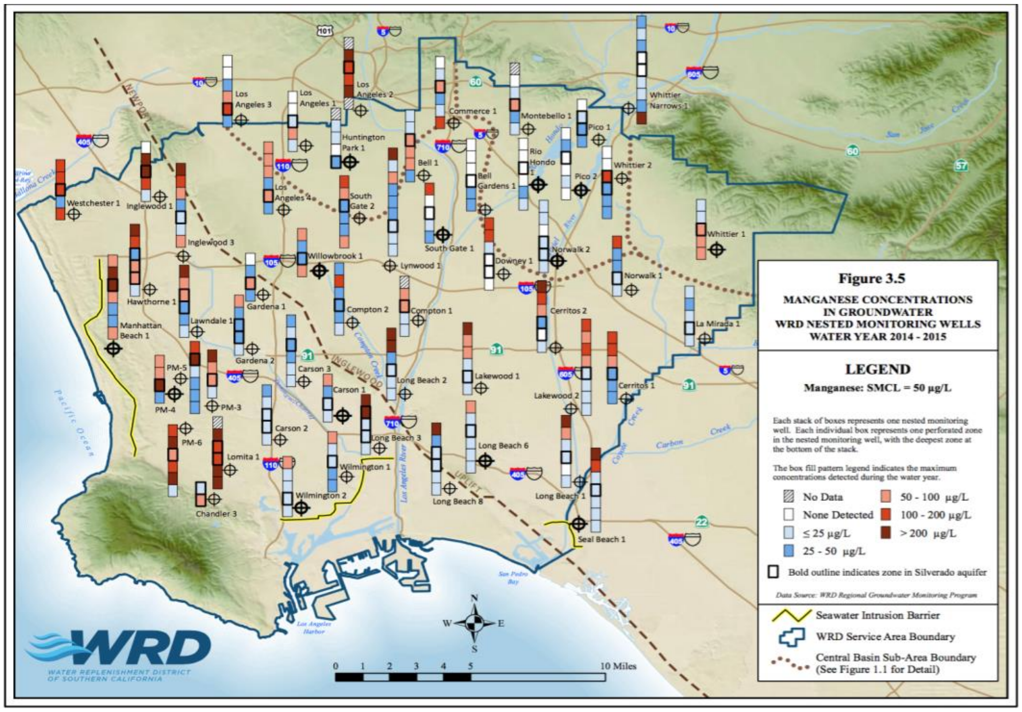


Figure 61. Manganese concentrations in in zone designations of aquifers. WRD Regional Groundwater Monitoring Report, 2016.

After reviewing the literature about DO and manganese contamination, we think that DO monitoring in drinking water and monitoring wells is extremely important to further shed light on this manganese problem. Overall, our analysis has shown that pointing to a source of manganese, whether it be natural or anthropogenic or a combination of both, is extremely difficult and much more research needs must be conducted on this front.

Regardless of the source of manganese, Maywood needs to continue monitoring treated drinking water to ensure that residents are not faced with aesthetically displeasing water in the future. If this is the case, current treatment infrastructure does not appear adequate enough to safely treat the manganese in raw groundwater.

Additionally, according to the 2015 Quarter 3 Groundwater Monitoring Report for Exide Technologies Vernon, the manganese concentrations in the shallow groundwater varied from 128 ug/L to 101,000 ug/L (Figure 62), the SMCL is 50 ug/L (EPA and E2 Environmental Inc.). However, metals, including manganese, do not typically migrate through aquifer layers as they are most likely adsorbed to sediments (Jaudon et al. 1989). For more discussion on Exide Technologies, refer to Section 1.21.1.

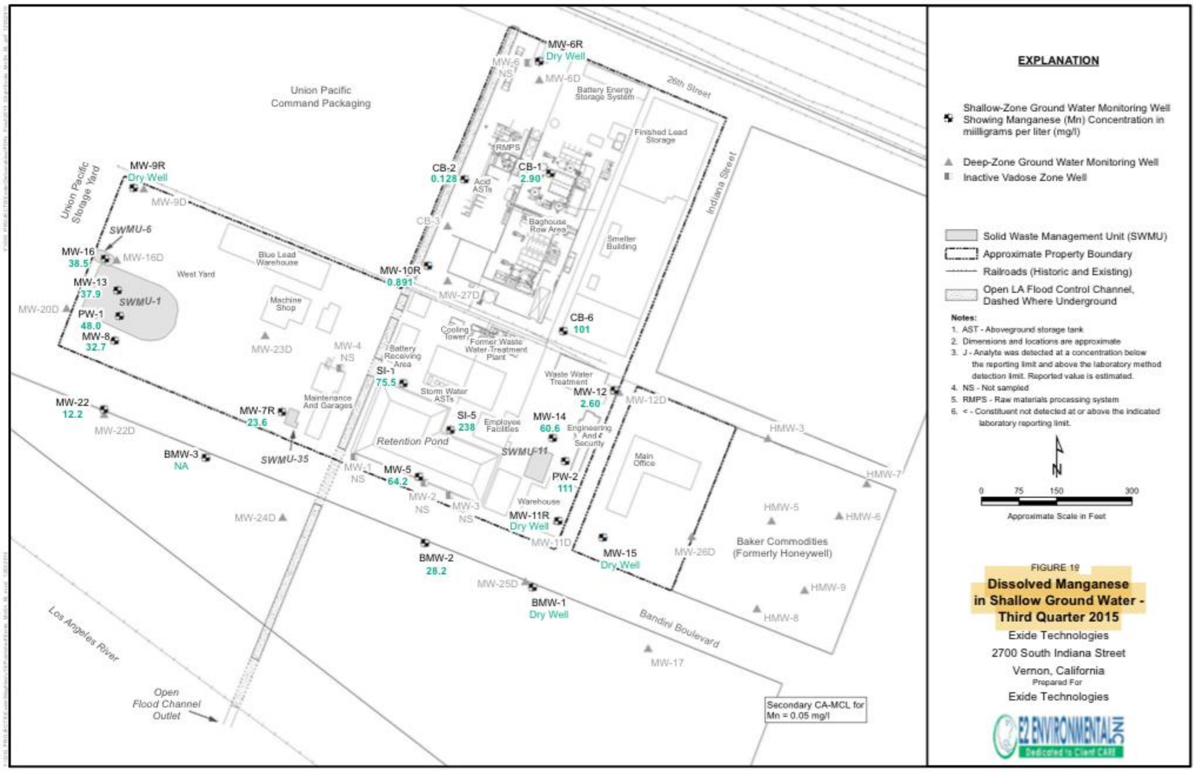


Figure 62. Dissolved manganese in mg/L in shallow groundwater at Exide Technologies in Vernon, California (E2 Environmental Inc.).

Since the manganese levels in the shallow groundwater are very high at Exide Technologies more research should be done to further investigate Exide Technologies as a potential source of the groundwater contamination in Maywood, California.

1.20 TCE

The modeling indicates that more accurate values occurred at maximum concentrations. Given that TCE is a well-known, man-made constituent (Johnson 2003), assessing an industrial source for this solvent is conceivably easier, and likely an advantageous pathway to continue to address broader contamination issues in Maywood's groundwater sources. Certainly, maximum values of 13,500 μg/L are an issue of concern, particularly due to the carcinogenic effects of TCE (Gist 1995). Maximum contaminations found are represented in Table 12 below.

While little can be discerned from the results obtained in ArcGIS, it is clear that maximum contaminations are prevalent between South Gate and Cudahy, as well as near the intersection of the 710 freeway and E Washington Blvd. Exide technologies is located in the latter described location. Additionally, Evoqua Water Technologies and Los Angeles Chemical Company are located in the highly concentrated area near Cudahy. Both Evoqua and LA Chemical Company are considered high profile polluters. Further investigation must be undertaken regarding the chemical histories of all three companies listed in this section and their relation to the Maywood area.

Well ID	Sample Date	TCE (μg/L)
MW-5	12/5/12	13500
MW -6	4/4/12	7940

Table 13. Maximum concentrations of TCE in the database.

1.20.1 Pemaco Chemical Corporation

Pemaco has historically been known to release TCE. Pemaco is a former chemical mixing facility, operational from the 1940s until 1991, located within Maywood along the LA River (Figure 63) (DTSC). Pemaco was named a Superfund site by EPA in 1997 (EPA).

Figure 63. Map showing location of Pemaco Chemical Corporation in relation to Maywood, California (GoogleMaps).

Remediation of the groundwater and soil contamination began in 2005, for 56 chemicals of concern, among them PCE and TCE (DTSC). However, "we [didn't] sample for lead, arsenic and manganese because they were not chemicals of concern for the Pemaco project."[2] However, TCE was a major concern and extensive studies have been done on the TCE contamination. In September 2007 electrical resistive heating (ERH) treatment system was used to clean up the groundwater and soil at the Pemaco site (EPA and National Association of Remedial Project Managers). After seven months of

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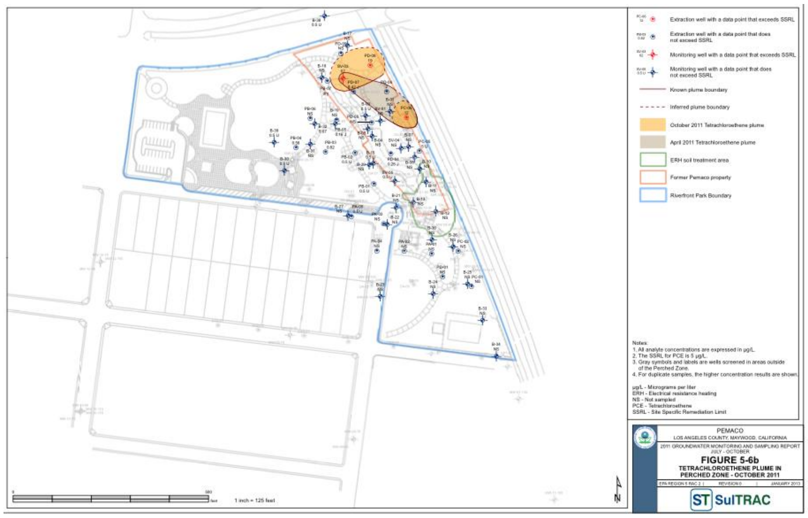
[2] RoseMarie Caraway, EPA remedial project manager for Pemaco, Personal Communication, April 15th, 2016

treatment the average TCE concentration was reduced from 15,000 µg/L to less than 100 µg/L (National Association of Remedial Project Managers). The contamination plumes varies by aquifer, see Table 13 (SulTRAC 2013). The most recent TCE groundwater plumes from 2013, on the Pemaco site can be seen in Figure 64.

Zone	Depth
A	75 to 80 feet
B	80 to 90 feet
C	95 to 110 feet
D	124 to 145 feet
E	160 to 175 feet

Table 14. Depths of aquifer zones under Pemaco (SulTRAC 2013).



Notes:
1. All analyte concentrations are expressed in μg/L.
2. The SSRL for trichloroethene is 5 μg/L.
3. Gray symbols and labels are wells screened in areas outside of the Perched Zone.
4. For duplicate samples, the higher concentration results are shown.

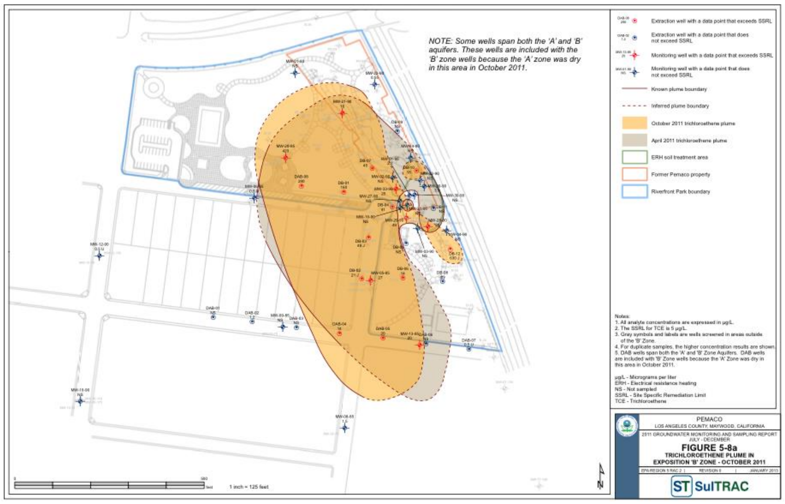
μg/L - Micrograms per liter
ERH - Electrical resistance heating
NS - Not sampled
SSRL - Site Specific Remediation Limit

PEMACO
LOS ANGELES COUNTY, MAYWOOD, CALIFORNIA
2011 GROUNDWATER MONITORING AND SAMPLING REPORT
JULY - OCTOBER

FIGURE 5-6c
TRICHLOROETHENE PLUME IN
PERCHED ZONE - OCTOBER 2011

EPA REGION 9 RAC 2 | REVISION 0 | JANUARY 2013

ST SulTRAC



NOTE: Some wells span both the 'A' and 'B' aquifers. These wells are included with the 'B' zone wells because the 'A' zone was dry in this area in October 2011.

Notes:
1. All analyte concentrations are expressed in μg/L.
2. The SSRL for TCE is 5 μg/L.
3. Gray symbols and labels are wells screened in areas outside of the 'B' Zone.
4. For duplicate samples, the higher concentration results are shown.
5. DAB wells span both the 'A' and 'B' Zone Aquifers. DAB wells are included with 'B' Zone wells because the 'A' Zone was dry in this area in October 2011.

μg/L - Micrograms per liter
ERH - Electrical resistance heating
NS - Not sampled
SSRL - Site Specific Remediation Limit
TCE - Trichloroethene

PEMACO
LOS ANGELES COUNTY, MAYWOOD, CALIFORNIA
2011 GROUNDWATER MONITORING AND SAMPLING REPORT
JULY - DECEMBER

FIGURE 5-8a
TRICHLOROETHENE PLUME IN
EXPOSITION 'B' ZONE - OCTOBER 2011

EPA REGION 9 RAC 2 | REVISION 0 | JANUARY 2013

ST SulTRAC

Notes:
1. All analyte concentrations are expressed in μg/L.
2. The SSRL for TCE is 5 μg/L.
3. Gray symbols and labels are wells screened in areas outside of the 'C' Zone.
4. For duplicate samples, the higher concentration results are shown.

μg/L - Micrograms per liter
ERH - Electrical resistance heating
NS - Not sampled
SSRL - Site Specific Remediation Limit
TCE - Trichloroethene

PEMACO
LOS ANGELES COUNTY, MAYWOOD, CALIFORNIA
2011 GROUNDWATER MONITORING AND SAMPLING REPORT
JULY - DECEMBER

FIGURE 5-9
TRICHLOROETHENE PLUME IN
EXPOSITION 'C' ZONE - OCTOBER 2011

EPA REGION 9 RAC 2 | REVISION 0 | JANUARY 2013

ST SulTRAC

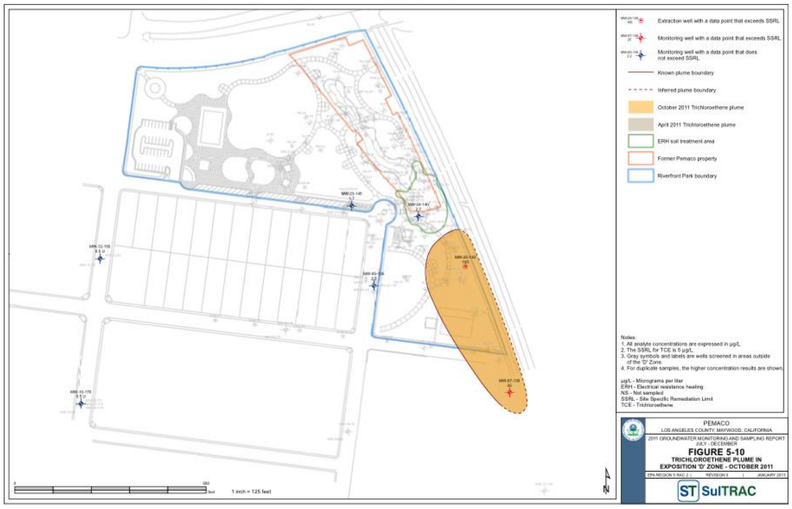


Figure 64. Extent of the TCE groundwater plume, in the aquifers under the former Pemaco site in October of 2011 (SulTRAC 2013).

The EPA Superfund program now lists the contaminated ground water status at Pemaco as “under control” (EPA 2016). Our sampling results had detectable limits under the MCL at the Riverfront Park, which is an indication that some TCE contamination is prevalent. Maywood Mutual Water Company #3 serves the area surrounding the former Pemaco site, and has been known to have a TCE contamination problem (Kintz 2015). More research should be conducted to determine if the TCE contamination in Maywood Mutual #3 is due to the TCE pollution from Pemaco Chemical Corporation.

1.21 Lead

It is clear from our database that there are lead exceedances in our study area. Depicted in Table 14 are the three maximum values for lead, keeping in mind the MCL is 15 µg/L. It's also important to note that the two highest concentrations were not included in the distribution maps shown in previous sections. This is because we chose the time period that had the most complete data and therefore would result in the most accurate maps. These two values are outside of this time period and therefore were not included in mapping but provide a chance for further investigation.

Well ID	Sample Date	Pb (µg/L)
MW-3	5/17/2012	360
MW-2	5/17/2012	110
MW-22	5/4/2009	77

Table 14. Maximum concentrations of lead in the database.

With all the limitations being considered, the distribution map Figure 48 shows the highest lead concentrations in the Cudahy area. The distribution moves north-west toward Bell while decreasing in concentration. There are five facilities in the Cudahy area known to have released lead. These are Armstrong World Industries Incorporation, Jervis Webb, Metal Surfaces Incorporation, Golden Oil Truck Supply and National Ready Mix Concrete Company. Armstrong World Industries Inc. is also categorized as one of the top eleven polluters in the Central Basin.

1.21.1 Exide Technologies

Two Exide Technologies facilities are in our list of the top 11 polluters (509 Randolph St, Commerce, CA; 2717 S Indian Street, Vernon, CA). Both facilities are just across the LA River from Maywood (Figure 65). Both facilities are former battery recycling sites that has been subject to state scrutiny for many decades. The Vernon facility has been making headline news for lead contamination in the soil and was recently closed in March 2015 to avoid criminal prosecution (Barboza 2015). The rest of this discussion will be about the Vernon facility. Exide Technologies has committed to pay $50 million to clean up the pollution, however after striking a deal with the state attorney, the executives of the company will not face charges (Barboza 2015). Since Exide Technologies is a very large facility, well known for pollution and very close to Maywood, we decided to look further into the possible groundwater pollution from the Exide Technologies site in Vernon, CA.

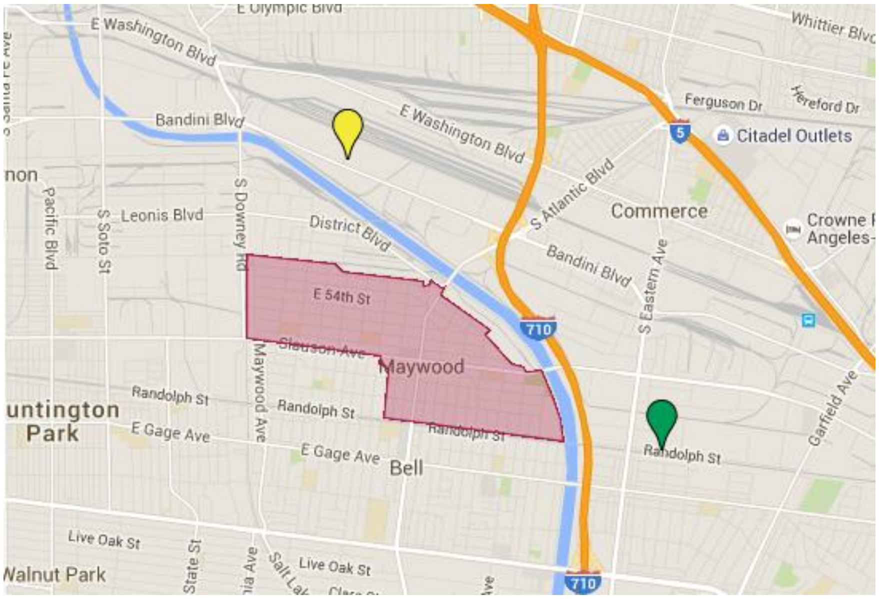


Figure 65. Map of Exide Technology facilities near Maywood, California. The yellow marker is the 2717 S Indian Street, Vernon facility is and the green marker is the 509 Randolph St, Commerce.

Since the closing of the Vernon facility, testing continues to show lead contamination in the soil within 1.7 miles of the facility affecting nearly 10,000 homes (LA Times, 2016). As of April 2016, studies have shown that children living in this area have double the risk of high lead in their blood when compared to national average (Barboza 2016). While there is lead contamination of air and soil, there is also evidence that the facilities contaminated the groundwater.

According to the 2015 Quarter 3 Groundwater Monitoring Report for Exide Technologies Vernon the lead concentrations were varied in the shallow groundwater. The lead concentrations varied from 2.38 µg/L to 66 µg/L, the MCL for lead is 15 µg/L (EPA and E2 Environmental Inc.).

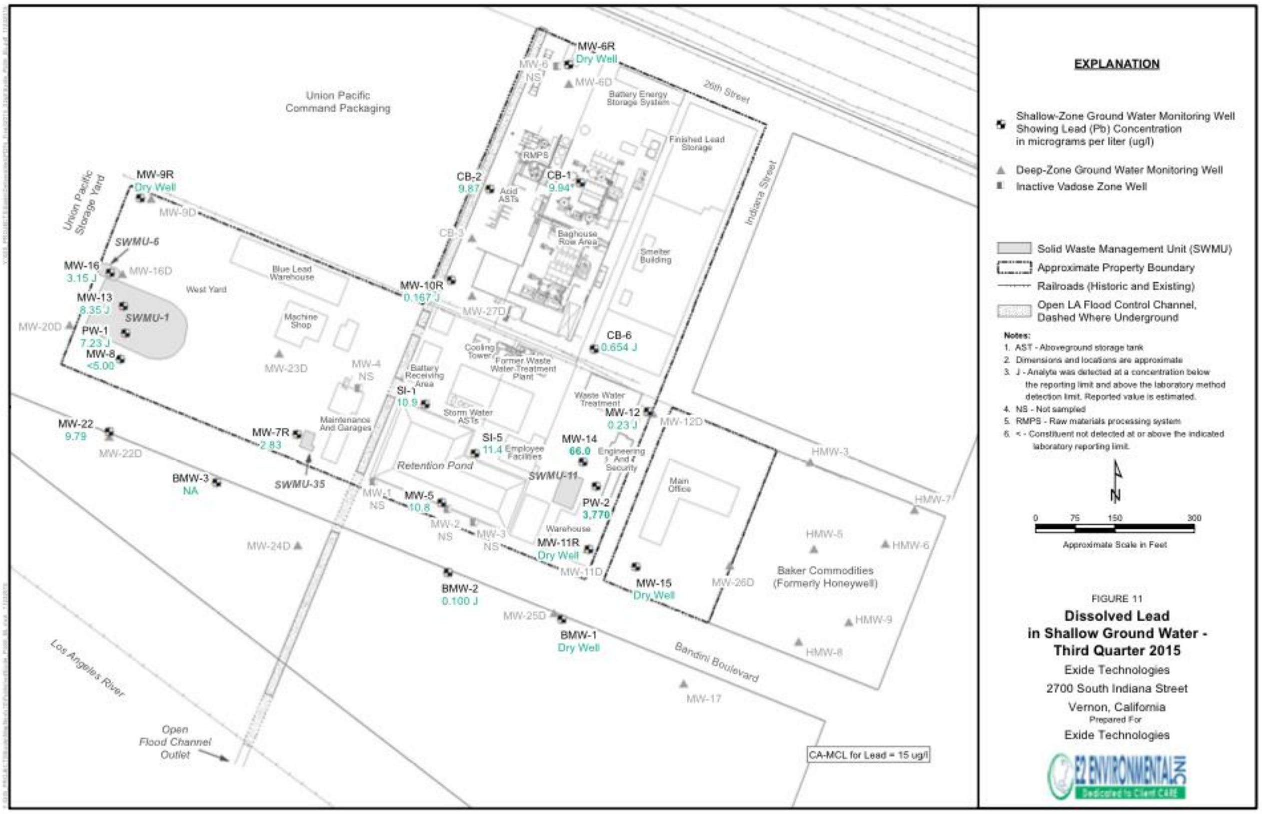


Figure 66. Lead concentrations in the shallow groundwater at Exide Technologies in Vernon, California. Concentrations are in µg/L (E2 Environmental Inc.).

1.22 Manganese as a Possible Primary Contaminant

While it appears that there are adverse health effects from manganese contamination in drinking water, it is inconclusive whether or not its status should be changed from a secondary contaminant to a primary contaminant. However, places such as Massachusetts, Connecticut, and Canada have recently made their standards of manganese levels in drinking water stricter, suggesting that the negative health impacts of manganese are gaining more attention as more research is done.

Nevertheless, the fact that manganese is often a visible concern in drinking water systems, its negative aesthetic effects merits a response to not drink the water, regardless of its status affecting health. As such, ensuring treatment of this constituent is crucial to maintaining a safe and drinkable source of water.

1.23 Current Safety of the Drinking Water

Our team took 21 water samples from Maywood for manganese, arsenic, lead, PCE, and TCE over two separate days, and all of the test results fell under the legal limits. Although our sample results were in compliance with state standards, they are not credible on their own. In order to obtain significant results, our team would have had to collect more samples over a longer duration of time to get a true sense of the current safety of the drinking water. In addition, even if the drinking water was deemed as safe to drink, there are still aesthetic effects that higher income communities with fewer minority residents would not be expected to consume. Residents have reported that their tap water will occasionally come out brown or red with a foul odor. Because of the low aesthetic quality and unknown safety of the water, residents still choose to buy bottled water, even when it costs a significant portion of their income. More confirmation regarding the safety of drinking water in Maywood, and monitoring and assessment of treatment must continue regardless of the outcome of the research in order to improve the taste, color, and odor of the water.

Project Obstacles

1.24 Difficulty Obtaining Data

From the beginning of our project, we found difficulties in obtaining the data necessary to do our analysis. In order to use geostatistical interpolation methods, we first needed datasets of various wells (within our 2.3-mile radius) that included coordinates, concentration values, and well depths. We began by using the Drinking Water Watch database, compiled and moderated by State Water Boards. This database had concentrations values of various constituents for all the active production wells in Maywood. These values were reported consistently over many decades. However, it lacked both the coordinates and depth. We then discovered that historically the coordinates of wells used for drinking water were considered national security and not allowed to be disclosed to the public.

Recently, Senate Bill 263 was put in place allowing for the dispersal of well completion reports and therefore production well locations. Well completion reports (WCR) are a mandated statement detailing the creation and completion of wells in California. We filed WCR requests for all of the production wells in Maywood with the Department of Water Resources. However, the mandate requiring well drillers to file a WCR is relatively new and therefore many of the production wells in Maywood did not appear to have WCRs on file. We received three WCRs back but two of the reports were for destruction of wells rather than completion. The only actual construction report did help us confirm the location for one of the wells. For the remaining production well coordinates, we used an approximate map sent to us by State Water Boards and Google maps street view.

In terms of well depths, all of the monitoring wells in GAMA listed depths to varying points in the well system, e.g., depth to groundwater, depth to top of screen, and other points. But it was unclear in each case which identified depth we would need for our analysis. We called staff at the State Water Board’s GAMA to obtain more information on the matter. During the call, it became apparent that these values may not be all that indicative of the depth where wells are testing. This obstacle was never assessed for monitoring wells and should be noted as a limitation for the groundwater quality database we created.

1.25 Redacting of Well Completion Reports

The dispersal of well completion reports (WCR) recently became legal as discussed in Section 7.1. The State Water Board, the agency that regulates WCR, is in the process of redacting all the WCRs onto an open online source. This seemed like an exciting development for our project but in reality, it caused many problems for us. This meant that many of the WCRs we requested were out of the State Water Board office to be scanned for online use. Additionally, many State Water Board offices were tremendously busy with the redaction process and unable to provide much help. In the next few years, the information, that we spent much of our project trying to find, will be easily available online.

1.26 Poor Communication within Agencies

More often than not emailing a contact from a federal, state, or municipal agency resulted in that contact pointing us to a different contact at another agency. We found ourselves in a web of various contacts and agencies all pointing us to each other. Even more common, agencies would claim they did not have the data we needed and pointed us to various project managers. Typically, these project managers were unaware of their clearance to give us this data and would politely decline our request. In addition to this, we also found that many agencies were unaware of many laws both new and old. Many agencies stated that they were still unable to give us drinking well locations even with the SB 263.

Department of Toxic Substance Control (DTSC) for example was extremely inconsistent. In order to file a public records request for drinking water well locations, we planned a trip to the DTSC in Chatsworth, CA. Two of our team members reached out to different contacts at DTSC confirming that we did not need a formal appointment submit a request. After driving an hour to Chatsworth, our members found themselves barred from receiving the requested data and not even allowed past the lobby. Even when our faculty advisor called their office and quoted the laws that allowed us to file a public records request, we were denied.

Recommendations

1.27 Data Accessibility

Retrieving data was the most consistent and pervasive obstacle we encountered throughout our project. We believe that agencies must work to put more of their data online in an easily understood and streamlined manner. The WCR redaction currently being done by WRD is a positive move forward. There must be more communication and consistency between agencies. One of the greatest setbacks in terms of creating the industrial source database was the inconsistencies between agency reporting. Agencies should have more communication to ensure that their reporting includes similar or comparable data. Since our study site was in a predominantly Spanish speaking community, we would also recommend that more of these documents and databases were translated to common languages.

1.28 Treatment

Water treatment facilities need to first recognize that the SMCL for manganese is insufficient to prevent aesthetic issues with the water and should instead aim to get concentrations to less than 15 μg/L (Knocke et al. 2015). Utilities should not begin treatment immediately but should instead attempt to understand the source of their contamination through effective monitoring. Once removal has been decided upon, facilities should develop an understanding of the common manganese treatment approaches, namely oxidation and filtration as well as sorption and surface oxidation. Although they were not discussed in this paper, alternative treatment approaches exist such as utilizing softening treatment, biological treatment, and membrane filtration.

Treatment plants need to carefully consider which oxidant they should utilize based on the chosen treatment technique. For instance, chlorine works poorly for direct oxidation of manganese but is an effective choice when using sorption and surface oxidation. Lastly, facilities need to recognize the complexities associated with treatment because controlling manganese levels does not stop at the entry point as manganese can continue to accumulate in the distribution system. Facilities need to assess their risk of accumulating manganese, minimize the amount that enters distribution systems, and avoid causing physical disturbances to the distribution system. Further design, treatment recommendations, and actual installment must be confirmed with engineering experts.

Manganese is not the sole constituent of concern. TCE, lead, and a variety of other contaminants not focused on in this project could be a current and/or future concern for Maywood residents. Likely, if treatment fronts of manganese are delayed due to its secondary contaminant level, treatment of manganese may be addressed through treatment of primary contaminants. Thus, all contaminants of concern can be treated in conjunction if treatment allows for that capacity.

1.29 Potential Changes to Legislation

1.29.1 Databases

Although there are a few databases about contamination available to the public online, most of these databases are full of flaws and very difficult to analyze in a useful way. Thus, potential regulation regarding the operation of TRI may be useful. TRI is one of the EPA's main resources to help the public learn about toxic chemical releases. Currently, data collection for pollution releases for most public databases is self-reported, which has proved to be ineffective. It should be the government's responsibility to collect data so that results cannot be skewed so easily. This can be done by hiring additional EPA staff to go to facilities near them and collect data themselves without any bias.

1.29.2 Enforcement

Nationwide, polluters have violated the Clean Water Act over 500,000 times (Duhigg 2009). These violations include not reporting releases and dumping chemicals at potentially lethal concentrations (Duhigg 2009). There is not nearly enough of an incentive for facilities to not pollute and for water distributors to make sure their water is completely safe to drink. State officials often overlook obvious illegal dumping, and the EPA often fails to interfere (Duhigg 2009). Lisa P. Jackson, the Administrator of the EPA from 2009 to 2013, even said that enforcement of water pollution laws is "unacceptably low" (Duhigg 2009). Less than three percent of the Clean Water Act violations in fines or punishments for the polluters at fault (Duhigg 2009). One of the main challenges to effective enforcement laws is successful lobbyists who work for powerful industries, and this issue is only becoming more prominent (Duhigg 2009). Besides a lack of enforcement in the California Code of Regulations, there are also many specific loopholes that allow facilities and water distributors to pollute water and supply polluted water to communities. For example, if a water system's average of four consecutive quarter of sample results is less than three times the secondary MCL for every constituent, it may apply for a nine year waiver of a secondary MCL (22 CCR § 64449.2). There is no reason that a water system should be rewarded for staying under three times the maximum limit for a contaminant or be able to apply for a waiver that lasts nearly a decade. In addition, if a facility cannot afford to build emergency facilities, cost is not a reasonable excuse for failure to comply. If this happens, the Board should "consider further action" (23 CCR § 2245). The CCR does not list any specific disciplinary action for this violation of the law, which makes it much easier for facilities to disobey without punishment.

1.30 Further research

1.30.1 More Groundwater Testing

In order to fully understand Maywood's unique manganese situation, we believe much more research is needed. For a phase II analysis, we believe more research should be done regarding: dissolved oxygen analysis, further depth analysis, as well as more in depth well water testing.

Since there is some question about the legitimacy of the testing done by state agencies, we would recommend a much more in depth water testing of Maywood and the surrounding areas. This would include many more locations as well as consistent testing over a longer period of time to account for natural fluctuations and error. In addition to this, more understanding of the inherent differences between treated drinking water and raw groundwater.

1.30.2 Dissolved Oxygen (DO)

Various reports have indicated that low DO levels can cause manganese to precipitate out of water and create dark particulate (Goldrath et al. 2006). Anoxic water conditions exist in the groundwater along the Los Angeles River, where Maywood is located, so completing further analysis is crucial to ruling out naturally caused manganese (Goldrath et al. 2006). This can be done by comparing the manganese levels and DO levels around the central basin. In addition to the water testing mentioned above, DO should also be tested.

Finally, further understanding the subsurface in the central basin is key to truly mapping the contamination distributions. Once the well completion reports (WCR) are redacted, the WCR for Maywood may more accessible. With those WCRs, it will be possible to better understand which aquifers they are pulling from. They include the column of material taken out to build the well. For example, materials like silt, gravel, clay and sand. The levels of materials that were reached in the construction of the well can be compared with the materials known at each aquifer. This would give a researcher more than enough information to say which aquifer the well is pulling groundwater from.

1.30.3 Industrial Source Identification

To fully understand the potential source of the groundwater pollution problem in Maywood further research needs to be done. By taking an in depth look into each individual polluters, similarly as we have done for Exide Technologies and Pemaco Chemical Corporation, more can be learned than by looking at the information provided by the databases. The in depth analysis of all polluters in the study area would make it easier to potentially identify an industrial source as the cause of the groundwater pollution. There also may be many other sources of industrial pollution that are reporting to other databases we did not use, as well the industries who are polluting illegally and not reporting to any agency.

1.31 Community Empowerment and Environmental Justice

For the last decade the people of Maywood have been mandated to pay for water with thick dark particulates. They have been forced to drink, bathe, and wash clothes in this water resulting in stained clothing, possible physical health effects and definite mental health impacts. Over and over again their voices have been disregarded and grant money has dissolved with no positive changes. Just across the county, a largely white, affluent community sees a much different response. Merely a month after the Porter Ranch methane gas leak, Governor Brown declared a state of emergency and funneled aid into Porter Ranch. To date, the California Department of Public Health mandated that SoCalGas fund the relocation of over 6,000 residents (KCET 2016). Additionally, both the Air Quality Board and Los Angeles County have started the litigation process against SoCalGas. It's important to note that the immediate health effects associated with methane are low to none including things like nausea, dizziness and headaches (NIH 2016).

While it may be argued that Porter Ranch differed from Maywood in the fact that there clearly was a large company accountable for the pollution, this is not necessarily the case. Not too far from Maywood, another lower income, minority community struggles to have their health concerns heard. Vernon currently struggles with Exide Technologies and their impacts to the community. Since 1981, Exide has been emitting lead into the air and continued to do so until it was officially shut down in 2014 (LA Times 2015). The county and state response to this catastrophe is underwhelming to say the least. In 2015, Governor Brown ordered Exide to fund the cleanup of households in Vernon. It wasn't until this past February that Brown proposed state spending in order to accelerate the cleanup process. It took state officials about 30 years to shut down a lead emitting facility while it took them months to shut down the Porter Ranch well. EPA states that there is no safe level of lead exposure and can cause longstanding, serious physical and mental damage (EPA 2015). There is a clear gap between the state response in white, affluent areas such as Porter Ranch and the lower income, predominantly minority regions like Vernon and Maywood.

In order to regain the resident of Maywood's trust, officials must reaccess the drinking water quality and health impacts. Once officials are confident with the water quality, they must work to communicate this to the residents. These notices must be inclusive for all residents. Improvements in this regard include translations in various languages and videos provided for those with hearing disabilities. For the last ten years, Maywood residents have not only felt suspicious of their drinking but also of the officials releasing news that their water is safe. It will take more than transparency to mend these relationships, which is why we recommend the state provide residents with home testing kits. Additionally, the state should offer reimbursements for the bottled water residents were made to purchase over the last decade.

Conclusion

Over the course of the project we made great strides in assessing the groundwater contamination in Maywood, however much more attention and resources must be diverted to ensure safe and clean drinking water. Currently, the residents are unsure if water is safe to use, which may be from a lack of transparency from the county level and/or governmental agencies in charge of water management. Data collection and assessment of water in Maywood should be increased.

Additionally, all of the assessments about the current status of treatment are outdated and current status of treatment in Maywood is not clear. Furthermore, it is also not known if the current treatment is working to the fullest capacity. Information regarding the safety and treatment the water needs to be fully communicated to residents.

The contamination distribution maps compile data from both drinking water and monitoring wells to give insight to the groundwater contamination status. While our maps explore contamination from a statistical perspective, it is recommended that creating a geochemical model that takes into account the complex hydrology of the Central Basin be explored. This is critical to understand the full extent of the groundwater contamination in Maywood and surrounding areas.

Finding the cause of the contamination is a difficult undertaking. Identifying the source of manganese was especially difficult because it could result from anthropogenic, natural, or geochemical processes. Additionally, the potential source for TCE and lead may be from outside of the three mile radius or from a historic site not being currently reported to any of the databases we investigated. Further investigation is necessary in order to determine the exact source of the groundwater contamination in Maywood.

Moreover, evidence shows that there may be adverse health effects of manganese in drinking water, including neurotoxic, reproductive, and developmental effects. These negative health effects are especially significant for certain at-risk populations including children, pregnant women, fetuses, seniors, and those with liver impairment and iron deficiency. While it is inconclusive whether or not manganese should be a primary contaminant, there should be more research into the health impacts of manganese in drinking water, especially on the impacts on the general population.

To best help the community have access to clean and safe drinking water we suggest further research be directed to cleaning up hazardous TCE and lead, as well as continual monitoring of manganese levels to ensure exceedances are not recorded.

Indeed, the residents of Maywood have been suffering from contaminated drinking water over a decade. This marginalized community has been vocal about their desire and need for clean water but have not been validated for their efforts. We hope that our research and recommendations will be able to shed light on these historical problems persistent in Maywood and bring the residents increased information, resources, and assurance of clean water that they deserve.

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