EVALUATING THE EXTENT AND SOURCES OF ZINC CONTAMINATION WITHIN EUGENE-SPRINGFIELD WATERWAYS

by

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Stormwater runoff from urban and suburban areas carries pollutants, adversely affecting water quality in local waterways. In the Eugene-Springfield metro area, a specific stormwater pollutant of concern is zinc- a known herbicide, antimicrobial, and toxin at certain concentrations for aquatic organisms. Notably, zinc has been rising in water quality measurements in Eugene over the past 20 years. Using 2019 as a case study year, data aggregation revealed similar zinc concentration patterns within the waterways of Springfield and Eugene. Potential sources of zinc contamination are numerous, but findings in this study indicated the greatest proportion of zinc pollution is likely from moss control products, vehicular tire- and brake-wear, and industrial discharges. Spatial modeling of these potential sources of zinc contamination revealed stormwater basins with high zinc pollutant severity potentials, in turn distinguishing areas for future stormwater sampling efforts. This work adds to the understanding of municipal stormwater pollution in the Pacific Northwest and can lead to informed strategies for source control, minimizing zinc loading to the environment.

Acknowledgements

First and foremost, I acknowledge that this project's study area lies within the traditional homelands of the Tribes and bands of the Kalapuyan people. The Kalapuyan people were dispossessed of and forcibly removed from their Indigenous homeland by the United States government following treaties in the 1850s. The zinc pollution on this land directly results from colonization. I would like to acknowledge and express my respect for the many descendants who are citizens of the Confederated Tribes of the Grand Ronde and the Confederated Tribes of the Siletz Indians, and who continue to be stewards of the land and the watersheds described in this study.

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I. Introduction

Stormwater in the Eugene-Springfield Metro Area

The Eugene-Springfield metro area is the third largest metro area in Oregon both geographically and based on population. Hydrologically, the cities meet near the main stem confluence of the Willamette and McKenzie rivers and encompass important headwater tributaries, smaller waterways, and their adjacent riparian areas and prairie wetlands. These regions provide important habitat for aquatic plants and animals and often coincide with recreation corridors where visitors swim, bike, boat, and fish (City of Eugene et al., 2002; City of Springfield & Public Works Environmental Services Division, 2010). Since the 1990s, concern towards the impact of urbanization on water quality within the Eugene-Springfield metro area has grown, particularly surrounding stormwater runoff. As defined by the city of Eugene, stormwater runoff occurs when rainfall is unable to be absorbed into the ground due to impervious surfaces such as paved streets, rooftops, and parking lots (City of Eugene & Lane Council of Governments, 1993). As the runoff travels over these surfaces during storm events, pollutants are picked up and deposited into public drainage systems and discharged into receiving waters.

Stormwater drainage basins are geographic regions where stormwater from the infrastructure in a city's public drainage systems flows into larger drainageways that ultimately converge as outfalls to rivers or other waterways. Stormwater basins are designated by each respective city, with Eugene containing seven major basins, and Springfield containing 15 (Appendix A). In total, the stormwater basins and their management plans cover about 76 square miles of diverse land uses from industrial and residential to urban greenways (City of Eugene & Lane Council of Governments, 1993). Springfield's stormwater drainage system has two major drainages, with one flowing to the Willamette River and another that flows to the McKenzie. Eugene's stormwater drainage system discharges further downstream on the Willamette River and to Amazon Creek (City of Springfield & Public Works Environmental Services Division, 2010; City of Eugene, 2020).

Both the cities of Eugene and Springfield are required by the federal Clean Water Act to obtain a Municipal Separate Storm Sewer System (MS4) permit under the National Pollution Discharge Elimination System (NPDES) permit program, which controls municipal stormwater discharge into larger waterways. This program aims to improve regional water quality using two measures: prescribing best management practices (BMPs), which reduce pollutants, and mandating water quality monitoring to track pollutant loads in local waterways. However, the NPDES permit program operates differently on cities of different sizes, with the cities of Eugene and Springfield classified under different permit-types (City of Eugene, 2020). As a result, the extent to which pollutant quantities are monitored within each city varies, with Eugene publishing a Stormwater Annual Report of its monitoring program at 12 locations since 1990, and Springfield conducting only intermittent monitoring of mandated pollutants since 2002 (City of Springfield & Public Works Environmental Services Division, 2010).

While most sampled pollutant concentrations have been decreasing during this time, data collected by the city of Eugene show zinc concentrations have consistently increased (Appendix B). In addition, despite differences in sampling frequency, both the cities of Eugene and Springfield report that samples taken from local waterways have exceeded Oregon's acute/chronic water quality criterion for total zinc (36.2 µg/L and 37.0 µg/L, respectively) (City of Eugene, 2020; City of Springfield & Public Works Environmental Services Division, 2010). However, the extent of zinc contamination within Springfield remains in question, and in both cities the sources of zinc contamination have not been identified. My research fills this gap, defining the most probable sources of zinc contamination and mapping their spatial extents, thereby taking significant steps towards identifying zinc contamination source control measures and mitigating the increasing zinc pollution seen in the Eugene-Springfield metro area.

Zinc in the Environment

Fate and Transport

Zinc is a common trace element in soils and can be released to the environment by natural and anthropogenic sources. In the dissolved phase, zinc typically exists as the Zn^{2+} ion, which does not volatilize and can readily bind to soils, decreasing its migration in the environment. However, zinc transport in waterways and leaching through soils can occur at sites where zinc loading rates are high and/or there are few suitable binding sites (e.g., organic matter, clay minerals) in the solids. Moreover, zinc can be transported in rivers and streams via the suspended load (National Center for Environmental Assessment, 2005).

Environmental Impact

Zinc concentrations recorded by the city of Eugene range between 0.3 µg/L and 120 µg/L. This wide range remains nontoxic for humans but can negatively affect aquatic organisms and ecosystem functioning at varying degrees (Agency for Toxic Substances and Disease Registry, 2005). Toxicity of zinc compounds on aquatic organisms is impacted by several environmental conditions, including hardness of dilution water, dissolved oxygen concentrations and temperature. Moreover, the resistance to zinc poisoning varies by species, making reported lethal concentrations of zinc vary widely. However, even at nonlethal levels, acute and chronic exposures can cause impacts on development, reproductive success, and other essential organ function in aquatic organisms (Paylar et al., 2022; Skidmore, 1964).

History of Zinc Monitoring in the Eugene-Springfield Metro Area

High zinc concentrations within the Eugene-Springfield metro area are of concern to the Metro Clean Water Partners, a coalition of officials from Lane County and the cities of Eugene and Springfield. I am conducting this study for the Metro Clean Water Partners, who wish to understand the extent of zinc contamination outside of Eugene and identify the anthropogenic sources of zinc within the Eugene-Springfield metro area with the goal of developing source control strategies.

Before I undertook this study, the city of Eugene had large volumes of waterway zinc concentration data. As a part of its Stormwater Annual Report, the city of Eugene conducts statistical analyses, summarizes sample findings from its water quality monitoring program, and compares these values to historic datasets. Monitoring of waterways in Eugene covers bi-monthly ambient water quality sampling in receiving waterways and grab samples taken from stormwater infrastructure during occasional storm events throughout the year. An ambient water sample is one taken directly from a waterway. The ambient sampling events in this study span multiple locations, including seven within the Willamette River Basin (five sites on the Willamette River, one near Delta Ponds, and one on Spring Creek) and six within the Amazon Basin (three on sites on Amazon Creek, one on Willow Creek, the A3 Channel, and the Amazon Diversion Channel) (Appendix C). Ambient water quality sampling is notably conducted at the watershed basin level (hydrologic cataloging unit 12) instead of the smaller, stormwater basins that directly relate to the geographic locations of stormwater infrastructure and its outfalls. The other type of sampling, the "grab" sample, is done directly from stormwater infrastructure, such as stormwater inlets, during a storm event. This sampling methodology better reflects the pollutant loading of stormwater runoff. The city of Eugene's sampling sites have largely remained the same since monitoring began in 1997, although sampling event frequency varies somewhat and in some years and/or seasons, locations are unable to be sampled due to a lack of water. Nonetheless, at testing locations total and dissolved zinc are measured, among a suite of 41 other water quality analytes (City of Eugene, 2020).

As of the 2019/2020 sampling period, an increasing trend was observed for dissolved and/or total zinc at all Amazon Basin and Willamette River sites, including the Coast Fork Willamette upstream of the urban growth boundary. Additionally, during the 2019/2020 monitoring period, zinc concentrations exceeded Oregon's acute and chronic water quality criterion at two Amazon Basin monitoring sites along Amazon Creek as well as Spring Creek within the Willamette River drainage basin (Figure 1). As compared to historic datasets, recent zinc values within the Willamette River Basin were significantly higher at all monitoring sites. In the Amazon basin, significant water quality improvements (as compared to historic datasets) have been made for almost every other analyte except zinc, which continues to trend upwards. Comparison of the Willamette River average zinc concentrations using the Mann-Whitney statistic revealed zinc concentrations increased from upstream of Eugene's urban growth boundary to downstream, indicating zinc inputs from within Eugene (City of Eugene, 2020).

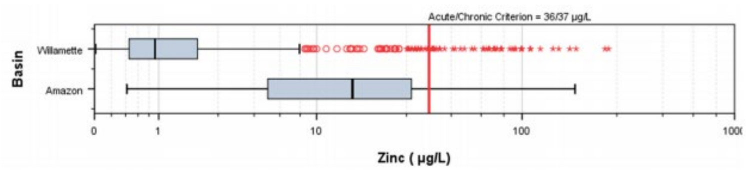

Figure 1: Boxplot of total zinc concentrations of all samples collected by the city of Eugene within the Willamette and Amazon basins in the 2019/2020 collection year. Samples within the Amazon basin more consistently exceeded Oregon's acute/chronic criterion for zinc, marked in this figure with a red vertical line at 36/37 µg/L. (Figure courtesy of the city of Eugene).

Finally, direct sampling of stormwater infrastructure at three locations, two within the Amazon Basin and one within the Willamette Basin, helps distinguish that the elevated zinc levels seen in ambient water quality monitoring are derived from anthropogenic sources. At every single stormwater testing location in 2019/2020, the concentration of zinc in each stormwater sample was greater than that of the receiving water body over the course of multiple storm events, with many concentration values exceeding Oregon water quality criterion for zinc (Figure 2). Specifically, within the Willamette River stormwater sampling location, the total zinc concentration in the stormwater was about 180 times higher than the concentration of zinc in the ambient water sample taken directly from the Willamette River (City of Eugene, 2020). The impact of short-term changes in water quality during and after storm events around specific stormwater outfalls can be significant, creating zones of toxicity of acute concern for aquatic species. Identifying the causes of zinc pollution in the Eugene-Springfield metro area is vital to address the sources of zinc contamination at their root and mitigate these negative environmental impacts.

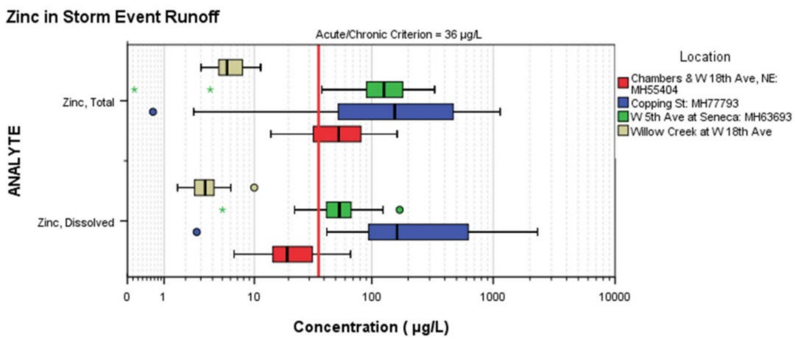

Figure 2: Box plot of zinc concentrations in storm event runoff from stormwater infrastructure sampling locations collected by the city of Eugene. Each stormwater sampling location, except that of Willow Creek, reports zinc concentrations above Oregon's water quality criterion for zinc, marked by the vertical red line. (Figure courtesy of the city of Eugene).

II. Research Objectives

The main research objectives of this project were to first identify the potential sources of zinc contamination within waterways in the Eugene-Springfield metro area, then to evaluate and compare the extent of zinc pollution within the two cities, and finally, analyze where, spatially, proposed sources of zinc have the potential to cause the highest levels of zinc pollution. To carry out this task, three specific objectives were identified:

1. Identify potential sources of zinc within waterways in the Eugene-Springfield metro area through literature review.
2. Understand the full extent of waterway zinc contamination across the Eugene-Springfield metro area by compiling multiple datasets of zinc concentration measurements.
3. Assess the potential distribution of the main sources of zinc pollution through spatial analysis to locate which stormwater basins are of highest concern for zinc pollution and warrant further investigation.

Properly evaluating the sources that cause zinc loading in stormwater runoff is extremely important as the increasing zinc contamination trends within Eugene-Springfield waterways can best be controlled at the source of the pollution.

III. Methodology

Identifying Potential Sources of Zinc

Foremost in this study, I conducted a literature review to identify the likeliest sources of zinc contamination from urban runoff in the Eugene-Springfield metro area. This literature review followed the process of 1) generating research questions and objectives, 2) searching the current scientific literature and municipal stormwater reports discussing zinc contamination, 3) assessing information applicability, 4) screening for quality of primary studies, and finally, 5) synthesizing the findings (Kosztyán et al., 2021). I began this review process by searching for extant studies in the Pacific Northwest, where climate and infrastructure mirror those found in the Eugene-Springfield metro area. Following this initial examination, I continued to search the literature iteratively, assessing the pertinence of sources as they pertained to Eugene-Springfield.

Mapping the Extent and Potential Sources of Zinc Pollution

Data Processing

In this study, I used many different datasets of zinc concentrations that were already sampled and compiled by different governmental agencies local to the Eugene-Springfield metro area. Each separate dataset underwent a process of acquisition, cleaning, and finally, merging. I obtained ambient and stormwater water quality analyte concentrations from the City of Eugene Annual Stormwater Monitoring report, Underground Injection Control (UIC) water quality data from Lane County, and Springfield-based water quality measurements from the Eugene Water and Electric

Board's (EWEB) baseline water quality monitoring program. Zinc concentration data collected by the City of Eugene between 2010-2020 followed protocol by the EPA as specified under the guidelines of 40 CFR 136 establishing test procedures for the analysis of pollutants (City of Eugene, 2020). These data were publicly available through the city of Eugene's Municipal Stormwater Permit and Monitoring Plan Website but were only available in files that contained thirty other analytes. Coordination with the Metro Clean Water Partners allowed access to water quality monitoring data from the UIC program for both Eugene and Springfield, with samples collected following the City of Eugene Wastewater Division Standard Operating Procedures (City of Eugene, 2021). To procure more total zinc concentration data for stormwater basins within the City of Springfield, I made a document request to EWEB, which provided water quality monitoring data between 2010-2020. I also underwent the documents request process to obtain industrial zinc discharge information from the NPDES 1200-Z General Industrial Stormwater Discharge Permit program in Eugene. These industrial zinc discharge quantities are self-monitored by permit registrants, monitored for quality assurance/quality control and are reported along with many other pollutant quantities four times per year between 2010-2020. However, due to regulations in the NPDES permit program between 2010-2013, only 2013-2020 pollutant discharge data were usable. Finally, I downloaded stormwater basin shapefiles from the city of Eugene's spatial data hub, and emailed GIS managers at the city of Springfield to obtain stormwater basin shapefiles for the city of Springfield as well.

Next, I implemented the cleaning of each dataset. Every data source described above provided data in the form of PDFs or Excel files. I first digitized the UIC zinc concentration PDF files by entering the zinc values and associated attribute information into an Excel file. For the industrial zinc discharge files, I used R 4.1.3 to join two separate files, one which each held geographic locations of each industrial facility and the other which held the name and associated zinc reporting values, into a single Excel file. I then processed all Excel files using Python 3.9 by deleting field blank values, isolating and selecting only zinc values from 41 other water quality analytes in the files, and grouping sample values based on sampling site. I also standardized the output column names in the zinc-specific files and converted all positional information into the standard Geographic Coordinate System WGS 84 for later mapping purposes. For every zinc sampling location and industrial discharge location I also calculated yearly summary statistics (minimums, maximums, averages, and standard deviations).

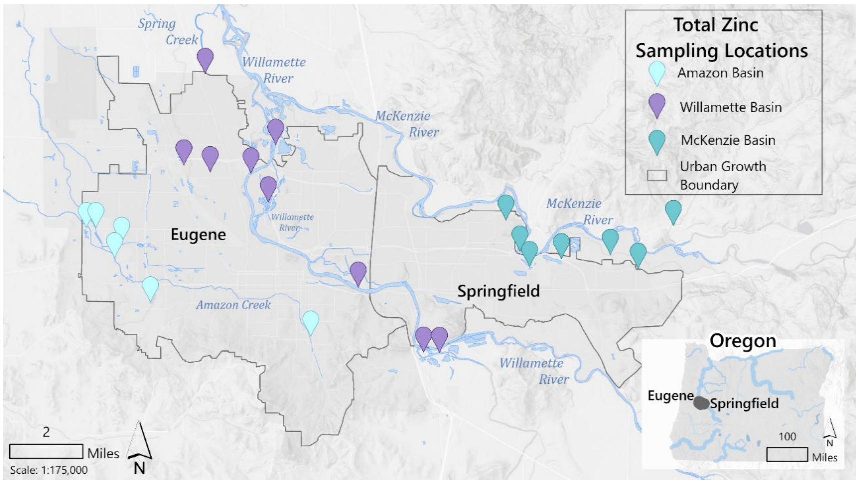

Figure 3: Map of ambient zinc concentration sampling locations across the Eugene-Springfield metro area. Blue locations= Amazon Basin, Purple locations= Willamette Basin, and Teal locations= McKenzie Basin. Samples are collected by a combination of the city of Eugene, Lane County, and the Eugene Water and Electric Board.

Dataset	Datatype	Year	Source
Eugene Ambient and Stormwater Water Quality Monitoring Data	Excel files	2010-2020	City of Eugene NPDES Stormwater Annual Report Water Quality Data
Springfield Water Quality Monitoring Data	Excel files	2010-2020	Eugene Water and Electric Board (EWEB)
Springfield Underground Injection Control (UIC) Water Quality Data	Excel files	2010-2020	City of Springfield Water Resources Program Coordinator
Eugene Underground Injection Control (UIC) Water Quality Data	Excel files	2010-2020	Lane County Water Resources Coordinator
Eugene Stormwater Basins	Shapefile	2022	City of Eugene GIS hub
Water Bodies in Eugene-Springfield	Shapefile	2022	City of Springfield GIS Coordinator
Eugene-Springfield Urban Growth Boundary	Shapefile	2019	UO GIS Collection
Eugene Land-Use Zoning	Shapefile	2019	UO GIS Collection
Springfield Land-Use Zoning	Shapefile	2019	UO GIS Collection
Eugene NPDES 1200-Z General Industrial Stormwater Discharge Permit Data	Excel file	2019	City of Eugene
Oregon Average Annual Daily Traffic Volumes	Shapefile	2019	ODOT GIS Data Hub
Oregon Transportation Network Road System	Shapefile	2019	ODOT GIS Data Hub

Table 1: Datasets used for mapping zinc concentrations and zinc source analysis. Each dataset name, original file type, year of collection and/or publication, and source agency are included.

GIS Method Considerations

For this study, I chose to focus on 2019 as a study year, including only source data and samples collected between 1/1/2019 and 12/31/2019 to compare the yearly values across the stormwater basins within Eugene-Springfield. I chose this year as the study year for all GIS methods because the most recent data are only available for 2019 and

2020. I decided to exclude 2020 from this study as there are documented, non-representative behaviors like reduced traffic due to the Covid-19 pandemic during statewide lockdowns which started in March 2020 and could change yearly zinc loading (Oregon Department of Transportation, 2021). Additionally, the 2020 fire season was particularly active surrounding the Eugene-Springfield metro area, with the potential for zinc deposition from ash to be seasonally high due to this source.

Zinc Concentration Mapping

Using ArcGIS Pro 2.8.6., I imported the cleaned Excel files of zinc concentration data that now included yearly minimums, maximums, averages, and standard deviations at each water quality sampling location across Eugene-Springfield between 2010-2020. I then combined the data from the City of Eugene annual stormwater reports, City of Eugene UIC data, and EWEB data, to gain greater spatial resolution of zinc pollution across Eugene-Springfield metro area, with a new total of 22 combined ambient water quality sampling locations. In addition to the six Amazon Basin and seven Willamette Basin testing locations described in the Introduction, the combination dataset includes two additional UIC zinc concentration sampling locations within the Willamette Basin. I also added a total of six sampling locations within Springfield's McKenzie Basin (two locations on the McKenzie River, one UIC outfall, three stormwater outfalls, and one location on the Keizer Slough). After combining the data sources, I split the shapefiles to display zinc concentration values in separate files based on year.

Modeling Potential Zinc Pollution from Zinc-based Moss Control Products

To assess where the potential zinc inputs from zinc-based moss control products (de-mossers) were in 2019, I used residential zoning codes to distinguish where roof types suitable for the use of zinc-based de-mossers would be located. I first downloaded the 2019 Springfield and Eugene zoning shapefiles from the University of Oregon GIS collection. The cities of Eugene and Springfield zone land to distinguish areas that are suitable for certain development types (Chapter 9 Land Use, 2014). Residential zones within Eugene and Springfield are zoned with city-specific codes but represent similar building categories (Table 2). After uploading the shapefiles in ArcGIS Pro, I selected for the specific residential codes with the two files and spatially joined the combination of both cities' residential zones together and converted the file to raster format.

Next, I quantified the potential zinc input from each residential land-use category based on residential housing characteristic designations from the City of Eugene Land Use Code designations and diagrams of housing densities provided by the City of Springfield, shown in (Appendix D) (Chapter 9 Land Use, 2014; City of Springfield, 2016). Single-family homes are more likely to have shingled-roof types which grow moss (as compared to metal roofs) and use de-mossers as a result. Due to this fact, I weighted low-density residential housing higher for potential zinc input to stormwater. High-density residential housing is more likely to have apartment high-rises with often metal roofing than other zoning designations, so it was ranked lower, but as zoning codes only apply to future housing developments and do not affect structures already in place, it was important to still account for some zinc input from these zoning designations due to older shingled building types (Table 2). Finally, I converted this zoning-based potential zinc loading layer into raster format (30m resolution).

Zone Name	City-Designated Zone Code	Zone Jurisdiction	Frequency in Study Area	Potential Zinc Loading Weight
LOW-DENSITY RESIDENTIAL	R-1	EUG	202	10
LOW DENSITY RESIDENTIAL	LD	SPR	2	10
MEDIUM-DENSITY RESIDENTIAL	R-2	EUG	93	5
MEDIUM DENSITY RESIDENTIAL	MD	SPR	2	5
ROWHOUSE	R-1.5	EUG	1	5
LIMITED HIGH-DENSITY RESIDENTIAL	R-3	EUG	14	3
GLENWOOD RESIDENTIAL MIXED USE	GRMU	SPR	1	2
MIXED USE RESIDENTIAL	MUR	SPR	1	2
HIGH-DENSITY RESIDENTIAL	R-4	EUG	15	2
HIGH DENSITY RESIDENTIAL	HD	SPR	2	2

Table 2: Summary of residential zoning classifications across Eugene-Springfield. All zone names, the city-designated zone codes, the number of land parcels with each zoning designation across the study area, and the potential zinc loading weight I created for each zone are stated.

Modeling Potential Zinc Pollution from Vehicular-derived Zinc

The Oregon Department of Transportation (ODOT) maintains a GIS data page with road networks and Annual Average Daily Traffic (AADT) volumes available on a yearly basis. I downloaded shapefiles for the Public Oregon Transportation Network, and AADT files for transportation networks during 2019. To distinguish between potential zinc pollution from different road-types, I used the Functional Classification designations of roads, which, as stated by the Eugene Functional Classification Standards, defines a road based on primary function, average traffic flow, as well as providing desirable roadway pavement width (City of Eugene, 1999). From the Public Oregon Transportation Network shapefile in ArcGIS Pro, I selected for high traffic "road" designations, named by the city of Eugene as interstate highways, non-state major arterials, non-state minor arterials, and non-state major collectors which have the functional class specifications of REG, MAJART, MINART, and MAJCOL, respectively (Table 3). Only high traffic volume functional classifications (AADT >2,500) were highlighted in this study because increased traffic results in an increase in zinc deposition from tire and break wear (McKenzie et al., 2009). Additionally, other functional classifications of roadways such as non-state neighborhood collectors were evenly spread through study area based on an aerial-assessment of the area and would therefore not cause potential high severity zinc pollution inputs at discrete locations.

Next, I split the polylines in the Public Oregon Transportation Network shapefile, which corresponded with each specific road-type, into its own feature class. I then created a buffer region around each road polyline feature class to create a polygon of each roadway's specific median curb-to-curb pavement width (Table 3). With the roads now in polygon form, I created another buffer region around each road-type of the same size to simulate the regions of potential zinc deposition adjacent to roadways. Following research conducted by Yan et al., who studied the relationship between zinc concentrations in roadside topsoil and distance from road edge, the buffer region's maximum distance from each road edge was 100 m (2013). Moreover, with the observation made by Yan et al. that zinc concentrations decreased exponentially as distance from the roadway increased, I created a 10-part buffer around each roadway reflecting the decrease in zinc deposition potential. After converting the roadways and buffers to raster format (30 m), I weighted each buffer in a gradient, signifying the exponentially decreasing potential amount of zinc deposited further away from roadways (Table 4).

City of Eugene Road Name	Functional Classification Description Key	Total Curb-to-Curb Pavement Widths	Median Curb-to-Curb Pavement Width	AADT Range Observed	Potential Zinc Loading Weight
Interstate Highway+	REG	110'	110'	20,000-75,000+	10
Non-state Major arterial	MAJART	68' - 94'	81'	20,000-45,000*	6
Non-state Minor arterial	MINART	36' - 70'	53'	7,500 - 20,000	4
Non-state Major collector	MAJCOL	*32' - 44'*	*38'*	2,500 - 7,500	2

Table 3: Roadway functional classification for non-state roads including specifications for width, Average Annual Daily Traffic (AADT), and corresponding potential zinc loading weight.

*45,000 highest AADT recorded by ODOT on non-state highways in study area
+Information from the ODOT Design Standard for Four-Lane Urban Freeway

Distance from Road Edge (m)	Potential Zinc Loading Weight
10	10
20	7
30	5
40	3.5
60	2
80	1
100	0.5

Table 4: Roadway buffer sizes and potential zinc loading weights based on potential zinc deposition distances from roadway.

Finally, I estimated the potential zinc contribution of each given roadway to the watershed based on traffic volumes, assuming higher traffic regions would cause more zinc pollution. To do this, I weighted the raster layers of each road type based on the AADT range observed on that road classification, 10, 6, 4, and 2, for interstate highways, non-state major arterials, non-state minor arterials, and non-state major collectors, respectively. These weights were multiplied by the buffer region weights, then all raster layers were merged.

Modeling Potential Zinc Pollution from Industrial Zinc Discharges

After the cleaning process was completed on the industrial zinc discharge data from the 1200-Z NPDES General Industrial Stormwater Discharge Permit program (described in the previous data processing section), I imported the excel files into ArcGIS Pro. I then split the zinc discharge information into separate years and focused on the data between 1/1/2019 and 12/31/2019. I grouped each cluster of industrial sources and added an attribute field to the shapefile to indicate which stormwater basin each facility was located within. Next, I conducted a kernel density analysis using the 2019 yearly average zinc discharge amount at each industrial location. The resultant values in this density analysis were then reclassified on a 0 to 10 scale, with pixels with the highest density of industrial zinc discharge sources receiving the highest weights.

Modeling Potential Zinc Pollution from the Combined Zinc Sources

To visualize the potential impact of the three major zinc sources– transportation-derived zinc, zinc de-mossers applied in residential areas, and industrial zinc inputs– I merged each of the raster layers described above which each individually show the zinc potential from each source. Next, I reclassified the intersecting data to highlight areas where the sources were potentially located in geographic space, and therefore have the potential to cause inputs of zinc into the landscape. In doing this merge, I created a zinc severity index with values from 0 to 10, with 10 signifying regions with potentially multiple high-severity zinc pollution sources. Each class (0-10) was created to include significant value breaks in the data, with values of 7, 8, 9, and 10, highlighting the most significant combinations of high-severity sources. Next, in ArcGIS pro I used zonal statistics and calculated the potential zinc severity across each stormwater basin using the mean pixel value within each basin from the combined potential zinc pollution severity map.

IV. Results and Discussion

Potential Sources of Zinc

There are potentially thousands of sources which may contribute to zinc in urban runoff within the Eugene-Springfield metro area. Here, I focus on sources of zinc for the metro area based on the urban and environmental conditions in Eugene-Springfield. For this reason, I began by examining reports conducted by other municipalities in the Pacific Northwest.

Previous Urban Zinc Source Identification Studies in the Pacific Northwest

Other regions have encountered elevated zinc concentrations in their urban waterways and conducted similar zinc source identification studies. A series of reports by the Department of Ecology in Washington assessed the sources of zinc in urban runoff in the Puget Sound (Washington Ecology, 2019; Washington Ecology, 2017; Washington Ecology, 2011; Washington Ecology, 2008;). These reports isolated potential sources of zinc, estimated zinc loading and release rates from these sources, and identified source-control methods. The most significant identified sources of zinc included zinc-based moss control products, vehicle tire and brake wear, and building materials. Commercial de-mossers were deemed to cause approximately 40% (average of 1,100 kg/yr) of the total annual zinc release in the study area (Washington Ecology, 2017). The second largest source of zinc identified in this study, accounting for almost 33% of the total zinc pollution, was vehicle use and the wear of related materials (tires and brakes). And finally, outdoor galvanized zinc surfaces and uncoated zinc metals found in siding and roofing materials, chain-link fencing, and gutters made up 25% of the annual estimated zinc release rate. Going forward in this study, I considered each of these sources in the Eugene-Springfield study area and further researched them below.

Zinc Herbicides:

Many moss-killing herbicides contain zinc-based compounds, including zinc chloride, zinc and copper sulfate mixes, and metallic zinc (as zinc strips). Each product is slightly different; zinc sulfates are either applied in powder form at approximately 99% concentrations or can be mixed with water. Per manufacturer instructions, brand name Moss B Ware advises consumers to combine up to three pounds of product with water to treat areas of approximately 55 m^2 . The average release rate for moss control products containing Zn sulfate is 1.76 $g/m^2/year$ (Washington Ecology, 2017).

Zinc strips, alternatively, are directly attached to roofs which release zinc on adjacent shingles during storm events. Exact zinc release rates for moss control products like zinc strips and zinc chloride have not been tested, but researchers at Oregon State University warn against application of these products during rainy weather as direct runoff is likely to be contaminated (Oregon State University, 2000).

Vehicular-Related Zinc

Tires often contain zinc oxides as a vulcanizing agent because they strengthen the rubber (EPA, 2008). Over the use of a tire, more than 10% of its mass is lost due to wear (Washington Ecology, 2011; Baensch-Baltruschat et al., 2020). A typical passenger vehicle has tires which contain approximately 10,000 mg/kg of zinc oxides, while the typical truck tire has zinc concentrations of 17,000 mg/kg (CASQA, 2015). As rubber tire tread gradually wears down, zinc is released into the environment. The

Environmental Sources Report by the State of California utilized the USGS tire wear rate and determined that zinc release factors would be 0.5 mg zinc/km travelled for car tires and 0.9 mg zinc/km travelled for truck tires (Councell et al., 2004). However, it is acknowledged that tire wear rates are more nuanced; wear rates depend on many factors, including characteristics of the tire itself, road surface, and rate of braking and turning. Regardless, multiple studies confirm that traffic is a major contributor to zinc in stormwater, with higher traffic volumes correlated with greater zinc inputs (Councell et al., 2004; Helmreich et al., 2010; Sebastiao et al., 2017; Semrod & Gourley, 2014; Washington Ecology, 2017). Moreover, most studies assume 100% of emitted tire wear debris may be deposited on proximate pervious surfaces or attached to the under-carriage of cars, both of which are subject to enter stormwater during storm events, with limited zinc amounts being adsorbed to the adjacent soil (Washington Ecology, 2017).

Zinc, in lesser amounts, is a component of vehicular brake pads and is sometimes an additive in lubricants and gasoline. In some studies, plated brakes represent a significant source of zinc pollution but not nearly as considerable as tire-wear. Finally, carwashes which spray the under-carriage of vehicles where zinc particles can build up, are also found to be a significant source of zinc to stormwater (McKenzie et al., 2009).

Outdoor Rubber

Recycled tires, in the form of tire shred and tire crumb, both leach zinc when in contact with water. Tire shred, chunks of tire measuring five to thirty centimeters, is primarily used in landfill construction and as a road base. Tires that are shredded into pieces smaller than 1 cm, called tire crumb, may be recycled in rubberized asphalt and artificial turf fields (Oregon Department of Transportation, 1995). Twenty percent of all federally funded asphalt paving projects must meet the rate of 20 pounds of rubber (from used truck and car tires) per ton of asphalt concrete mix because of the Intermodal Surface Transportation Efficiency Act (ISTEA). Therefore, the construction of asphalt roads and the use and wear on these roads could potentially release zinc into the environment. Moreover, zinc leachate levels correlate inversely with particle size. Smaller particles contribute more zinc to the environment (CASQA, 2015).

Additionally, considerable amounts of zinc appear to leach from artificial turf fields where rubber crumb is loose and exposed. A study conducted in the Netherlands estimated that zinc concentrations in the infiltrating rainwater on these fields were between 0.1 and 1 mg/L. Zinc runoff from these fields, however, can be minimized using effective drainage systems like sand under the tire crumb infill layer (Vos et al., 2008).

Used rubber in the form of tires is a significant source of waste in Oregon overall. Oregonians discard about four million used tires every year, two thirds of which, according to the Oregon Waste Tire Management Summary, are not disposed of properly. Of these waste tires, those which are combusted or recycled, and later contact water may contribute to zinc contamination (Oregon Department of Environmental Quality, 2019).

Other outdoor uses of rubber include playground surfaces and erosion control devices; however, in these cases zinc is physically bound into the polymeric structure of the product and is unlikely to contribute meaningful quantities of zinc to the environment (CASQA, 2015).

Outdoor Zinc Surfaces

Multiple publications report outdoor zinc surfaces as a source of zinc contamination in stormwater runoff (Heijerick et al., 2002; Clark et al., 2009; CASQA, 2015). Particularly, galvanized steel and zinc sheets have been identified as sources of zinc contamination as they have many outdoor uses and form impermeable surfaces which generate urban stormwater runoff. These sheets serve as roofing materials, gutters, flashing, drainage pipes, and fencing in urban and industrial areas. In addition to traditional galvanized steel and zinc sheet, zinc-containing outdoor building materials include Anthra-Zinc, Galvan, Galvalume, and spray-on zinc coatings. Prevailing environmental conditions like air quality, rain quantity and rain intensity all determine the amount of zinc leached into stormwater runoff water. Researchers in Sweden determined that concentrations of zinc leaching from these zinc-based building materials ranges from 23.3 and 101 µg Zn/L in stormwater runoff (Heijerick et al., 2002).

Paneling that is unpainted or uncoated hot-dip galvanized steel also act as sources of zinc contamination. A study conducted by Pennsylvania State researchers found the zinc leaching rate for these types of paneling was 5-30 mg/L in stormwater runoff throughout the first two years of monitoring; pre-painted aluminum-zinc alloy panels, however, showed much less zinc leaching, with leaching two orders of magnitude less than the unpainted or uncoated alloys (Clark et al., 2009).

Guardrails made from galvanized metals also cause zinc contamination in stormwater runoff. The release rates for galvanized steel were used to estimate the zinc leaching into stormwater runoff from guardrails to be at rates of 20 mg/L (Port of Seattle, 2017; Washington Ecology, 2017).

Other unprotected zinc surfaces that could potentially contribute to zinc contamination include galvanized roofing, gutters, fencing, piping, guard rails, light poles, mechanical equipment, and brass sculpture and ornamentation (CASQA, 2015). While it is difficult to weigh the relative contributions of all types of zinc-containing outdoor building materials, a recent study conducted by the Washington Department of Ecology found that the bulk of zinc release originates from uncoated chain-link fencing, and the pollution from other sources like roofing and siding materials is much less (2019).

Industrial Zinc Sources

Zinc is discharged by industrial sources both directly and indirectly through conveyance systems (ditches, stormwater drainage systems) into waterways in the Eugene-Springfield metro area. The National Pollutant Discharge Elimination System, pursuant to ORS 468B.050 and the Federal Clean Water Act, regulates these industrial stormwater discharges using municipal 1200-Z permitting systems. For years, the Oregon permit relied on benchmarks and reference concentrations for impairment pollutants. Benchmarks are guideline concentrations, not limitations; a benchmark or reference concentration exceedance, therefore, is not a permit violation. This policy was written with the intention that businesses would adaptively manage their sites by implementing pollutant reduction strategies when monitoring results indicated there was an issue. However, it became evident that some businesses were not implementing substantive pollutant reduction strategies, and as a result, the 1200-Z Industrial

Stormwater Discharge permitting system has changed over the past decade during renewal processes undertaken by the Oregon Department of Environmental Quality. Among these changes were new reporting processes of total zinc discharge concentrations, the establishment of a timeframe by which benchmarks would be met or the permittee would have to implement a pollutant reduction strategy stamped by a professional engineer or engineering geologist (Oregon Department of Environmental Quality, 2012).

During this time, the total zinc benchmark also changed from 0.09 mg/L to 0.12 mg/L in 2018, then again in 2021 to regional benchmarks based on water hardness, which, for the Willamette Valley (including the Eugene-Springfield metro area), is 0.14 mg/L. In the new 2021 1200-Z permitting system, stricter pollutant control policies were also put into place for businesses discharging into 303(d) listed waters, or waters that are impaired, where they must meet impairment concentrations; if they do not, then total zinc monitoring requirements escalate to a numeric water quality-based effluent limit equal to impairment monitoring concentrations, which for the Willamette Valley, is 0.0572 mg/L for total zinc (Department of Environmental Quality, 2021).

In the city of Eugene, permitted industries include those related to metal work (galvanizing, sheeting, scrap and waste metal recycling, electroplating), wood products (manufacturing, wood storage, wood preserving), rubber vulcanization, industrial/farm machinery, petroleum terminals, paint and varnish production, and finally, food/beverage manufacture. The number of permits given each year fluctuates, and since 2013 the number of permittees has ranged between 44 and 73 with no increasing or decreasing trend seen during this time. In aggregate, however, zinc from industrial facilities may make a significant impact on local water quality, particularly due to the clustering of these industries in west Eugene stormwater basins. Springfield has multiple industrial facilities which discharge zinc, but due to different permitting and recording structures I was unable to record them in this report.

Treated Wood

Zinc borate and zinc oxide, as components of Ammoniacal Copper Zinc Arsenate or ACZA, are both used as wood preservatives in Pacific Northwest industries and urban products. Zinc naphthenate is a flame retardant also used in wood treatment. These zinc-based wood treatments and preservatives are used in treating decks, fences, siding, and other domestic wood sealants to protect against mildew, rot, and fungus (Techniseal Wood Preservatives, 2018). In addition, ACZA is a common treatment for utility poles. Eugene has a utility-pole treatment facility run by McFarland Cascade, and ACZA, among others, is a common treatment (Wood Pole Producers, 2020). In a study conducted by the US Forest Service, ACZA-treated wooden walkways released measurable amounts of zinc into stormwater runoff suggesting that wood treatments may be a contributing factor to localized zinc contamination (Lebow et al., 2000).

Log-sort yards are an additional place where zinc contamination to the environment has been identified. In a study conducted in Washington state, it was found that log-sort yards used copper and arsenic smelting slag as road ballast. As trucks drove over this material the acidic wood waste leached zinc into stormwater runoff (Smith et al., 1999).

Zinc-based Paint

Zinc-based white pigments were once commonly found in paints used on building exteriors, but their use has diminished since the 1950s. If such a building remains unpainted today, it could be a local source of zinc. Today, most zinc-based paints are used only in special circumstances for anticorrosion purposes on bridges, shipping containers, and outdoor industrial containers (CASQA, 2015).

Other paints sometimes use zinc as an antimicrobial additive but at much lower concentrations. However, the EPA does not require paint manufacturers to notify customers of paint zinc content, so it is hard to draw a conclusion as to the extent of antimicrobial zinc-containing paint in Eugene-Springfield metro area (EPA, 2005). No known studies have been conducted on the zinc leaching rates from these paints.

Zinc Rodenticides

Zinc phosphide is commonly used by urban consumers and agricultural producers as a rodenticide for the control of gophers, mice, rats, and other small rodents. Zinc phosphide and its degradation products appear to have a low potential for groundwater or surface water contamination as zinc phosphide readily undergoes hydrolysis, the product of which, zinc ions, readily sorb onto soil (EPA, 1998). However, aerial application of zinc phosphide in agriculture has a higher potential of leaching and contaminating water sources (Eason et al., 2013).

Municipal Biosolids and Composts

Municipal biosolids, a product of municipal wastewater treatment used in agriculture, may contain high levels of zinc. The average concentrations of zinc in municipal biosolids from the United States were found to range between 609 and 1,202 mg/kg zinc dry weight (ATSDR, 2005). Oregon State University researchers, however, report that the average amount of zinc in Oregon biosolids was 719 mg/kg, a number at the lower end of this range (Sullivan et al., 2017). There is no evidence that suggests municipal biosolids or composts are used in the Eugene-Springfield metro area in a manner that would enter stormwater runoff, however.

Forest Fires

Air deposition from forest fires also contributes zinc to the environment. Stein and Brown (2009) found large-scale fires may deposit zinc into local watersheds, temporarily increasing levels in urban runoff. They cite data from the 2003 southern California wildfire season when atmospheric deposition rates of zinc went up by a factor of six for an unburned site in San Fernando Valley, which was approximately 20 miles from the border of the Piru and Simi Fires. Researchers studying the 2009 Station Fire in southern California reported that filtered and total concentrations of zinc were elevated in surface waters during and after storms because of the fire and were correlated to the amount of rainfall, the pH of stormflow, and the concentration of suspended sediment, which is an important mechanism for zinc transport. These researchers found that ash and debris from buildings burned in fires at the wildland-urban interface can have substantially elevated levels of zinc (Burton et al., 2016). With increased fire frequency around the Eugene-Springfield area, air deposition of zinc from forest fires should be further investigated.

Major Sources of Zinc

After defining potential sources of zinc contamination for the study area, I prioritized the drivers of zinc pollution based on which sources were chronic and in amounts enough to influence annual zinc concentration trends. As zinc readily binds to soil particles, many of the likeliest, largest sources of zinc contamination either must release directly to surface waters or release to impervious surfaces where runoff directly into stormwater drainage basins and later to receiving waters occurs during storm events.

Using this information and the conclusions from previous reports, I derived that zinc-based de-mossers and vehicular tire and brake wear are major sources of zinc in Eugene-Springfield urban stormwater runoff (Figure 4). Additionally, industrial sources of zinc deposition, as measured by the NPDES 1200-Z General Industrial Stormwater Discharge permitting process, could contribute significant quantities of zinc to urban runoff. While building materials and other forms of outdoor zinc have the potential to be very numerous within the study area, analysis conducted by the Washington Department of Ecology found its report overestimated the contribution of zinc from these sources, which encouraged me to not include outdoor zinc building materials as a source within this study (2019). Additionally, as the geographic locations of these zinc-based building materials are unavailable, inclusion of this source was beyond the scope of this project.

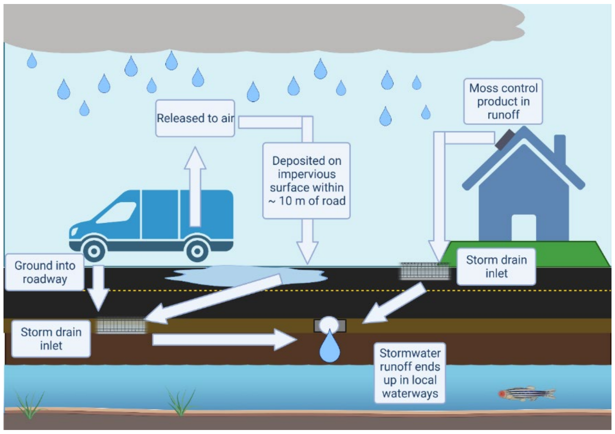

Figure 4: Conceptual model for the loading of zinc to the environment from zinc-based moss control products and vehicular-derived zinc due to tire- and brake-wear.

GIS Evaluation of the Extent of Zinc Contamination

Ambient Waterway Zinc Concentrations

My first step in evaluating the extent of zinc contamination within Eugene-Springfield was mapping the zinc concentrations compiled from the city of Eugene, Lane County, and EWEB. This map, showing Eugene-Springfield wide zinc concentrations from ambient water quality sampling in 2019 is shown in Figure 5. Across the 22 sampling locations in the Eugene-Springfield metro area, a total of 105 samples were taken between 1/1/2019 and 12/31/2019. Samples within the Willamette basin yielded the lowest average total zinc concentration of the three basins with a mean of 20.01 µg/L (n=37) and a standard deviation of 38.76 µg/L. The Amazon Basin and McKenzie basin followed with average total zinc concentrations of 40.08 µg/L (n=41) and 56.13 µg/L (n=27), respectively. However, comparatively, the McKenzie basin's average total zinc concentration was heavily influenced by an extreme maximum value of 984 µg/L, causing a standard deviation of 187.6 µg/L. Amazon basin, alternatively, exhibited a standard deviation of 21.05 µg/L (Table 5).

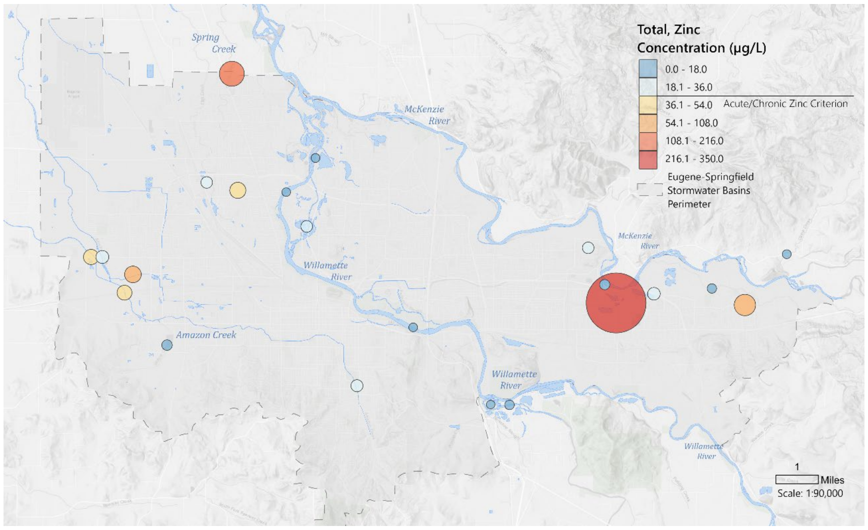

Figure 5: Map of average zinc concentrations (µg/L) reported at each ambient waterway sampling locations within Eugene-Springfield in 2019. Both size and color of the circle at each sampling location correspond with the average, total, zinc concentration measured at the site. Colors in the blue range are below the Oregon acute/chronic zinc criterion and colors ranging from yellow to red exceed this value (36/37 µg/L).

	Willamette	Amazon	McKenzie
Num. of Samples	37	41	27
Minimum (µg/L)	0.474	10.9	0.6
Median (µg/L)	3.92	35.7	9
Maximum (µg/L)	180	83.5	984
Range (µg/L)	179.5	72.6	983.4
Mean (µg/L)	20.01	40.08	56.13
Standard Deviation (µg/L)	38.76	21.05	187.6

Table 5: Summary statistics of zinc concentrations at ambient waterway sampling locations by basin (Willamette, Amazon, and McKenzie) within Eugene-Springfield in 2019.

A wide range of total zinc concentration values were reported in each basin, with the McKenzie basin showing the greatest range. In the McKenzie values ranged between 0.6 µg/L and 984 µg/L, the Willamette Basin exhibited a smaller range of 179.5 µg/L, and finally, the Amazon basin followed with a range of 72.6 µg/L. As seen in the boxplot in Figure 5, outliers, which are defined to be values 1.5 times the interquartile range (25^{th} to 75^{th} percentile) of the data set, were found in the Willamette and McKenzie basins. In both basins, these outliers influenced the large range of total zinc concentration values witnessed in 2019. Looking closer at where these high total zinc concentration samples were taken reveals that smaller water bodies (like creeks or stormwater culverts) yielded higher concentrations of total zinc as compared to large rivers (like the Willamette or McKenzie Rivers). Pollution is diluted in water bodies with greater water volumes which helps explain the extreme ranges of total zinc concentration values within the Willamette and McKenzie Basins, where sampling occurs in both high-volume rivers and low-volume creeks (Appendix E).

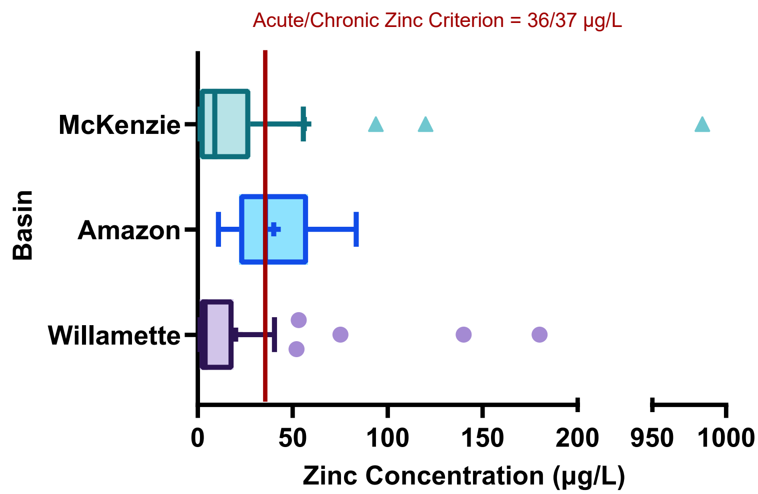

Figure 5: Box plot of the zinc concentrations recorded in the McKenzie, Amazon, and Willamette basins at ambient water quality sampling locations in 2019. The red vertical line in this plot represents the acute/chronic criterion for total zinc set by the state of Oregon. Any samples recorded to the right of this line exceed the Oregon water quality criterion for zinc. This analysis shows every basin recorded zinc concentration exceedances.

Exceedances of Oregon's acute/chronic criterion for zinc (36/37 µg/L) are most prevalent within the Amazon basin, with almost 50% of samples meeting or exceeding this criterion (Figure 5). The average total zinc concentration value in this basin, 38.76 µg/L, also exceeds both criteria. Whereas exceedances in the McKenzie and Willamette Basins are less common, there were still samples noted in both basins which exceeded the 36/37 µg/L criteria for zinc, with the McKenzie Basin even experiencing more exceedances. For the purposes of this study, the confirmation that the McKenzie basin exhibits similar patterns of zinc concentration exceedances as those in the Willamette basin, and even exhibit worryingly large outliers, reinforces the reasoning to conduct a metro-area-wide study of the sources of zinc pollution within Eugene-Springfield.

Storm Event Zinc Concentrations

The city of Eugene sampled only three stormwater infrastructure locations in 2019, each geographically located within a different stormwater basin (Figure 6). The city sampled two storm events but did not systematically sample every stormwater infrastructure location. They sampled a storm event on 4/1/2019 in the Amazon basin and Bethel-Danebo basin sites, and a storm event on 9/15/2019-9/16/2019 in the Willamette basin and Bethel-Danebo Basin sites (Table 6). Every single storm event sample exceeded both the acute/chronic criterion for zinc by at least 5 μg/L, with the sites within the Amazon and Bethel-Danebo basins far exceeding this value.

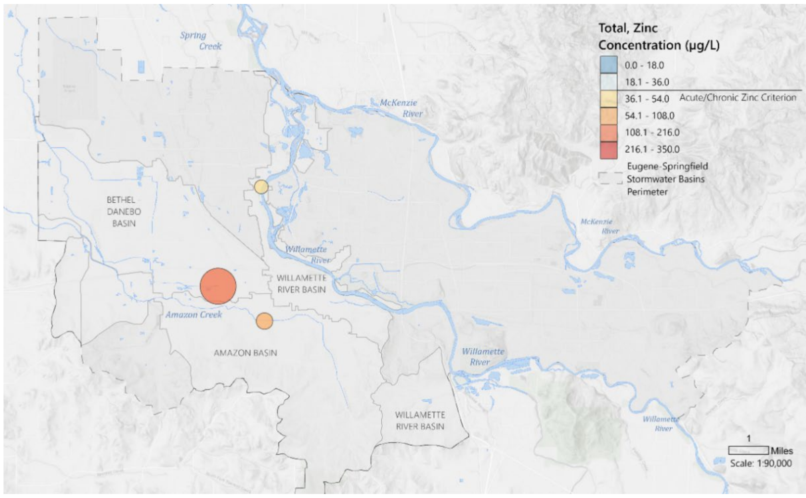

Figure 6: Map of average stormwater total zinc concentrations (µg/L) at stormwater infrastructure sampling locations within Eugene in 2019. Both size and color of the circle at each sampling location correspond with the average, total zinc concentration measured at the site. Every location sampled exceeded the Oregon zinc concentration acute/chronic criterion 36/37 µg/L.

Storm event sampling directly measures stormwater runoff and by proxy, anthropogenically sourced zinc contamination, so these findings support the evaluation that zinc contamination is derived from human sources within the Eugene metro area. However, the city of Eugene's limited number of stormwater infrastructure sampling locations during storm events and the resulting poor spatial and temporal resolution of the stormwater runoff data makes it difficult to identify specific stormwater basins where anthropogenic input of zinc is higher than others. As a result, I turned to other GIS methods for predicting sources of zinc within the Eugene-Springfield metro area for this study.

Sampling Location	Date	Zinc Concentration (µg/L)	Stormwater Basin
Chambers&W18th; MH55404	4/1/2019	61.4	Amazon
Copping St.	9/15/2019	43.1	Willamette
West 5th-Seneca; MH63693	4/1/2019	330	Bethel - Danebo
West 5th-Seneca; MH63693	9/16/2019	77.5	Bethel - Danebo

Table 6: Zinc concentrations (µg/L) from storm event sampling of stormwater infrastructure in Eugene. Sampling conducted by the city of Eugene.

GIS Evaluation of the Potential Sources of Zinc Contamination

The final phase of this zinc analysis involved mapping each of the potentially most significant zinc sources individually (zinc-based moss control products, vehicular tire- and brake-wear, and industrial zinc discharge), and lastly, mapping the potential extent of all three significant zinc sources in combination. It is important to note that each of the following analyses describe only the potential spatial extent of each source, specifically focused on 2019, based off data available. All the potential zinc severity values were not based off specific measurements but my own holistic assessment of the perceived zinc input severity from each source based on locational information. As a result, it is important to read the maps less as potential zinc pollution severity gradients across the Eugene-Springfield metro area.

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Potential Zinc Pollution Severity from Zinc-based Moss Control Products

A map of the potential zinc contamination severity with respect to zinc-based moss control products is shown in Figure 7. Much of the area within the cities of Eugene and Springfield is classified as some type of residential zone, with low-density residential being the most prevalent type of zoning. As a result, the map of the potential zinc inputs to stormwater runoff due to zinc-based moss control products shows little variation in potential zinc pollution severity, with the largest region classified as high zinc pollution potential. High density residential regions are common throughout the study area, with other housing zones far sparser and only a fraction of the total area. The low-density residential, are weighted as locations with the most severe inputs of zinc because single family homes with shingle rooves are the most likely to utilize zinc-based moss control products to deal with moss growing on rooves (Washington Ecology, 2017).

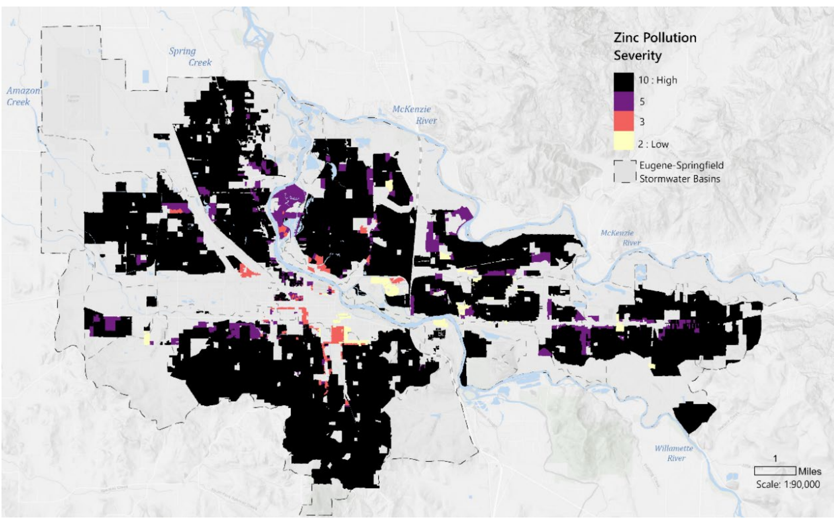


Figure 7: Map of potential zinc pollution severity from zinc-based moss control products across Eugene-Springfield. Darker colors on this map indicate higher potential for zinc pollution due to zinc-based moss control product use. Higher zinc-based moss control products are associated with lower-density residential regions, which occupy many regions on this map.

While using zoning codes is not the most spatially precise means of locating where residences that utilize zinc-based moss control (maybe only a few houses on each residential block), a survey estimating product popularity based on home improvement store zinc-based moss control product sales, or interviews with roofing professionals, like those utilized by Washington Department of Ecology (2017), was beyond the scope of this report. However, while zoning is not spatially precise, it is largely accurate. Each residential zoning codes are most likely to use zinc-based moss control products, and the relative potential severity of input from each zone type is representative of the probability of buildings with moss-prone rooves. While intra-low-density residential housing may not have an even distribution of houses using zinc-based de-mossers, the potential zinc concentration loads from neighborhoods with buildings using these products are significant and necessary to include in this study.

Finally, it is also critical to mention that zoning only occurs within the urban growth boundary, a subset of the total perimeter for the Eugene-Springfield stormwater basins, as seen in the empty perimeter region on the map of zinc input severity from residential regions (Figure 7). However, due to the strict urban growth boundary regulations in Oregon, there would not be high-density housing outside of the urban growth boundary, and therefore by the measures in this study, there would not be substantial inputs from zinc-based de-mossers in these regions regardless.

Potential Zinc Pollution Severity from Vehicular Tire- and Brake-wear

A map of potential zinc contamination severity with respect to vehicular tire- and brake-wear is shown in Figure 8. Across the study area, I found that highest-traffic volume roadways - interstate highways and non-state major arterials - were less numerous than roadways of lower functional classification designations, such as non-state minor arterials and non-state major collectors. This pattern contributes to significant zinc inputs on and around interstate highway and non-state major arterials.

In general, these major road classifications cut across many stormwater basins, potentially causing zinc inputs in each. The Amazon stormwater basin does not have any interstate highways yet includes a large proportion of roadways with lower-traffic functional classifications. In fact, roads with highest functional classifications are dominant in stormwater basins that eventually empty to the Willamette and McKenzie Rivers. However, stormwater basins that eventually reach Amazon creek have a high density of lower classification roads.

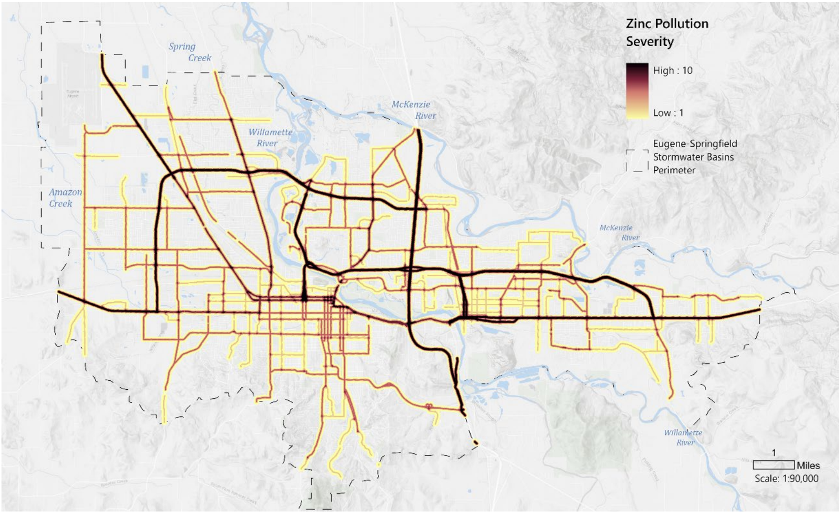


Figure 8: Map of potential zinc pollution severity from vehicular-derived zinc deposition across Eugene-Springfield. Only roadways with average annual daily traffic above 2,500 vehicles are represented in the figure. Roadways with the greatest amount of traffic are dark purple in hue, indicating greater potential zinc pollution severity. Roadways in lighter purple and yellow have lesser potential zinc pollution severity.

My methodology estimates the contribution of roadways to zinc concentrations within the Eugene-Springfield metro area based on traffic volume, which was found to be the most important indicator of total zinc build-up from transportation by Councell et al. (2004). In the absence of data giving the exact average annual daily traffic volume (AADT) for the roads within Eugene-Springfield, functional classifications of these roadways were used. Functional classifications set the road width and estimate AADT for each roadway, both which I used to create the roadway zinc pollution severity index used in Figure 8. The relationship between zinc concentration rates and distance from roadways contributed by Yan et al. (2013), allowed me to create buffer regions around roads.

Contribution of zinc from roadways to actual zinc concentrations within waterways in Eugene-Springfield is dependent on multiple factors that could not have been controlled for within this spatial study. Differences in proximate surface-type (pervious vs. impervious), driving behavior, type and age of vehicle, road surface, weather conditions, the characteristics of the brake and tire material, and their level of maintenance, are among the many variables that could be considered in making this type of estimate (Councell et al., 2004).

However, although consideration of these variables was beyond the scope of this report, one important variable, balancing the contribution of zinc for tire-wear vs. brake-wear, was incorporated in the methodology. Proximity of zinc loading from tire- and brake-wear can be quite varied based on roadway type, or the functional classification of the roadway (Department of Ecology Washington, 2011). For example, tire wear will always occur, at varying levels, with vehicle movement. Brake wear, in contrast, only occurs when the brake mechanism is employed. As a result, highway traffic under low traffic volume conditions may apply brakes relatively rarely, resulting in less brake-derived zinc deposition. Conversely, braking at higher speeds results in considerably more brake wear and highways still experience traffic congestion and high rates of braking. However, it is still expected that major and minor arterial roadways and major collector roadways will have higher brake wear than interstate-highways due to the increased frequency and intensity of braking. As brake wear has a lower associated zinc loading rate as compared to tire-wear, I have high confidence that the zinc deposition from transportation index is appropriately graded (Figure 8), with larger traffic volumes weighted to show greater potential zinc deposition rates.

Potential Zinc Pollution Severity from Industrial Zinc Discharge

A map of the zinc deposition from industrial sources is shown in Figure 9, and its corresponding map of the potential zinc contamination severity with respect these industrial sources is shown in Figure 10. I found that in 2019 all zinc-discharging industrial facilities were clustered in west Eugene, across mainly three stormwater basins, with limited sites in an additional fourth basin. In order of the highest to lowest number of industrial facilities in each basin, was Bethel-Danebo, River Road Santa Clara, Amazon, and Eugene’s Willamette, with 21, 14, 7, and 3 facilities respectively. In each basin a different number of samples were collected in each basin with 72, 50, 34, and 9, samples collected in Bethel-Danebo, River Road Santa Clara, Amazon, and Eugene’s Willamette stormwater basin respectively. The average total zinc discharge amount within each stormwater basin ranks slightly differently, with Bethel-Danebo averaging 0.458 mg/l (standard deviation: 0.6232), Willamette River averaging 0.3561mg/L (standard deviation: 0.2321 mg/L), River Road Santa Clara averaging 0.3279 mg/L (standard deviation: 0.4360 mg/L), and finally, Amazon averaging 0.2480mg/L with a standard deviation of 0.3779 mg/L (summarized in Table 7). In each basin, over 50% of the reported sample values exceeded the benchmark for total zinc set by the Oregon Department of Environmental Quality that was active in 2019 (0.12 mg/L), with over 75% of samples collected within the Bethel-Danebo stormwater basin and the Willamette River stormwater basin exceeding this value (Figure 11).

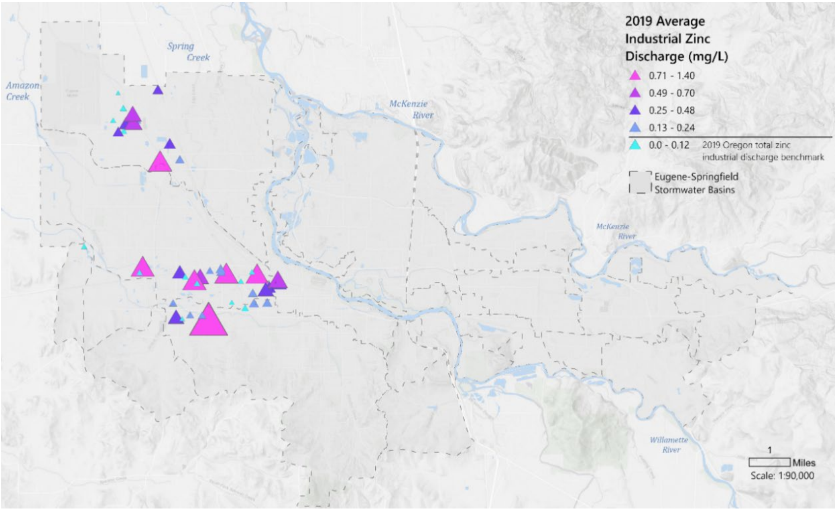


Figure 9: Map of annual average zinc concentrations (mg/L) discharged from industrial facilities in Eugene. Both size and color of the triangle at each industrial zinc discharge location correspond with the zinc concentration in their reported stormwater discharge. The larger triangles and pink hues indicate higher annual averages of zinc concentrations. All industrial facilities are located within one of four stormwater basins in west Eugene – Amazon, Bethel-Danebo, River Road Santa Clara, or Willamette.

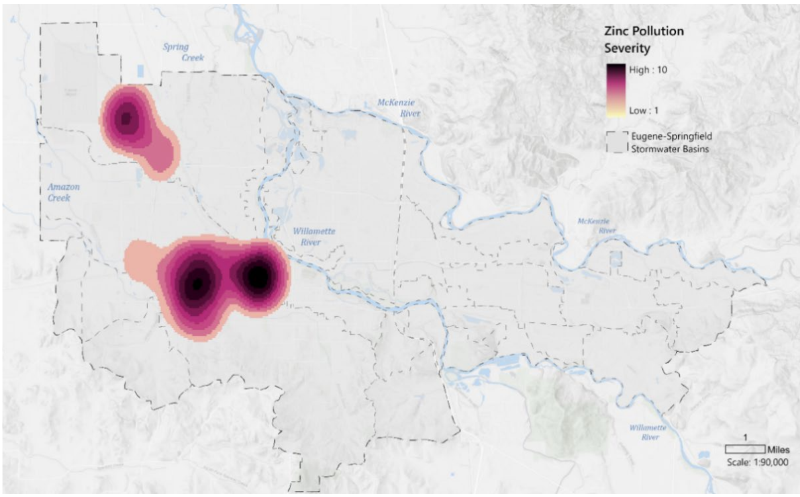


Figure 10: Map of the potential zinc pollution distribution severity due to zinc discharge from industrial facilities. This map is based on a kernel density analysis of the average annual zinc discharge reported for each industrial source within Eugene. Darker purple regions indicate higher quantities of zinc pollution discharge from regions of high-density and high-concentration industrial zinc discharge activity.

	Willamette	**Amazon**	**Bethel – Danebo**	**River Road Santa Clara**
Num. of Samples	9	34	72	50
Minimum	0.0916	0.0210	0.00660	0.00317
Median	0.370	0.125	0.220	0.170
Maximum	0.800	2.090	3.100	2.70
Range	0.7084	2.069	3.093	2.697
Mean	0.3561	0.2480	0.4528	0.3279
Standard Deviation	0.2321	0.3779	0.6232	0.4360

Table 7: Summary statistics for industrial zinc discharges (mg/L) in 2019 by stormwater basin.

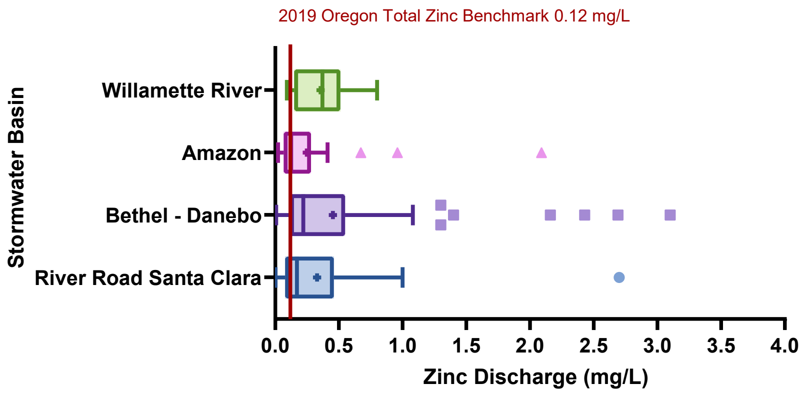


Figure 11: Boxplot of reported industrial zinc discharge (mg/L) in 2019 by stormwater basin. The highest average industrial zinc discharge amounts were seen in the Bethel-Danebo stormwater basin followed by the Willamette River basin, River Road Santa Clara basin and Amazon basin. The red vertical line in the figure indicated Oregon's total zinc benchmark set for industrial discharge in 2019, at 0.12 mg/L.

To measure the potential zinc pollution severity of the zinc discharge from industrial sources and compare this source to the other major zinc sources, I conducted a kernel density analysis on the average total zinc discharge concentrations reported by each facility. This analysis highlighted three major zones of high severity zinc deposition, with the two most severe cluster-centers located within the Bethel-Danebo stormwater basin. The third cluster center was based in the River Road Santa Clara stormwater basin (Figure 10).

This summary of industrial sources discharging zinc within the Eugene-Springfield metro area is not exhaustive. Within the data, I had to exclude 33 reported values within the 2013-2019 period that did not have an associated collection date facilities and four entries that were missing the name/location of the industrial facilities. It is possible some of these entries should be in the summarized facilities data. Additionally, there are no Springfield facilities listed. The data I acquired are from the city of Eugene, but this does not mean there are no industrial activities in Springfield that emit zinc, just not locatable in this study. And finally, some facilities that may serve as sources of zinc to stormwater runoff, such as auto maintenance/repair, tire shops, and car washes, are not listed as industrial businesses, yet may also contribute to zinc discharge based off the types of products they deal with (tires, oil, brakes, cleaning the undercarriage of cars) (Councell et al., 2004; Department of Ecology, 2011; McKenzie et al., 2009). Still, the finding that industrial zinc discharges are clustered in at least four, west Eugene stormwater basins provides utility for spatially summarizing the location of the known, probable major sources of total zinc to Eugene-Springfield waterways.

Combined Source Potential Zinc Pollution Severity

My methodology to evaluate the major sources of zinc pollution within the Eugene-Springfield metro area culminated in the creation of a map showing the combined zinc pollution potential from the three major sources of zinc contamination (Figure 12), which was then summarized in a map of potential zinc pollution by stormwater basin (Figure 13). I found the stormwater basins with the greatest potential for zinc pollution to be Springfield's Willamette River Basin, Laurel Hill Basin, Amazon basin, South Cedar Creek basin, and Q Street Floodway Basin. At first, I found these results surprising, especially because Figure 12 shows in red the most severe potentials of zinc pollution within the Bethel-Danebo and Amazon stormwater basins where there are industrial activities, high-traffic roads, and high-density residential zoning all within proximity. However, when organized by stormwater basins, the greatest zinc pollution potentials outside of Amazon basin are characterized by a high proportion of high-density residential land use and high-traffic roadways, with little to no quantified industrial sources. The Amazon basin, in contrast, is characterized by the most numerous industrial facilities of any basin, and it also encompasses many parcels of high-density residential land use.

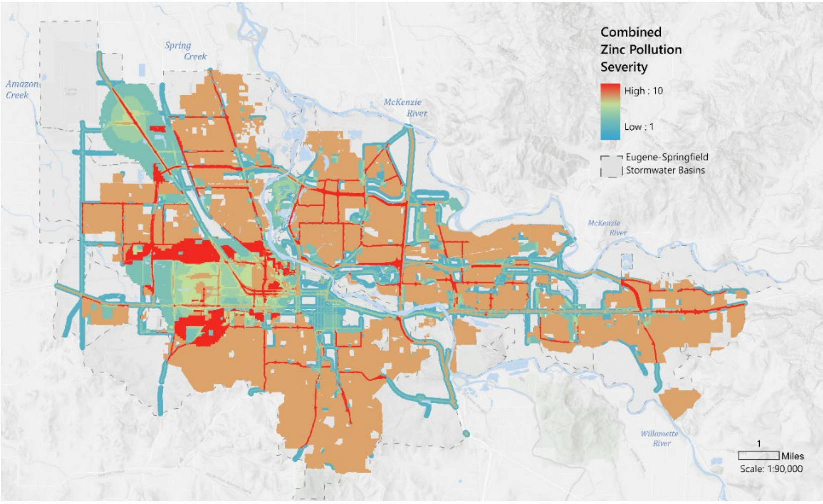


Figure 12: Map of the potential zinc pollution severity across Eugene-Springfield from the three main, combined sources of zinc pollution. Highest potential zinc pollution severity is indicated by red hues, which are concentrated within the Amazon and Bethel-Danebo stormwater basins, but also seen on roadways throughout the study area. Other high values, indicated in orange, are spread across the whole study area.

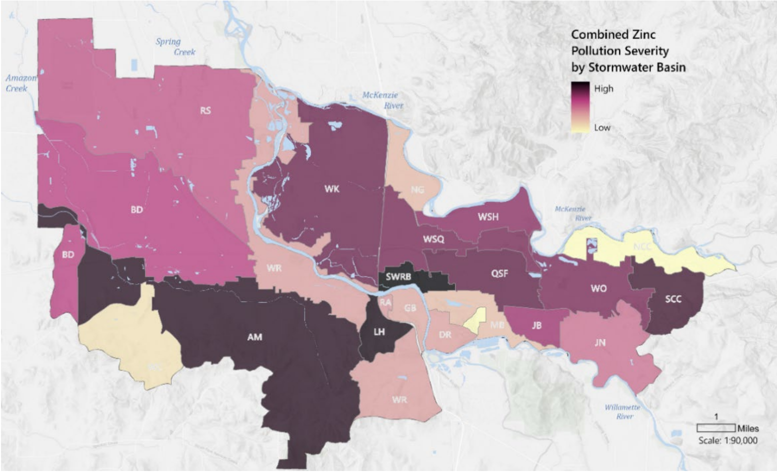


Figure 13: Map of the potential zinc pollution severity in stormwater runoff from the combined sources by stormwater basin across Eugene-Springfield. Darkest purple hues indicate stormwater basins with greatest potential zinc pollution, and lighter pink and yellow hues indicate lesser potential zinc pollution severity.

The lack of storm-event sampling across the study area in 2019 poses challenges for comparing proportions of anthropogenically derived zinc contamination in stormwater to the predictive GIS evaluation of major zinc sources by stormwater basin. To confirm the predictive findings, sampling of proximate stormwater outfalls in these high zinc deposition regions should be conducted, and a separate study comparing the identified high zinc stormwater basins to low total zinc stormwater basins would prove valuable. Future sampling efforts could thus be informed by the potential zinc pollution ranking of stormwater basins created in this study, which in turn, can help identify specific sources of zinc pollution and eventually mitigate zinc pollution within waterways of Eugene-Springfield.

V. Conclusions

Throughout the course of this project, I found zinc-based moss control products, vehicular tire- and brake-wear, and industrial zinc inputs to be the most likely sources of zinc contamination in stormwater runoff within the Eugene-Springfield metro area. Combining zinc concentration data within waterways in the Amazon, Willamette, and McKenzie basins offered not only important insight into the extent of zinc contamination within Eugene-Springfield waterways in the study year of 2019, but also created a wealth of spatiotemporal zinc concentration data (individual zinc concentration values and summary statistics by sampling location) between 2010-2020.

Specifically in 2019, mapping concentrations of total zinc in Springfield's McKenzie basin revealed exceedances of the Oregon zinc concentration acute/chronic criterion (36 µg/L and 37 µg/L), on comparable levels to those seen in Eugene's Willamette basin. Additionally, these studies revealed the Amazon basin experienced the most numerous and consistent exceedances of the Oregon zinc concentration acute/chronic criterion.

The final phase of this project modeled the potential geographic distribution of zinc from zinc-based moss control products, vehicular tire- and brake-wear, and industrial zinc discharge within the municipal stormwater drainage systems of Eugene and Springfield. This source evaluation revealed potential stormwater basins of concern for highest expected zinc loading rates from the three main sources identified in the literature review. Specifically, the five stormwater basins with the greatest potential for zinc pollution from the combined sources were Springfield's Willamette River basin, Springfield's Laurel Hill basin, Eugene's Amazon basin, Springfield's South Cedar

Creek basin, and Springfield's Q Street Floodway basin. These findings indicate zinc contamination is potentially greatest in parts of Springfield, where minimal to no ambient waterway sampling and stormwater sampling has occurred. Overall, this study adds to the understanding of the extent of zinc pollution across the Eugene-Springfield metro area and the distribution of the sources of this zinc contamination.

VI. Next Steps and Implications

Elevated zinc levels within urban stormwater runoff and receiving waterways must be addressed for Clean Water Act compliance, and more importantly, for the ecological and environmental health of the Eugene-Springfield metro area. The most feasible way to curb zinc levels in urban runoff is to stop the zinc pollution at its sources.

My ability to identify the specific sources of zinc contamination within the Eugene-Springfield metro area was constrained based on the availabilities of datasets from governmental entities. There are two courses of action which could help fill in the remaining gaps regarding the sources of zinc pollution in Eugene-Springfield. First, it would be useful to gather more data on the prevalence and use of zinc-based moss control products, zinc-based building materials, and other potential zinc pollution sources. To determine the frequency of use of zinc-based moss control products, a combination of surveys of the sales of these products at home improvement stores, door-to-door surveys with residents, or interviews with roofing professionals who often apply these products would be helpful. The consideration of zinc pollution from zinc-based outdoor materials would also be possible with the use of either algorithm-based modelling of the prevalence of zinc-surfaces (guardrails, chain-link fence, metal roofing, gutters, etc.) like that conducted by the Washington Department of Ecology (2017) or through remote sensing. And finally, the acquisition and inclusion of industrial discharge data from Springfield businesses would also be necessary to gain a better understanding of the impact of industrial activity in both municipalities on the increasing zinc pollution in local waterways.

Additionally, a comprehensive sampling effort is needed to confirm the modelled potential zinc pollution severity across stormwater basins in Eugene-Springfield. It would be necessary to collect stormwater grab samples from stormwater basins of highest concern for zinc pollution to confirm the findings of this report. An effort on the scale of the current ambient water quality monitoring that is conducted by the city of Eugene in waterways but applied to the quantification of zinc concentrations in stormwater is imperative. This would mean the systematic sampling of multiple locations in each stormwater basin during multiple storm events throughout a yearly reporting period. A wholistic sampling effort of stormwater infrastructure within stormwater basins would allow the direct comparison and quantification of the urban runoff entering the waterways around Eugene-Springfield.

Finally, to ultimately reduce zinc pollution, control strategies for zinc mitigation need to be identified and implemented. My report identified the likeliest sources of zinc in the Eugene-Springfield metro area, and each source requires different source control efforts. For the control of zinc-based moss control products, I propose stricter regulatory guidance for these products within Eugene-Springfield, if possible. Alternatives to zinc-based moss control products exist, including manual removal of moss through power-washing. Alternatively, zinc strips, as compared to powder zinc moss control products, release far less zinc to the environment. At the very least, educating the public on the detrimental effect of these products is necessary and advocating for the use of manual removal and/or the use of zinc strips can minimize zinc loading to the environment. To reduce zinc loading from vehicular tire- and brake-wear, installing a vegetated buffer zone between roadways and stormwater drainages which act as zinc filtration zones, has been found to decrease zinc loading to stormwater runoff (CASQA, 2015). Additionally, regular street cleanings appear to help minimize zinc buildup on roadways (Davis, 2010). Finally, some control over industrial zinc discharge is already being implemented, with the new 2021 iteration of the NPDES 1200-Z permit set by the Oregon Department of Environmental Quality. However, most of the sampling is still self-managed by businesses, which poses problems for verification of zinc concentration values.

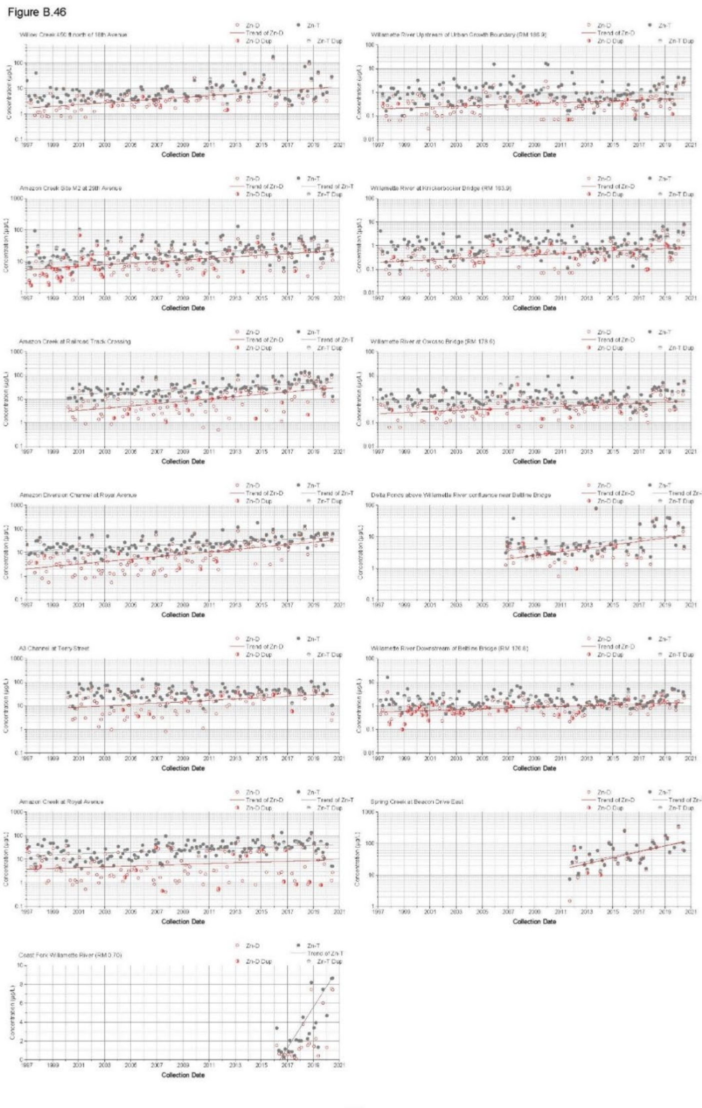
Zinc pollution in the Eugene-Springfield metro area is threatening the environmental and ecological health of local aquatic ecosystems. This report analyzed the extent and sources of zinc contamination in the Eugene-Springfield metro area. To reduce zinc loading to the environment, this report advocates for more stormwater sampling, metro-area specific source prevalence identification, and most importantly, source control.

VII. Appendices

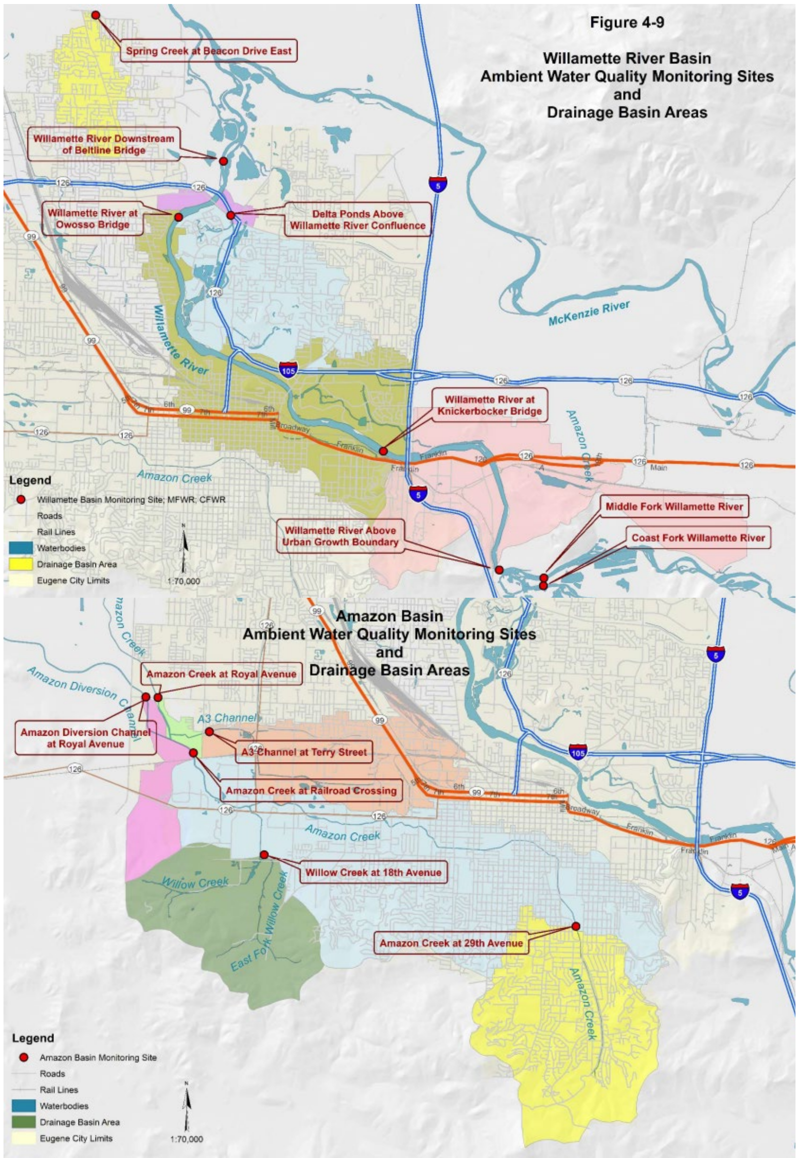
Appendix A: Major Stormwater Basins within the Eugene-Springfield metro area. Major basin codes and IDs were created for analysis purposes in this project.

Major Stormwater Basin	SW Basin ID	City
Dorris Ranch Basin	DR	Springfield
Glenwood Basin	GB	Springfield
Jasper - Natron Basin	JN	Springfield
Jasper Basin	JB	Springfield
Millrace Basin	MB	Springfield
North Cedar Creek Basin	NCC	Springfield
North Gateway Basin	NG	Springfield
Q Street Floodway Basin	QSF	Springfield
Quarry Creek Basin	QC	Springfield
Riverview-Augusta	RA	Springfield
South Cedar Creek Basin	SCC	Springfield
West Springfield Hayden Bridge Basin	WSH	Springfield
West Springfield Q Street Basin	WSQ	Springfield
Weyerhaeuser Outfall Basin	WO	Springfield
Willamette River Basin	SWRB	Springfield
Willakenzie	WK	Eugene
Willamette River	WR	Eugene
River Road - Santa Clara	RS	Eugene
Amazon	AM	Eugene
Willow Creek	WC	Eugene
Bethel - Danebo	BD	Eugene
Laurel Hill	LH	Eugene

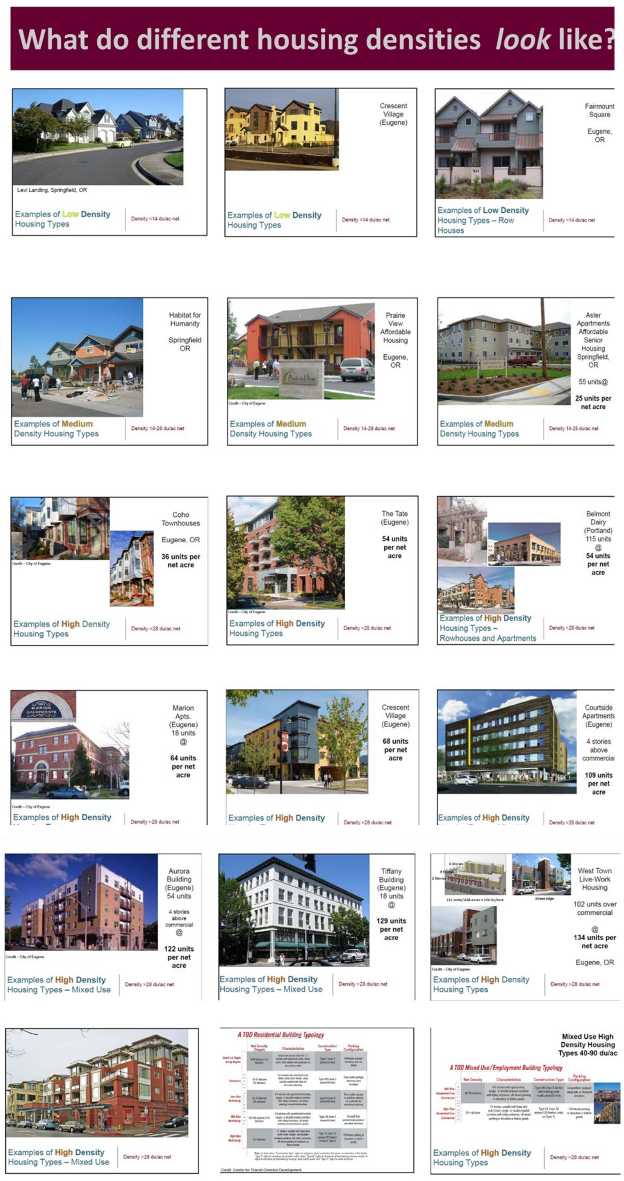
Appendix B: Zinc concentration trend lines since 1997 at each ambient water quality testing location within the city of Eugene. Figure courtesy of the city of Eugene.



Appendix C: City of Eugene ambient water quality monitoring locations within the Willamette River Basin and Amazon Basin. Maps courtesy of the city of Eugene.



Appendix D: Examples of different housing densities within Eugene-Springfield and their representative building types. Figure courtesy of the city of Springfield.



Appendix E: Zinc Concentration summary statistics at each ambient water quality sampling location within the Willamette, Amazon, and McKenzie basins, 2019.

Sampling Location	MIN (µg/L)	MAX (µg/L)	MEAN (µg/L)	STDEV (µg/L)	Stormwater Basin	HUC Basin
A3 Channel at Terry Street	32.4	83.5	56.08	20.41316	Bethel - Danebo	Amazon
Amazon Creek at Railroad Track Crossing	18.1	82.9	44.31667	22.76	Amazon	Amazon
Amazon Diversion Channel at Royal Avenue	20	64.2	46.01667	16.68873	Amazon	Amazon
Willow Creek 450 ft north of 18th Avenue	3.77	43.6	14.038	16.86245	Willow Creek	Amazon
Amazon Creek Site M2 at 29th Avenue	12	59.6	24.86667	17.81793	Amazon	Amazon
Amazon Creek at Royal Avenue	10.9	56.5	30.83333	17.80895	Bethel - Danebo	Amazon
UIC 92	21.4	21.4	21.4	0	West Springfield Hayden Bridge Basin	McKenzie
42nd Stormwater Culvert @ Weyco	27.7	984	348.2333	550.5965	Weyerhaeuser Outfall Basin	McKenzie
Cedar Cr @ Saunders Bridge	0.6	19.8	6.98	8.794999	North Cedar Creek Basin	McKenzie
69th Stormwater Channel @ Thurston Rd	55.6	120	87.8	45.53768	South Cedar Creek Basin	McKenzie
Camp Cr @ Camp Creek Rd Bridge	0.7	7.6	3.083333	3.127566	Outside	McKenzie
Keizer Slough @ SUB Bridge	0.8	27.5	11.825	11.25	Weyerhaeuser Outfall Basin	McKenzie
52nd Stormwater Channel @ Hwy126	7.5	93.8	28.83333	33.97992	Weyerhaeuser Outfall Basin	McKenzie
Willamette River Downstream of Beltline Bridge (RM 176.8)	0.916	5.41	2.977667	1.891304	Willamette River	Willamette
Willamette River at	0.474	2.39	1.503	0.843914	Willamette River	Willamette

Owosso Bridge (RM 178.6)						
Willamette River at Knickerbocker Bridge (RM 183.9)	0.484	4.7	1.6175	1.640332	Willamette River	Willamette
Willamette River Upstream of Urban Growth Boundary (RM 186.9)	0.295	1.84	1.028	0.637639	Outside	Willamette
Spring Creek at Beacon Drive East	53.2	180	112.075	58.38672	River Road - Santa Clara	Willamette
Delta Ponds Upstream of Willamette River Confluence	5.36	40.4	23.014	16.3169	Willakenzie	Willamette
Coast Fork Willamette River (RM 0.70)	1.32	16.8	7.613333	6.039972	Outside	Willamette
UIC 44	52	52	52	0	River Road - Santa Clara	Willamette
UIC 48	5.2	36.5	20.85	22.13244	River Road - Santa Clara	Willamette

Appendix F: Total Zinc Concentration Summary Statistics for Facilities in Eugene, OR with 1200-Z industrial zinc stormwater permits, 2019.

Facility	Latitude	Longitude	Min (mg/L)	Max (mg/L)	Mean (mg/L)	StDev (mg/L)
Armur Coatings	44.07058	-123.20813	0.0066	0.17	0.0712	0.086902
Valley Milling & Lumber - Iowa	44.06114	-123.1384	0.117	2.43	0.7788	0.990898
Peterson Pacific Corporation	44.11138	-123.18873	0.077	0.11	0.0935	0.023334
Emerald Steel Fabricators, Inc.	44.11446	-123.18802	0.087	0.24	0.15175	0.065971
Seneca Sawmill Company	44.1153	-123.18233	0.073	0.29	0.15725	0.097698
The OBRC	44.05053	-123.12486	0.2	0.24	0.22	0.028284
The Truss Company, Inc.	44.11115	-123.19144	0.069	0.45	0.2595	0.269407
Bowtech Archery	44.11948	-123.18895	0.078	0.12	0.099	0.029698
Bulk Handling Systems - Danebo	44.06354	-123.17943	0.246	1.08	0.77325	0.370298
Pacific Recycling, Inc.	44.06208	-123.14647	0.044	0.22	0.132	0.124450
Precision Machine	44.04575	-123.16306	0.21	0.96	0.4775	0.332001
Superior Steel Fabrication	44.05997	-123.15125	0.18	0.87	0.525	0.487903
Oregon Tread Rubber Company	44.05878	-123.15405	0.166	2.69	0.77808	0.804424
Arauco	44.06136	-123.18092	0.0708	0.0708	0.0708	0
Western Pneumatics, Inc.	44.06161	-123.14109	0.061	0.24	0.177	0.100583
Pierce Fittings Inc.	44.06092	-123.12331	0.068	3.1	0.74311	1.013008
Glory Bee Foods	44.06263	-123.14117	0.22	0.23	0.225	0.007071
Oregon Ice Cream Company	44.05072	-123.11841	0.15	0.32	0.22	0.088881
Al's Sheet Metal	44.05064	-123.16452	0.072	0.26	0.144	0.101429
Apex Machinery	44.05785	-123.11321	0.0916	0.203	0.14865	0.048628
Attune Foods	44.10135	-123.16123	0.095	0.32	0.18125	0.0975
Western Structures	44.04499	-123.14711	0.672	2.09	1.381	1.002677
Pacific Corrugated Pipe Company	44.10078	-123.17092	0.015	2.7	0.791	1.092705
Obie Construction, Inc.	44.045	-123.16009	0.036	0.036	0.036	0
PMF	44.05622	-123.11738	0.16	0.47	0.3475	0.135984
Rolling Frito-Lay Sales, LP	44.0508	-123.13573	0.04	0.04	0.04	0
Architectural Millwork Mfg. Company	44.06159	-123.12582	0.057	0.062	0.0595	0.003535
Valley Milling & Lumber Cascadian Division	44.12607	-123.17197	0.0321	0.987	0.25883	0.362943592
Schnitzer Steel Industries, Inc. Plant 2	44.0583	-123.13131	0.029	0.12	0.06367	0.049217206
Lake Eugene	44.11422	-123.1876	0.2	0.57	0.385	0.261629509

Western Coating, Inc.	44.11457	-123.18404	0.305	0.718	0.546	0.138405202
Oldcastle Precast, Inc.	44.12488	-123.19151	0.00317	0.0143	0.00942	0.005691277
Avant Arc	44.05779	-123.11266	0.37	0.55	0.46333	0.090184995
Rexius/Conveyor Application Systems	44.04629	-123.15029	0.087	0.3	0.1438	0.088939305
States Veneer	44.11749	-123.18433	0.036	1	0.5365	0.536055656
A & K Development Company	44.05546	-123.1191	0.084	1.4	0.4775	0.626638386
USF Reddaway, Inc.	44.0576	-123.15278	0.047	0.12	0.0835	0.051618795
Weyerhaeuser NR Company	44.06158	-123.16124	0.17	0.77	0.4325	0.279090786
Quality Metal Finishing, Inc.	44.04644	-123.15616	0.046	0.24	0.129	0.080936189
Whittier Wood Products	44.05983	-123.15853	0.079	0.095	0.087	0.008
Parker Eugene Facility	44.11521	-123.19388	0.046	0.056	0.051	0.007071068
Tyree Oil	44.05893	-123.11317	0.42	0.8	0.61	0.268700577
Mohawk Metal Company	44.10697	-123.16614	0.29	0.32	0.305	0.021213203
Zip-O-Log Mills, Inc. W6	44.05417	-123.12546	0.14	0.24	0.19	0.040824829
FORREST Technical Coatings	44.04882	-123.12921	0.021	0.28	0.1165	0.101097163

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