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Copper and Zinc in Urban Runoff

Phase 1 – Potential Pollutant Sources and Release Rates

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Copper and Zinc in Urban Runoff

Phase 1 –
Potential Pollutant Sources and Release Rates

by

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Abstract

The *Puget Sound Toxics Loading Assessment* (PSTLA) identified copper and zinc as pollutants of concern due to their potential to harm the health of Puget Sound. The PSTLA determined copper and zinc loading is particularly high in stormwater runoff from industrial/commercial areas.

To support pollutant source control efforts, the loading of copper and zinc in the built environment will be estimated for an urban area in western Washington in a two-phased project. During Phase 1 of the study, the potential loading from various sources of copper and zinc are calculated using literature release rates, the exposed surface area of construction materials, and the annual vehicle miles traveled. On average, an estimated 800 pounds of copper and 5,900 pounds of zinc are released each year from the materials reviewed in the study area in Thurston County.

The primary sources of copper are vehicle brake wear, roofing materials, parking lots, treated lumber, building siding, and vehicle exhaust. The main sources of zinc are moss control products, building siding, parking lots, vehicle tire wear, chain-link fence, roofing materials, and vehicle brake wear. The sources with the most uncertain loading values are roofing materials, parking lots, and metal salvage operations.

It is recommended that stormwater monitoring data be collected to verify the quantity of copper and zinc released from parking lots, building roofing and siding materials, streetlights, and roof gutters.

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Introduction

Problem Description

The *Puget Sound Toxics Loading Assessment* (PSTLA) identified copper (Cu) and zinc (Zn) as two of the top five pollutants of concern due to their potential to harm the health of Puget Sound. Because of the quantity of Cu and Zn released to Puget Sound, there is potential to harm aquatic organisms (Norton et al., 2011). Progress has been made in understanding the sources, fate, and transport of Cu and Zn in urban runoff. However, data gaps still exist that limit our ability to develop a comprehensive source control strategy.

Many studies have assessed the sources of Cu and Zn in urban runoff. The PSTLA study found that surface runoff is the major delivery pathway for both Cu and Zn to Puget Sound. The highest concentrations of Cu and Zn are measured from commercial/industrial land use. The elevated Cu and Zn concentrations were especially evident in surface runoff during storm events (Norton et al., 2011). A more recent study of flow-weighted stormwater samples from western Washington showed that commercial and industrial lands contributed higher concentrations of Cu and Zn, than other land uses (Hobbs et al., 2015).

The California Stormwater Quality Association (CASQA) reviewed the available studies on the sources of Zn to urban runoff. The CASQA review included a recommendation to identify major sources in a small urban watershed and to develop a source inventory based on local watershed information (CASQA, 2015).

The Washington State Department of Ecology's (Ecology's) recent roofing assessment study recommended that other roofing components (e.g., flashings, gutters, downspouts, fasteners, HVAC systems) and exposed galvanized materials (e.g., fencing, guardrails, and light posts) be evaluated as sources of metals in stormwater runoff (Winters et al., 2014).

Vehicles are another potential source of Cu and Zn (CASQA, 2015; Davis et al., 2001; Paulson et al., 2012; Roberts et al., 2011; Wesley and Whiley, 2013). The release of Cu and Zn from vehicle use include Zn from tire wear (Councell et al., 2004), Cu from brake wear (Wesley and Whiley, 2013), and both Cu and Zn from road surface wear (Kennedy et al., 2002) and leaking petroleum products (Davis et al., 2001).

There are many other materials within commercial/industrial lands, in addition to roofing materials and vehicle components, which contribute Cu and Zn. Further investigation is needed to assist in developing a strategy to identify and prioritize important sources of Cu and Zn.

Project Summary

The goal of the urban copper and zinc (CuZn) study is to build on existing data to develop a comprehensive data set of the relative importance of individual sources of Cu and Zn within an urban watershed. The focus of this study is on the primary release of Cu and Zn. Flows that transport Cu or Zn to the environment (e.g., stormwater runoff, air deposition, discharges from human activities) are not true sources but conveyance of metals from the primary source.

This report summarizes the findings from Phase 1 of the CuZn study. Phase 1 inventories the potential sources of CuZn, calculates CuZn loading using literature release rates, and informs monitoring strategies for Phase 2 of the study.

Study Area

The CuZn study area is located in the lower Woodland Creek watershed primarily within the City of Lacey but also in a portion of Thurston County, in western Washington State (Figure 1). Woodland Creek is part of the Henderson Inlet watershed.

This area was selected for this study for the following reasons:

- It reflects the land use in other Puget Sound urban areas.
- Area size is manageable, allowing for comprehensive review of potential Cu and Zn sources.
- Location is logistically convenient for unpredictable stormwater monitoring schedule.

The 2016 land use in the study area is 36% commercial/industrial, 14% residential, and 34% undeveloped. Of the area currently developed, 66% is commercial/industrial land use (Figure 2). The study area is undergoing rapid development (Collyard and Anderson, 2017).

The 2010 land use for the 12 counties bordering Puget Sound is approximately 18.5% commercial/industrial, 47.5% residential, 32.4% undeveloped, and 1.6% agricultural. The land-use profile of the study area compares more closely with land use in concentrated urban areas.

Urban areas bordering Puget Sound have similar development. Commercial areas include box stores, strip malls, banks, hotels, fast food restaurants, and mid-rise office buildings. Industrial areas vary depending on the type of industry but typically include large warehouses, shipping and receiving zones, cellular towers, power transmission lines, and chain-link fencing. The building materials and traffic volumes in the study area are representative of the sources of Cu and Zn present in commercial and industrial areas throughout the Puget Sound area.

The 2010 population of the study area is approximately 7,600. The total 2010 population of the 12 Puget Sound counties is 4.47 million.

The population and Puget Sound land-use values are approximate. Some 2010 census blocks are bisected by the study area boundary. Furthermore, the population has increased and additional land has been developed since the 2010 census.

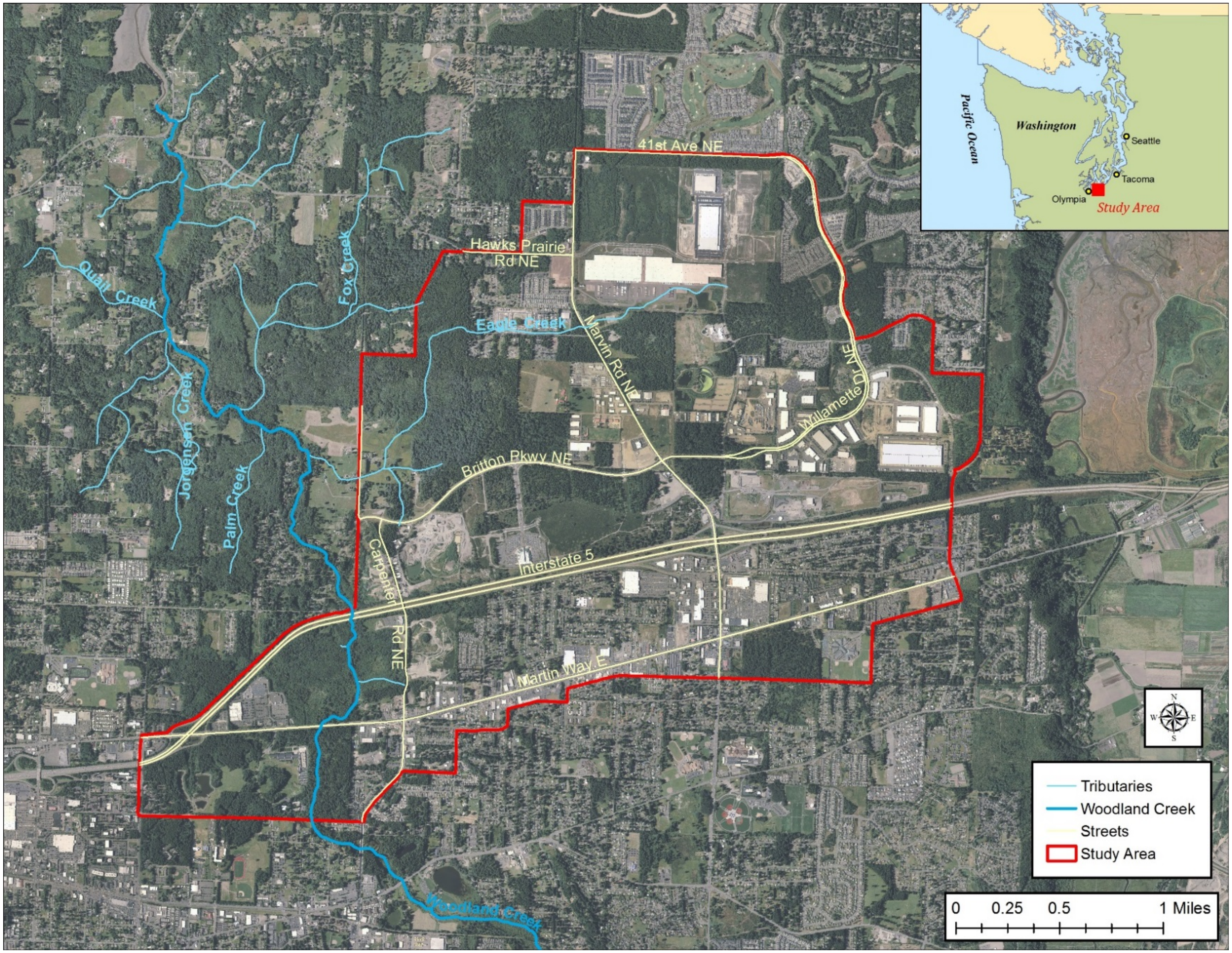

Figure 1. Urban copper and zinc study area: a portion of the lower Woodland Creek watershed within the City of Lacey and part of Thurston County.

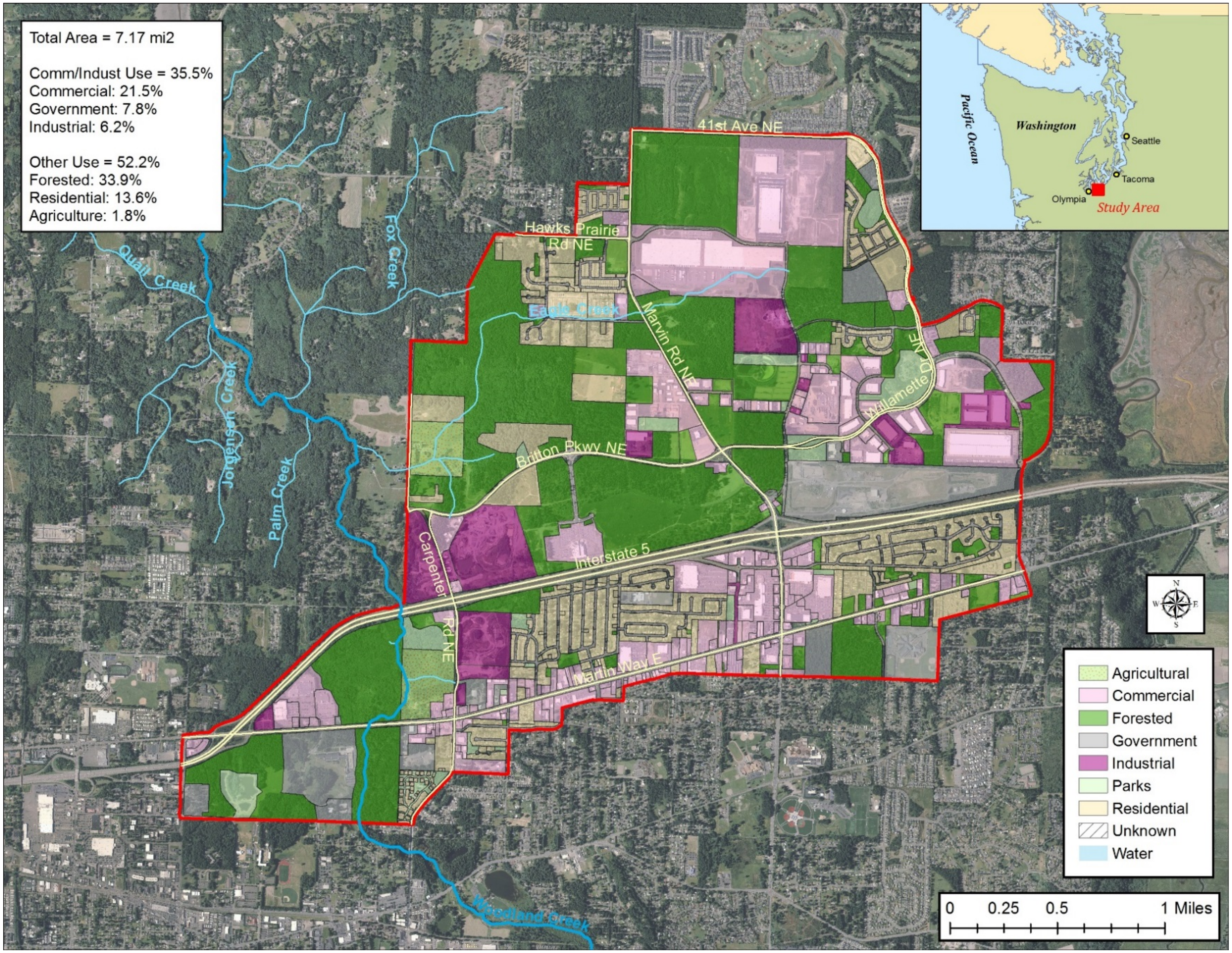

Figure 2. Land use in the urban copper and zinc study area (2016).

Methods

Release rates for known primary sources of Cu and Zn were compiled (Appendix Q). Where possible, a range of release rates are calculated (minimum, maximum, median, and mean) to provide an estimate of loading value uncertainty. In addition, release rates for short-term studies are converted to annual release rates to incorporate temporal, spatial, and climatic variability.

The release rates represent the release of total recoverable metals. Dissolved metals are more bioavailable, and hence potentially harmful, to aquatic life. Phase 2 of this study will monitor the release of total and dissolved Cu and Zn.

Complete details on the loading calculations are provided in Appendices A through Q.

The potential loading of Cu and Zn from sources in an urban environment are calculated from the compiled literature release rates and either the total exposed surface area of building materials or the wear rate per vehicle kilometers traveled. The calculated loading values represent a worst-case estimate that assumes complete contact of precipitation with the exposed surface area. Loading values are calculated in grams per year and then converted to pounds per year. Example equations are shown below.

$$Loading\left(\frac{g\ Zn}{yr}\right) = Exposed\ Surface\ Area\ (m^2) \times Release\ Rate\ \left(\frac{g\ Zn}{m^2-yr}\right)$$

$$Loading\left(\frac{g\ Cu}{yr}\right) = Vehicle\ Wear\ Rate\ \left(\frac{g\ Cu}{km-vehicle}\right) \times Vehicle\ Kilometers\ Traveled\left(\frac{km}{yr}\right)$$

The exposed surface area of known sources of Cu and Zn are determined through Geographic Information System (GIS) analysis. Source information incorporated into this analysis includes building footprints, Thurston County Assessor building data, traffic volume counts, water usage, and aerial imagery.

For construction materials in the built environment, the surface area is calculated using geometry. Example equations for building walls and streetlight pole surface areas are given below.

$$Surface\ Area_{BuildingWall}\ (m^2) = Building\ Perimeter\ (m) \times Height\ (m)$$

$$Surface\ Area_{LightPole}\ (m^2) = Lateral\ Area_{Cylinder} = 2\pi \times Radius\ (m) \times Height\ (m)$$

For vehicle and road wear, the wear rate is calculated using literature values for the percent of Cu or Zn in a vehicle component and the total component wear rate per kilometer traveled. An example equation for a brake wear release rate is given below.

$$Brake\left(\frac{g\ Cu}{km}\right) = Brake\ Wear\ \left(\frac{g}{km-vehicle}\right) \times Brake\ Copper\ (\%)$$

Results

Overview

Based on analysis of Cu and Zn sources in the 7.2 square-mile commercial/industrial area, the estimated average annual loading is 800 pounds of Cu and 5,900 pounds of Zn. This represents an estimate of the typical Cu and Zn loading from a similar sized commercial and industrial area in western Washington. The primary sources of Cu are vehicle brake wear, roofing materials, parking lots, treated lumber, building siding, and vehicle exhaust (Table 1, Figure 3). The main sources of Zn are moss control products, building siding, parking lots, vehicle tire wear, chain-link fence, roofing material, and vehicle brake wear (Table 2, Figure 4).

Parking lots, where Cu and Zn from vehicle wear and leaks accumulate, are a secondary source of Cu and Zn. The method for estimating potential vehicle wear and leak loading uses vehicle kilometers travelled on roadways in the CuZn study area (Appendices E and G), but does not account for vehicles parked at businesses. The parking lot loading calculation uses the surface area of parking lots and the release rates from a previous parking lot study (Appendix P).

Groundwater extracted from aquifers for use as potable water contributes an average of 1,400 lb/yr of Cu and 1,200 lb/yr of Zn in the study area. In addition, plumbing fixtures release 209 lb/yr Cu and an undetermined quantity of Zn (Table 3). Potable water and plumbing releases of Cu and Zn are collected by wastewater treatment facilities and may be reinjected into groundwater, where the Cu and Zn is adsorbed to soil particles. Metal removal efficiencies vary depending on the type of wastewater treatment, but tend to remove 50-90% of Cu and Zn (Bucher, 2008; Busetti et al., 2005; da Silva Oliveira et al., 2007). Potable water and plumbing sources are not included in the following analysis, because the majority of metals from these sources are removed before reaching the aquatic environment.

The estimated total loading values provided in this report (Tables 1-7) are rounded to two significant figures. This level of accuracy represents the variability in the loading estimates. The individual source loading estimates are reported to more significant figures to match the calculation detail provided in Appendices A through P. The variability of the individual source loading values is addressed in terms of the uncertainty scores shown in Tables 5 through 7.

Table 1. Average copper loading by source.

Source	Cu (lb/yr)	Cu (%)
Brake Wear	469	58.7%
Roofing Materials	178	22.3%
Parking Lots	53	6.6%
Treated Lumber	50	6.2%
Siding Materials	22	2.8%
Vehicle Exhaust	18	2.3%
Road Wear	4.2	0.53%
Metal Salvage	3.9	0.49%
Fungicide	0.021	0.003%
Vehicle Leaks	0.0024	0.00%
Total	**800**	

Table 2. Average zinc loading by source.

Source	Zn (lb/yr)	Zn (%)
Moss Control	2,527	42.8%
Siding Materials	920	15.6%
Parking Lots	790	13.4%
Tire Wear	744	12.6%
Chain-link	242	4.1%
Roofing Materials	235	4.0%
Brake Wear	118	2.0%
Roof Gutters	64	1.1%
HVAC	59	1.0%
Vehicle Exhaust	49	0.8%
Streetlights	34	0.57%
Metal Salvage	28	0.47%
Guardrails	26	0.45%
Signs	12	0.21%
Road Wear	4.9	0.08%
Vehicle Leaks	2.8	0.05%
Cell Towers	1.5	0.03%
Total	**5,900**	

Table 3. Average potential copper and zinc loading from water use.

Source	Copper Loading		Zinc Loading	
	(lb/yr)	(%)	(lb/yr)	(%)
Potable Water	818	49.9%	700	57.2%
Plumbing	209	12.8%	na	na
Irrigation	612	37.4%	524	42.8%
Total	**1,600**		**1,200**	

nd = no data

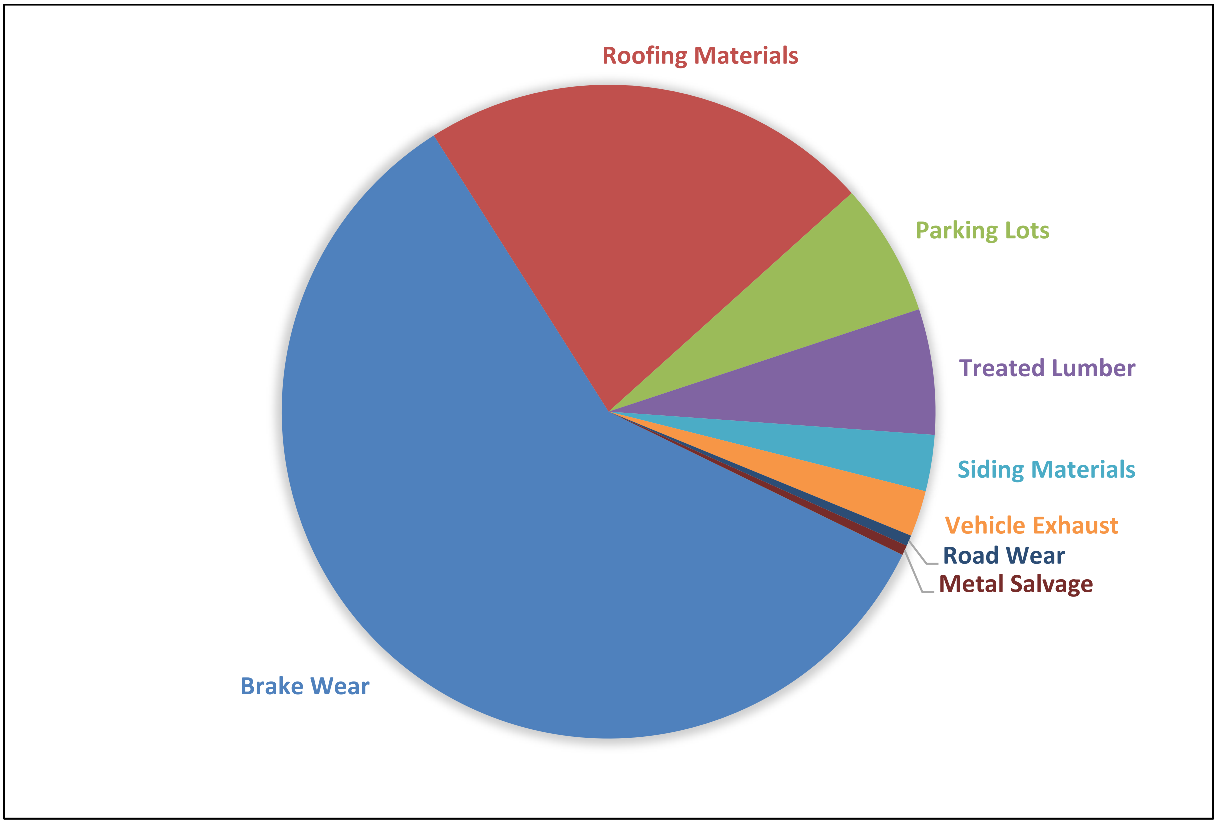

Figure 3. Potential copper loading by source.

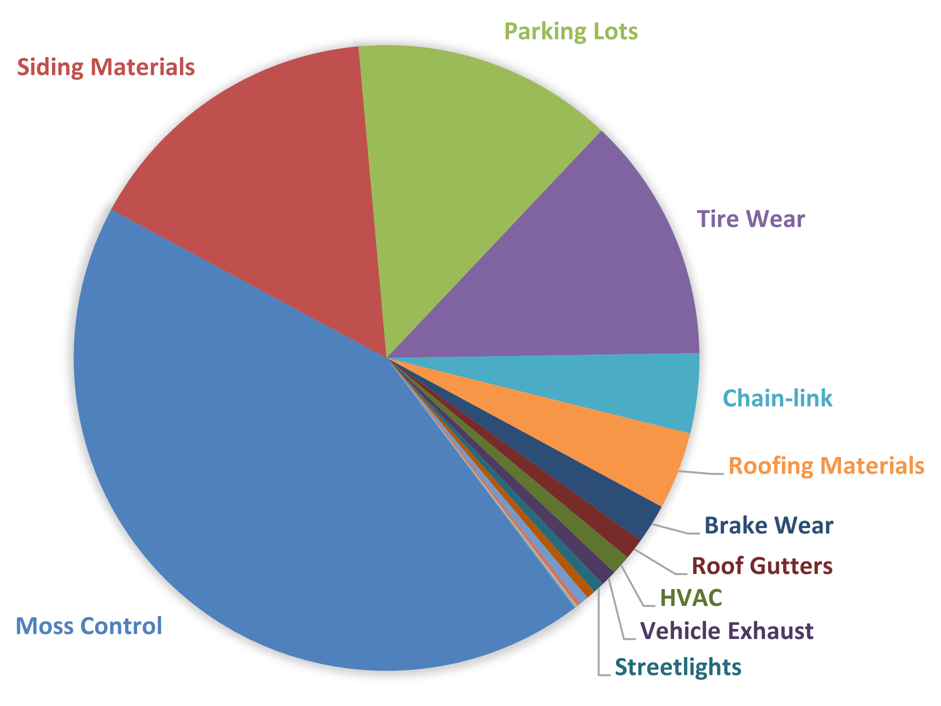

Figure 4. Potential zinc loading by source.

Uncertainty

The uncertainty of Cu and Zn loading values is classified using the coefficient of variation (CV) or relative standard deviation. The CV is calculated as the ratio of the standard deviation to the mean (Miller and Miller, 2014). The CV increases with more variation in loading values.

The standard deviation is a measure of the variation or dispersions of data around the mean. The mean is the average value of a data set. Low standard deviation indicates that data do not vary far from the mean. For this study, the standard deviation is calculated by the “range rule,” where the standard deviation is equal to the range divided by four (Triola, 2017). This is based on the assumption that the data are normally distributed and that four times the standard deviation captures the range of the data. This is necessary since only the minimum, maximum, median, and mean loading values are calculated using the release rates. There is not a population of random loading values from which the standard deviation can be calculated.

The loading values for each potential source are ranked according to the CV. The uncertainty score is a qualitative classification of the variation of loading values (Table 4). The uncertainty score classes are delineated to indicate when the standard deviation is less than 50% of the mean value (good), between 50 and 150% of the mean (fair), and greater than 150% of the mean (poor). The uncertainty score is an aid to identifying sources needing further study.

$$Standard\ Deviation = \frac{Range}{4}$$

$$Coefficient\ of\ Variation\ (CV) = \frac{Standard\ Deviation}{Mean}$$

Table 4. Uncertainty classification system.

Uncertainty Score	CV
Good	< 0.5
Fair	0.5-1.5
Poor	> 1.5

Loading

The average Cu loading is 800 lb/yr and ranges from 300 to 2,600 lb/yr (Table 5). The total Cu loading uncertainty is fair. In other words, the variation of total Cu loading is within 50-150% of the mean loading value. The average Zn loading is 5,900 lb/yr and ranges from 2,000 to 18,000 lb/yr (Table 6). The total Zn loading uncertainty is fair.

The estimated total loading values provided in this report are rounded to two significant figures (Tables 1-7). This represents the level of accuracy and variability of the Cu and Zn loading estimates. The loading values for the individual Cu and Zn sources are shown with more significant figures to match the calculation detail provided in Appendices A through P. The variability of the individual source loading values is displayed using the CV and uncertainty scores (Tables 5-7).

The analysis discussed in this report is for known sources of Cu and Zn. The uncertainty scores for the total loading of Cu and Zn are only for the sources estimated in the CuZn study. The total median loading for Cu and Zn are less than the minimum loading value, because median release rates for many potential sources are not available.

Only the average loading is calculated for many potential sources. The literature for the Cu or Zn release from these sources is limited, and only average release rates are reported. The uncertainty of sources with only an average loading value cannot be calculated, because a range of loading values is not available. The sources with only an average loading value have no data (nd) listed for the minimum, median, and maximum loading values (Tables 5 and 6).

Table 5. Summary statistics for copper loading (lb/yr).

Source	**Min**	**Median**	**Mean**	**Max**	**Range**	**Std Dev**	**CV**	**Uncertainty**
Brake Wear	280	nd	469	623	343	86	0.18	Good
Roofing Materials	12.5	112	178	1,496	1,484	371	2.08	Poor
Parking Lots	1.77	14.2	52.5	361	359	90	1.71	Poor
Treated Lumber	5.38	11.8	49.5	48.2	43	11	0.22	Good
Siding Materials	0.23	9.50	22.2	77.9	78	19	0.87	Fair
Vehicle Exhaust	nd	nd	18.2	nd	nd	nd	nd	nd
Road Wear	nd	nd	4.25	nd	nd	nd	nd	nd
Metal Salvage	0.0080	0.064	3.92	14.0	14	3.5	0.89	Fair
Fungicide	nd	nd	0.021	nd	nd	nd	nd	nd
Vehicle Leaks	nd	nd	0.0024	nd	nd	nd	nd	nd
Total	**300**	**100**	**800**	**2,600**	**2,300**	**600**	**0.75**	**Fair**

nd = no data, mean = average, Std Dev = standard deviation, CV = coefficient of variance

Table 6. Summary statistics for zinc loading (lb/yr).

Source	Min	Median	Mean	Max	Range	Std Dev	CV	Uncertainty
Moss Control	1,264	nd	2,527	6,318	5,054	1,264	0.50	Fair
Siding Materials	44.9	524	920	2,801	2,756	689	0.75	Fair
Parking Lots	20.0	200	790	5,199	5,179	1,295	1.64	Poor
Tire Wear	445	nd	744	1,188	742	186	0.25	Good
Chain-link	86.4	264	242	345	258	65	0.27	Good
Roofing Materials	47.1	173	235	1,795	1,747	437	1.86	Poor
Brake Wear	70.6	nd	118	157	86	22	0.18	Good
Gutters	12.7	33.4	64.5	162	150	37	0.58	Fair
HVAC	17.4	51.5	58.8	106	89	22	0.38	Good
Vehicle Exhaust	nd	nd	49.1	nd	nd	nd	nd	nd
Streetlights	7.97	22.3	33.6	74.7	67	17	0.50	Fair
Metal Salvage	0.0095	1.51	27.7	128	128	32	1.16	Poor
Guardrails	9.66	29.6	26.5	36.3	27	6.7	0.25	Good
Signs	3.97	11.9	12.4	20.2	16	4.0	0.33	Good
Road Wear	nd	nd	4.91	nd	nd	nd	nd	nd
Vehicle Leaks	nd	nd	2.78	nd	nd	nd	nd	nd
Cell Towers	0.48	1.45	1.48	2.37	1.9	0.47	0.32	Good
Total	**2,000**	**1,300**	**5,900**	**18,000**	**16,000**	**4,000**	**0.68**	**Fair**

nd = no data, mean = average, Std Dev = standard deviation, CV = coefficient of variance

Conclusions and Recommendations

Sampling Recommendations

The goal of Phase 1 of the CuZn study is to identify data gaps and uncertainty in the current knowledge about sources of Cu and Zn. Sources with limited available data and uncertainty are good candidates for the Phase 2 monitoring.

To help identify sampling candidates, the loading and uncertainty tables are combined and ranked from greatest to least loading variability (Table 7). Loading values in orange indicate sources with large loading variability or limited data, yellow indicates moderate variability, and green indicates loading values with low variability. The sources with the greatest variability and potential to contribute Cu or Zn should be considered for future monitoring.

Table 7. Loading uncertainty summary (ranked by the coefficient of variance for zinc loading).

Source	Zn (lb/yr)	Zn CV	Zn Score	Cu (lb/yr)	Cu CV	Cu Score
Vehicle Exhaust	49	nd	nd	18.2	nd	nd
Road Wear	4.9	nd	nd	4.2	nd	nd
Vehicle Leaks	2.8	nd	nd	0.0024	nd	nd
Fungicide	na	na	na	0.021	nd	nd
Treated Lumber	na	na	na	49.5	0.22	Good
Roofing Materials	235	1.86	Poor	178	2.08	Poor
Parking Lots	790	1.64	Poor	53	1.71	Poor
Metal Salvage	28	1.16	Poor	3.90	0.89	Fair
Siding Materials	920	0.75	Fair	22.2	0.87	Fair
Gutters	64	0.58	Fair	na	na	na
Moss Control	2,527	0.50	Fair	na	na	na
Streetlights	34	0.50	Fair	na	na	na
HVAC	59	0.38	Good	na	na	na
Cell Towers	3.0	0.32	Good	na	na	na
Signs	15	0.31	Good	na	na	na
Chain-link	242	0.27	Good	na	na	na
Guardrails	41	0.25	Good	na	na	na
Tire Wear	744	0.25	Good	na	na	na
Brake Wear	118	0.18	Good	469	0.18	Good
Total	**5,900**	**0.68**	**Fair**	**800**	**0.75**	**Fair**

na = not applicable, nd = no data; CV = coefficient of variance

Using the above assessment strategy, it is recommended that the following sources be sampled to measure their potential release of Cu and Zn:

- Siding materials
- Parking lots
- Roofing materials
- Roof gutters
- Streetlights

Painted wood and metal siding should be included in monitoring efforts. Painted wood siding released the majority of Cu and Zn contributed by siding materials. The second largest contributor of Zn from siding materials is painted metal (Tables B-3 and B-4).

Parking lots may be a substantial secondary source of both Cu and Zn (Tables 5 and 6). Vehicle wear and fluid leaks concentrate on parking lot surfaces. The release rates used for parking lots are from one study in Texas (Appendix P). Local sampling of parking lot stormwater sheetflow and catch-basin sediments will provide an estimate of parking lots as a secondary source of Cu and Zn to Puget Sound.

Roofing materials have been evaluated by many studies. The majority of research has been conducted via pilot studies, where the runoff from small-scale roofing panels was analyzed. Building materials monitoring in the built environment will provide loading values for full-scale structures including auxiliary roofing components (e.g., HVAC and gutters). Sampling roof systems in the built environment will incorporate variations in material age and condition.

The following roofing materials should be included in monitoring efforts: metal, asphalt shingles with algae resistant granules (AAR), ethylene propylene diene terpolymer (EPDM), and thermoplastic polyolefin (TPO). The largest quantity of Cu and Zn from roofs are released from AAR and metal roofs, respectively. EPDM represented only 2.3% of the roof surface area in the CuZn study area and is the second largest source of estimated Zn released from roofs (Tables C-5 and C-6). Limited data are available in the literature regarding Cu and Zn leaching from TPO roofing materials (Winters et al., 2014).

Sampling from building roofing and siding materials of different ages and condition is advised. The degradation of protective coatings on construction materials may lead to increases in metal leaching (ARC, 2003).

There is limited information about the quantity of Cu and Zn leached from streetlights and roof gutters. The loading values for streetlights and gutters are calculated using release rates from small-scale galvanized and painted metal panels. Sampling these sources will provide a loading estimation and verification for this method.

Sampling designs that incorporate other potential sources are advised. For example, stormwater runoff sampling at one building should be comprehensive and include HVAC units, roofing and siding materials, gutters and downspouts, and a parking lot in consecutive sequence. This approach would allow the researcher to quantify the Cu and Zn contributed by each building component.

Fate and Transport

The goal of the CuZn study is to quantify the total potential of Cu and Zn loading from various sources. This will assist local source control efforts to identify the most likely sources of elevated Cu and Zn in stormwater runoff. The scope of the study does not include analysis of the fate and transport of Cu and Zn released from the various sources.

Stormwater runoff may flow onto impervious surfaces and be transported into streams and rivers. This can lead to toxic conditions in the environment, which may be detrimental to the health of aquatic organisms (McIntyre et al., 2008; Spromberg et al., 2016). Following best management practices (BMPs) should ensure that leached metals in stormwater runoff are retained and adsorbed to soil particles, limiting the release of harmful compounds to the aquatic environment (Clary et al., 2011; Helmreich et al., 2010). For example, Zn leached from chain-link fencing or highway runoff may flow onto a grassy median, where the majority of Zn will be bound to the soil (Golding, 2006; McIntyre et al., 2015).

Summary

On average, an estimated 800 pounds of Cu and 5,900 pounds of Zn are released each year from construction materials and vehicle wear in the CuZn study area.

The primary sources of Cu are vehicle brake wear, roofing materials, parking lots, treated lumber, building siding, and vehicle exhaust. The main sources of Zn are moss control products, building siding, parking lots, vehicle tire wear, chain-link fences, roofing materials, and vehicle brake wear.

The sources with the most variable loading values are roofing materials, parking lots, and metal salvage operations. The sources with the greatest variability and potential to contribute Cu or Zn should be considered for future monitoring efforts.

It is recommended that the following sources be sampled to measure their potential release of Cu and Zn:

- Siding materials
- Parking lots
- Roofing materials
- Roof gutters
- Streetlights

These monitoring recommendations will be incorporated into a quality assurance project plan (QAPP) for Phase 2 of the CuZn study. That QAPP will provide a detailed study design to help fill the data gaps identified in this Phase 1 report.

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Appendices

Appendix A. Water Use

Overview

The average Cu loading from water use and plumbing in the urban CuZn study area is 1639 lb/yr. The average Zn loading from water use is 1223 lb/yr (Table 3).

Cu is present in the potable water provided to the study area and leached from plumbing fixtures (e.g., Cu pipes, brass fixtures). The source water average Cu content is 0.26 mg/L. The average tap water from buildings constructed before 1987 contains 0.40 mg/L of Cu (WDOH, 2016). The difference between tap and source waters indicates that plumbing fixtures in older buildings contribute 0.14 mg/L of Cu.

Kimbrough (2009) found that brass fittings in homes built after 1987 contribute Cu and Zn to the wastewater. However, data for tap water in new homes are not available for the study area.

The study area source water contains an average of 0.22 mg/L Zn. The quantity of Zn leached from plumbing fixtures was not calculated. Tap water Zn content is not available for the study area. The average tap water Zn measured 0.14 mg/L in California homes (Kimbrough, 2009), less than the Zn found in the lower Woodland Creek source water. Kimbrough (2009) did not provide an average quantity of Zn leached from plumbing fixtures to allow for the calculation of Zn released from plumbing fixtures in the CuZn study.

Potable water and plumbing releases of Cu and Zn are collected by the wastewater treatment facilities and may be reinjected into groundwater where the Cu and Zn is adsorbed to soil particles (LOTT, 2013). Metal removal efficiencies vary depending on the type of treatment but tend to remove 50-90% of Cu and Zn (Bucher, 2008; Busetti et al., 2005; da Silva Oliveira et al., 2007). These processes decrease the chance of Cu and Zn from potable water use reaching aquatic environments in quantities harmful to organisms.

Lead and Copper Rule

In 1986, leaded brasses were banned for plumbing fixtures where human consumption was likely (Kimbrough, 2009). Under the Lead and Copper Rule (LCR), water suppliers are required to sample tap water in buildings constructed before 1987 (USEPA, 2008).

For the CuZn study, buildings constructed before 1987 are separated from buildings constructed after 1987. The LCR tap water results for pre-1987 buildings are used to determine the contribution of Cu from plumbing fixtures. That plumbing contribution is applied to all pre-1987 buildings. The source water metal content is used to calculate the quantity of Cu and Zn released by the potable water consumed in all buildings.

GIS analysis of county assessor data indicates that 45% of buildings and 49% of residences in the CuZn study area were built before 1987 (Thurston, 2016). For this study, an average of 47% of structures is used to estimate the number of buildings built before 1987.

Water Consumption

The total annual water usage in the CuZn study area is 661 million gallons (2.5 billion liters). This includes commercial, residential, and irrigation use. Businesses and residences use 378 million gallons (57.2%) of water. Irrigation consumes 283 million gallons (42.8%) of water. The water used in buildings is collected and treated by wastewater treatment plants. Water used for irrigation may be directly released to the environment, unless it is captured by stormwater collection systems.

There are 17 water supply systems in the study area (Table A-1). The source water for these systems is provided by groundwater wells. The City of Lacey provides water to 1,830 potable water accounts and 229 irrigation accounts. The Thurston County Public Utility provides water to the Tanglewilde neighborhood and adjacent businesses. The water consumption quantities for the Tanglewilde neighborhood and the Shamrock trailer court are calculated. Water consumption data for a few small water systems are negligible or unavailable (Table A-1).

Only 42.7% of the land area covered by the Tanglewilde neighborhood is located in the study area. The water used in the Tanglewilde portion of the study area is calculated as 42.7% of the total water used by the Tanglewilde neighborhood.

$$Tanglewilde_{StudyArea}\left(\frac{gal}{yr}\right) = 0.427 \times Tanglewilde_{Total}\,(\frac{gal}{yr})$$

$$Tanglewilde_{StudyArea}\left(\frac{gal}{yr}\right) = 0.427 \times 171{,}894{,}454\ gal/yr = 73{,}449{,}788\ gal/yr$$

Water consumption data for the Shamrock Trailer Court are not available. The number of mobile homes present and the average daily water use for the Martin Way Mobile Home Park are used to calculate the water usage.

$$Shamrock\ \left(\frac{gal}{yr}\right) = Homes \times Daily\ Use_{MartinPark}\ (\frac{gal}{day - home}) \times 365\ \left(\frac{day}{yr}\right)$$

$$Shamrock\ \left(\frac{gal}{yr}\right) = 12\ homes \times 15\left(\frac{gallons}{day - home}\right) \times 365\ \left(\frac{day}{yr}\right) = 65{,}700\ gal/yr$$

The quantity of water used by a few small water systems is negligible or unavailable. The Hawk Acres water system provides water to only two residences in the study area. The businesses in the study area with water provided by the JOS water system are now serviced by the City of Lacey. The commercial building with water provided by Kevin Turner Investments has been demolished. Data were unavailable for the private wells owned by Rags to Riches and Fon Morcus (Table A-1).

Table A-1. Water consumption by water system.

Water System Name	Annual Use		
	(gallon)	(liter)	(%)
City of Lacey - Water Accounts	289,360,744	1,095,349,570	43.77%
City of Lacey - Irrigation Accounts	283,072,170	1,071,544,730	42.82%
Tanglewilde (part in Study Area)	73,449,788	278,037,694	11.11%
Alpine Mobile Estates	4,734,000	17,920,139	0.72%
Tolmie Park 239	4,619,648	17,487,270	0.70%
Eagle Estates	2,117,800	8,016,745	0.32%
Shattuck 1	1,629,257	6,167,409	0.25%
Tolmie Cove Apartments (Duplexes)	1,342,585	5,082,238	0.20%
Floating Bear	314,740	1,191,421	0.05%
Martin Way Mobile Home Park	269,720	1,021,001	0.04%
Eason, Dan B	146,000	552,670	0.02%
Shamrock Trailer Court	65,700	248,702	0.01%
Hawk Acres	na	na	na
Morcus, Fon	nd	nd	nd
Rags to Riches	nd	nd	nd
JOS	na	na	na
Kevin Turner Investments	na	na	na
Total	**661,122,153**	**2,502,619,588**	

na = not applicable = very little or no water use in study area; nd = no data available

Copper Loading

The Cu content and loading values in potable water, irrigation water, and contributed by plumbing fixtures are shown in Table A-2. Cu loading is calculated as the product of Cu concentration and water use, then converted to pounds per year.

$$Copper\left(\frac{mg}{yr}\right) = Copper\left(\frac{mg}{L}\right) \times Water\ Use\left(\frac{L}{yr}\right)$$

$$Copper\left(\frac{lb}{yr}\right) = Copper\left(\frac{mg}{yr}\right) \times \frac{1\ g}{1000\ mg} \times \frac{1\ lb}{453\ g}$$

Table A-2. Copper released from water use.

Source	Water Consumption (L/yr)	Copper (mg/L)				Copper Load (lb/yr)				
		Min	Median	Mean	Max	Min	Median	Mean	Max	%
Potable Water (<1987)	672,605,183	0.02	0.17	0.26	1.30	30	252	384	1928	23.4%
Plumbing (<1987)	-	0.00	0.17	0.14	2.40	0	245	209	3559	12.8%
Potable Water (>1987)	758,469,675	0.02	0.17	0.26	3.70	33	284	433	6187	26.4%
Irrigation Water	1,071,544,730	0.02	0.17	0.26	3.70	47	402	612	8741	37.4%
Total	**2,502,619,588**					**110**	**1183**	**1639**	**20414**	

The total water provided to the study area is separated into water used by buildings built before and after 1987. The Cu loading from plumbing ($\text{Copper}_{\text{Plumbing}}$) occurs when source water interacts with building plumbing and leaches metals from Cu pipes and brass fixtures (Kimbrough, 2009; Belitz et al., 2016). The Cu loading from plumbing is calculated using the difference between the average Cu concentrations in tap water sampled under the LCR (0.40 mg/L) and the source water (0.26 mg/L) used in all buildings in the study area (WDOH, 2016). The Cu concentration of the source water is applied to the influent of pre-1987 buildings ($\text{Copper}_{<87\text{Potable}}$), all water use in post-1987 buildings ($\text{Copper}_{>87}$), and irrigation water ($\text{Copper}_{\text{Irr.}}$). Example equations are given below.

$$Copper_{Plumbing}\ \left(\frac{mg}{yr}\right) = \left[Copper_{LCRTap}\ \left(\frac{mg}{L}\right) - Copper_{Source}\ \left(\frac{mg}{L}\right)\right] \times Water\ Use_{<87}\ \left(\frac{L}{yr}\right)$$

$$Copper_{<87Potable}\ \left(\frac{mg}{yr}\right) = Copper_{Source}\ \left(\frac{mg}{L}\right) \times Water\ Use_{<87}\ \left(\frac{L}{yr}\right)$$

$$Copper_{>87}\ \left(\frac{mg}{yr}\right) = Copper_{Source}\ \left(\frac{mg}{L}\right) \times \left[Water\ Use_{>87}\ \left(\frac{L}{yr}\right) + Water\ Use_{Irr.}\ \left(\frac{L}{yr}\right)\right]$$

Water used by pre- and post-1987 buildings is calculated as a percent of the total non-irrigation water consumption (see below). Buildings built before 1987 comprise 47% of the total buildings in the study area. The quantity of water used for irrigation is provided by the City of Lacey (Lacey, 2016).

$$Water\ Use_{<87} = 0.47 \times Water\ Use_{NonIrrigation}$$

$$Water\ Use_{>87} = 0.53 \times Water\ Use_{NonIrrigation}$$

Zinc Loading

Zn content and loading values in the source and irrigation waters are shown in Table A-3. Zinc loading is calculated similar to Cu loading, except Zn leached from plumbing fixtures is not incorporated. Zinc is likely leached from brass fixtures (Kimbrough, 2009). However, source water Zn concentrations in the study area are greater than Zn concentrations reported from plumbing leaching studies (Kimbrough, 2009). This does not allow for the contribution of Zn from brass fittings to be calculated.

Table A-3. Zinc released from water use

Source	Water Consumption (L/yr)	Zinc (mg/L)				Zinc Load (lb/yr)				
		Min	Median	Mean	Max	Min	Median	Mean	Max	%
Potable Water	1,431,074,858	0.0052	0.20	0.22	0.98	16	631	700	3092	57.2%
Irrigation Water	1,071,544,730	0.0052	0.20	0.22	0.98	12	472	524	2315	42.8%
Total	**2,502,619,588**					**29**	**1103**	**1223**	**5407**	

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Appendix B. Building Siding

Overview

The estimated Zn released from building siding materials is 920 lb/yr. This represents 15.7% of the total Zn released to the urban CuZn study area (Table 2, Figure 4). The estimated Cu released from building siding is 22 lb/yr. Building siding contributes 2.8% of the Cu released to the study area annually (Table 1, Figure 3).

Building siding loading is calculated as the product of material surface area and corresponding literature release rate.

$$Loading_{Siding}\left(\frac{g}{yr}\right) = Surface\ Area\ (m^2) \times Release\ Rate\ (\frac{g}{m^2 - yr})$$

Release rates for different building siding materials are compiled below.

The total surface area of building siding in the study area is 12.3 million ft^2 (1.15 million m^2). The method for calculating building siding surface areas is discussed below.

Release Rates

The release rates for building siding materials is shown in Table B-1.

The building siding release rates are compiled from a study at the University of Maryland (Davis et al., 2001). In that study, building siding materials were washed with synthetic rain water and the runoff analyzed for trace metals. Davis et al. (2001) developed release rates (ug/m^2) from the metals concentrations and surface areas washed.

The release rates in Table B-1 were converted from ug/m^2 to g/m^2/yr using an estimated number of wash events per year (see equations below). The average annual rainfall at the University of Maryland is 44.26 in/yr (USClimateData, 2017). Davis et al. (2001) report an average wash volume of 140 mL (8.54 in^3) and an average wash area of 240 cm^2 (37.2 in^2).

$$Average\ Wash\ Rainfall\ Equivalent\ \left(\frac{in}{sample}\right) = \frac{Average\ Wash\ Volume\ (in^3)}{Average\ Wash\ Area\ (in^2)}$$

$$Average\ Wash\ Rainfall\ Equivalent\ = \frac{8.54\ in^3}{37.2\ in^2} = 0.23\ in/sample$$

$$Storms\ \left(\frac{events}{year}\right) = \frac{Average\ Annual\ Rainfall\ (\frac{in}{yr})}{Average\ Wash\ Rainfall\ Equivalent\ (\frac{in}{sample})}$$

$$Storms\ \left(\frac{events}{year}\right) = \frac{44.26\ in/yr}{0.23\ in/sample} = 192.7\ events/year$$

$$Release\ \left(\frac{g}{m^2 - yr}\right) = \left(Release\ \left(\frac{ug}{m^2}\right) \times \frac{1\ g}{1x10^6\ ug}\right) \times 192.7\ (\frac{events}{yr})$$

Table B-1. Siding material release rates from Davis et al. (2001)

Source	**Copper Release Rate**				**Zinc Release Rate**				**Units**
	Min	**Median**	**Mean**	**Max**	**Min**	**Median**	**Mean**	**Max**	
Concrete wall	ND	0.000016	0.000035	0.00017	0.00022	0.0014	0.00012	0.0019	g/m^2/yr
Brick	0.0012	0.0044	0.0091	0.0540	0.0050	0.1388	0.4047	4.4326	g/m^2/yr
Painted Wood	ND	0.0066	0.0154	0.0540	0.0069	0.3084	0.5396	1.6189	g/m^2/yr
Metal	ND	ND	0.0003	0.0009	0.0050	0.0231	0.1330	0.4818	g/m^2/yr
Unpainted Wood	0.0008	0.0044	0.0231	0.0617	0.0108	0.0385	0.0636	0.1407	g/m^2/yr
Vinyl	0.0008	0.0015	0.0031	0.0067	0.0046	0.0127	0.0116	0.0175	g/m^2/yr

ND = non-detect

Siding Area

The exposed surface area of building siding is calculated using the building footprint perimeter and wall height. Commercial wall heights were provided by Thurston County (Thurston, 2016). For buildings without wall heights recorded (e.g., residential structures), a wall height of 10 feet (3.048 meters) per story was used.

$$Area_{Siding}\ (m^2) = Building\ Perimeter\ (m) \times Building\ Height\ (m)$$

Building footprints are used to calculate building perimeter lengths. The building footprints for buildings constructed before 2003 were provided by Thurston County (Thurston, 2016). The footprints of buildings constructed after 2003 were digitized in GIS using aerial imagery (Ecology, 2012; Ecology, 2015). To digitize building footprints in GIS, aerial imagery is displayed and polygons are created that represent the outlines of the buildings shown.

The surface areas of the various siding materials installed in the study area are presented in Table B-2.

Siding Material

Building siding materials are recorded by Thurston County for most structures (Thurston, 2016). Siding materials not recorded are identified using street view imagery (BingMaps, 2017; GoogleMaps, 2017).

The Thurston County Assessor siding materials classification system is simplified for this study to represent the siding types analyzed by Davis et al. (2001). The simplification of Assessor codes is shown in Table B-2. Some assumptions are made to accomplish this classification. For instance, it is assumed that all wood siding in the study area is painted.

Table B-2. Siding material classification system and surface areas

Assessor Siding Material		**Surface Area**	**CuZn Study Siding Group**	**Surface Area**	
Description	**Code**	**(m^2)**		**(m^2)**	**(%)**
ASBESTOS-SHNG	AB	367	Asbestos	367	0.03%
ALUMINUM-VINYL	AL	1936	Aluminum-Vinyl	99953	8.72%
VINYL	VN	98017			
MASONRY-VENEER	MV	2046	Brick	19593	1.71%
BRICK	BR	17547			
ENAMELED-METAL	EM	70390	Metal, painted	119344	10.41%
PORCELAINIZED-STEEL	PS	0			
METAL-GLASS	MG	48954			
METAL	ML	0			
CORRUGATED-METAL	CM	4276	Metal, unpainted	4276	0.37%
BLOCK	BL	35076	Concrete	281062	24.52%
CONCRETE	CN	27841			
CURTAIN	CU	0			
PRECAST-CC-PANEL	PC	49510			
STUCCO	SO	4363			
TILTUP-CC-PANEL	TU	164273			
STONE	ST	0	Stone	168	0.01%
STONE-VENEER	SV	168			
FRAME	FR	16047	Wood, painted	621428	54.22%
HARDBOARD	HB	4490			
LOG	LG	16743			
PLYWOOD	PL	358954			
WOOD-SIDING	WD	225194			
NONE	NO	0	No Walls	0	0.00%
OTHER	OT	0			
TOTAL		**1146191**		**1146191**	

Zinc Loading

The surface area of each siding material and the Zn released from each is shown in Table B-3. The siding materials that contribute the most Zn are painted wood (739 lb/yr), painted metal (141 lb/yr), unpainted metal (19 lb/yr), and brick (17 lb/yr).

Any materials with loading values marked as “not applicable” have not released statistically significant quantities of Zn in previous studies.

Table B-3. Potential zinc loading from siding materials.

Siding Material	Surface Area			Zinc Loading (lb/yr)				
	(ft^2)	(m^2)	(%)	Min	Median	Mean	Max	%
Wood, painted	6,688,995	621,428	54.2%	9.5	422	739	2218	80.6%
Concrete	3,025,327	281,062	24.5%	0.14	0.87	0.074	1.2	0.2%
Metal, painted	1,284,610	119,344	10.4%	27	71	141	360	13.5%
Aluminum-Vinyl	1,075,884	99,953	8.7%	1.0	2.8	2.5	3.9	0.5%
Brick	210,896	19,593	1.7%	0.22	6.0	17	191	1.1%
Metal, unpainted	46,024	4,276	0.37%	6.9	21	19	26	4.0%
Asbestos	3,950	367	0.03%	nd	nd	nd	nd	nd
Stone	1,808	168	0.01%	nd	nd	nd	nd	nd
Total	**5,648,500**	**1,146,191**		**45**	**524**	**920**	**2801**	

Copper Loading

The surface area of each siding material and the Cu released from each is shown in Table B-4. The siding materials that contribute the most Cu are painted wood (21 lb/yr), aluminum-vinyl (0.68 lb/yr), and brick (0.39 lb/yr). Any materials with loading values marked as “not applicable” have not released statistically significant quantities of Cu in previous studies.

Table B-4. Potential copper loading from siding materials.

Siding Material	Surface Area			Copper Loading (lb/yr)				
	(ft^2)	(m^2)	(%)	Min	Median	Mean	Max	%
Wood, painted	6,688,995	621,428	54.2%	<DL	9.0	21	74	94.5%
Concrete	3,025,327	281,062	24.5%	<DL	0.01	0.02	0.11	0.1%
Metal, painted	1,284,610	119,344	10.4%	na	na	na	na	na
Aluminum-Vinyl	1,075,884	99,953	8.7%	0.18	0.32	0.68	1.5	3.4%
Brick	210,896	19,593	1.7%	0.05	0.19	0.39	2.3	2.0%
Metal, unpainted	46,024	4,276	0.37%	na	na	na	na	na
Asbestos	3,950	367	0.03%	nd	nd	nd	nd	nd
Stone	1,808	168	0.01%	nd	nd	nd	nd	nd
Total	**5,648,500**	**1,146,191**		**0.2**	**9.5**	**22**	**78**	

Other Considerations

The trace metals found in wash water from building siding may not be entirely from the siding materials. Some metals may have been deposited on the building surface from local resuspension of road dust and atmospheric deposition (Davis et al., 2001).

Zinc is likely only present in very old paints. Over the last 60 years, paints containing zinc oxide have been replaced with paints containing titanium oxide (CASQA, 2015). Most buildings older than 60 years have been painted multiple times over that period.

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Appendix C. Building Roofing

Overview

The estimated Cu released from building roofing materials are 178 lb/yr. Building roofing contributes 22.3% of the Cu released to the urban CuZn study area annually (Table 1, Figure 3). The estimated Zn released from building roofing materials is 235 lb/yr. This represents 4.0% of the total Zn released to the study area (Table 2, Figure 4).

The metals loading from building roofing materials is calculated as the product of the material surface area and the corresponding literature release rate.

$$Loading_{Roofing}\left(\frac{g}{yr}\right) = Surface\ Area\ (m^2) \times Release\ Rate\ (\frac{g}{m^2 - yr})$$

The total surface area of building roofing in the study area is 17.8 million ft^2 (1.66 million m^2). The method for calculating building roofing surface area is discussed below.

Release rates for different building roofing materials are compiled below.

Roof Area

The exposed surface area of building roofs are calculated from building footprints, roof pitch, and roof complexity. This method is used by professional roofers to estimate roof areas (AAA, 2009).

$$Roof\ Area\ (m^2) = Footprint\ Area\ (m^2) + (Footprint\ Area\ (m^2) \times Slope\ Factor) + (Footprint\ Area\ (m^2) \times Roof\ Complexity\ Factor)$$

Building footprints for buildings constructed before 2003 were provided by the Thurston County Assessor (Thurston, 2016). The footprints of buildings constructed after 2003 were digitized in GIS using aerial imagery (Ecology, 2012; Ecology, 2015). To digitize building footprints in GIS, aerial imagery is displayed and polygons are created that represent the outlines of the buildings shown.

For this study, roofs were separated into low-slope and steep-slope roofs. Low-slope roofs are assumed to have a roof slope of 9.46˚(2:12 pitch). All steep-slope roofs are assumed to have a roof slope of 26.6˚(6:12 pitch). The slope factors for the 2:12 and 6:12 pitch roofs are 101% and 112%, respectively (AAA, 2009).

Roof complexity increases with variability in roof shape. Flat, hipped, gable, mansard, and gambrel roofs are represented in the study area (Figure C-1). Adding gables, dormers, and valleys increases the complexity of any roof type (AAA, 2009).

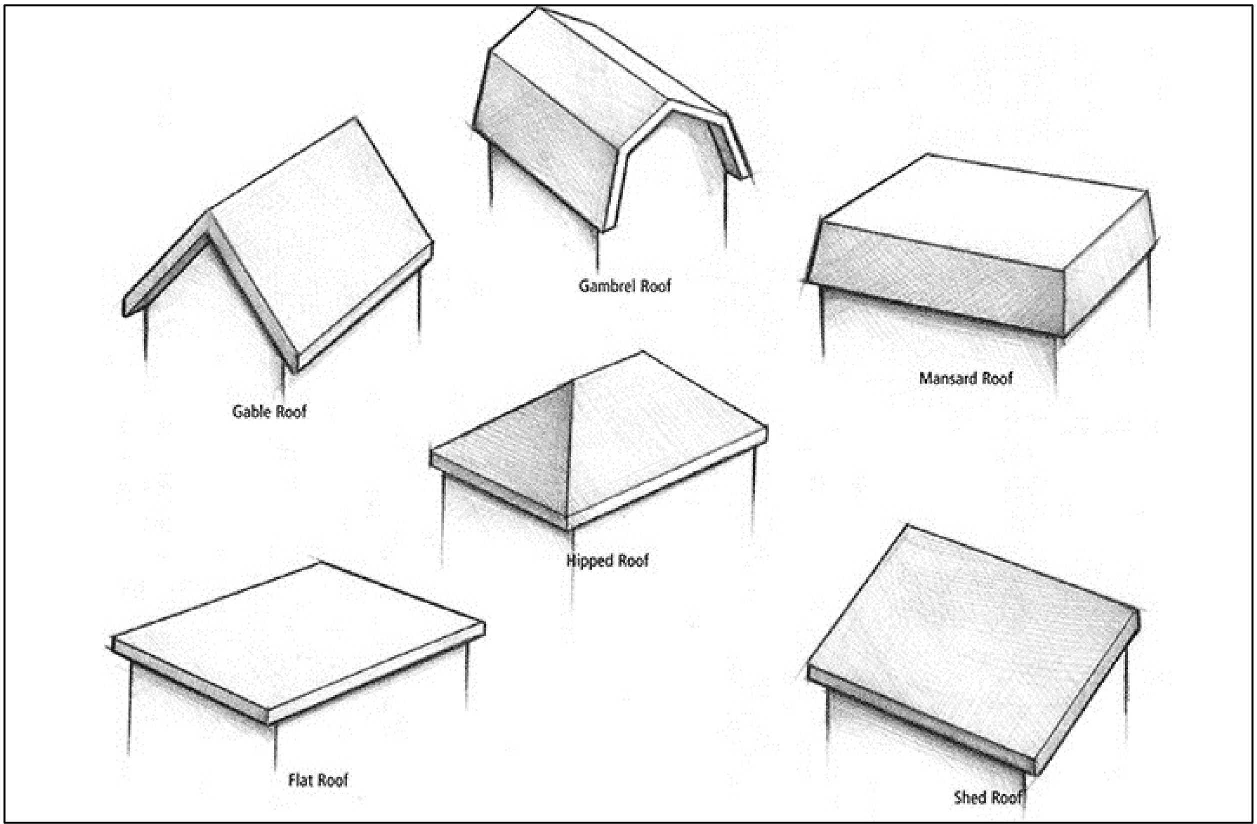

Figure C-1. Simplified examples of roof types (HomeDesigner, 2017)

Table C-1. Roof complexity and slope factors used to calculate roof areas

Roof Type	Complexity Factor	Roof Slope (˚)	Slope Factor
Flat	0%	9.46	101%
Hip		26.6	112%
Gable	10%		
Mansard			
Gambrel	17%		

Examples roof area calculations are shown below.

$$Roof\ Area_{flat}\ (m^2) = 100\ m^2 \times (100\ m^2 \times 1.01)\ \times (100\ m^2 \times 0.00) = 201\ m^2$$

$$Roof\ Area_{gable}\ (m^2) = 100\ m^2 \times (100\ m^2 \times 1.12)\ \times (100\ m^2 \times 0.10) = 222\ m^2$$

$$Roof\ Area_{gambrel}\ (m^2) = 100\ m^2 \times (100\ m^2 \times 1.12)\ \times (100\ m^2 \times 0.17) = 229\ m^2$$

Roofing Material

Residential roofing materials are provided by the Thurston County Assessor (Thurston, 2016). Commercial roofing materials are identified using aerial imagery (Ecology, 2012; Ecology, 2015) applying the guidelines shown in Table C-2.

The Thurston County Assessor roofing classification system was used with a few modifications. Roll-roofing (RR) and tar-gravel (TG) roof types are grouped as built up roofs. Shake (SH) and wood-shingle (WS) roof types are grouped as wood shingle roofs. Commercial roofing materials are not recorded by the Thurston County Assessor. Commercial roofing categories for ethylene propylene diene terpolymer (EPDM) and polyvinyl chloride/thermoplastic polyolefin (PVC/TPO) were added.

Table C-2. Commercial roofing material identifying characteristics.

Roofing Material	Slope	Strip Width (feet)	Color	Seams	Other
Shingle	steep	na	tan, variable	shingles	look for roof with texture
Metal	steep	na	dark, variable	lines	look for lines running perpendicular to roof ridge
Built Up	low	3	dark, splotchy	distinct	sometimes white and granulated; narrow strip width
EPDM	low	na	black	none	rare in the Pacific Northwest
PVC/TPO	low	>5	white	indistinct	heat welded, often leaving no seams

Two categories of roofing material could not be identified by these methods.

- The percent of asphalt shingles containing algae resistant granules.
- The percent of roofs that are thermoplastic polyolefin (TPO) and polyvinyl chloride (PVC) within the white, low-slope roofing materials.

To address the above questions, six local roofing professionals were interviewed. From the roofing interview responses, the following assumptions are used.

- 61% of asphalt shingles installed on steep-slope roofs contain algae-resistant (AR) granules.
  - Older roofs may not follow this assumption. Asphalt shingle with AR have decreased in price and increased in popularity since 2010 (Pioneer, 2017).
  - Asphalt shingles with AR are likely to be used when roofs are replaced.
- 57.5% of white, low-slope roofs are comprised of PVC.
- 42.5% of white, low-slope roofs are comprised of TPO.

The roofing market assumptions above are applied to the surface area of asphalt shingles and white, low-slope roofing materials to determine the surface area of roofs with PVC, TPO, and asphalt shingles with AR.

The surface areas of the various roofing materials installed in the urban CuZn study area are presented in Table C-5.

Release Rates

The building roofing material release rates are compiled from multiple roofing studies (Table C-3). The roofing material release rates used in this study are given in Table C-4.

Winters et al. (2014) measured stormwater runoff from experimental roofing panels constructed in the urban CuZn study area. The release rates determined by Winters et al. (2014) best represent the Cu and Zn leaching from roofing materials in the study area, since the roofing panels were exposed to the same climatic conditions. Climatic differences in rainfall quantity and intensity, wind direction, and atmospheric concentrations of sulfur dioxide and chloride can impact the quantity of Cu and Zn leached from roofing materials (Hedberg et al., 2015; Odnevall-Wallinder and Leygraf, 2017). In addition, Winters et al. (2014) monitored the first year of Cu and Zn release from new roofing panels. Release rates are likely to vary with roof age and material degradation.

Table C-3. Previous studies providing roofing material release rates.

Source	Studies	Summary	References
Wood Shakes (treated)	1	na	Winters et al. (2014)
Asphalt Shingle with AR	2	Average	Barron (2006), Winters et al. (2014)
Asphalt Shingle	2	Average	Barron (2006), Winters et al. (2014)
Painted Galvanized	2	Average	Persson and Kucera (2001), Winters et al. (2014)
PVC	1	na	Winters et al. (2014)
EPDM	1	na	Winters et al. (2014)
Built Up	*	*	Good (1993), Winters and Graunke (2014) – literature review
Clay Tile	*	*	Persson and Kucera (2001), ARC (2003), Winters and Graunke (2014)

*AR = algae resistance, PVC = polyvinyl chloride, EPDM = ethylene propylene diene terpolymer; na = not applicable (only one study); * Release rates for built up and clay tile roofing described in text*

Table C-4. Roofing material release rates.

Source	Copper Release Rate				Zinc Release Rate				Units
	Min	Median	Mean	Max	Min	Median	Mean	Max	
Wood Shakes (treated)	1.50	4.68	6.02	17.9	-0.0251	0.0287	0.0313	0.107	$g/m^2/yr$
Asphalt Shingle with AR	0.016	0.162	0.264	2.186	na	na	na	na	$g/m^2/yr$
Asphalt Shingle	-0.002	0.008	0.013	0.133	na	na	na	na	$g/m^2/yr$
Painted Galvanized	na	na	na	na	0.103	0.269	0.537	1.37	$g/m^2/yr$
TPO	na	na	na	na	na	na	na	na	$g/m^2/yr$
PVC	na	na	na	na	-0.017	0.011	0.016	0.185	$g/m^2/yr$
EPDM	na	na	na	na	0.074	0.383	0.584	2.71	$g/m^2/yr$
Built Up	0.0009	nd	nd	0.166	0.009	nd	nd	1.155	g/m^3
Clay Tile	0.0028	0.0019	nd	0.071	0.006	0.0185	nd	0.85	g/m^3

na = not applicable = no statistically significant quantity of copper or zinc released, nd = no data

Barron (2006) analyzed runoff from roofing panels with asphalt shingles in Palo Alto, California. Persson and Kucera (2001) collected runoff from pilot-scale roofing panels exposed to the environment in Stockholm, Sweden. Good (1993) collected stormwater runoff from sawmill roofing on the coast of Washington State. The Auckland Regional Council conducted a roofing study that sampled runoff from both pilot-scale roofing panels and whole roof systems in New Zealand (ARC, 2003). Winters and Graunke (2014) provide the minimum and maximum concentrations of trace metals from a literature review of roofing material studies.

The minimum and maximum release rates for built up and clay tile roofing materials are compiled from all the studies listed in Table C-3. The median release rates for built up and clay tile roofing materials are the average of the median concentrations reported by the Auckland Regional Council (ARC, 2003).

The release rates used for built up and clay tile roofing materials are roof runoff concentrations converted from ug/L to g/m^3. These release rates are applied to rainfall volumes (m^3) impacting the surface area of built up and clay tile roofs in the urban CuZn study area (see example equations below). The average annual rainfall depth for the study area is 39.49 inch (1.00 meter) (Thurston, 2017).

$$Release\ Rate_{ClayTile}\ \left(\frac{g}{m^3}\right) = Concentration_{ClayTile}\ \left(\frac{ug}{L}\right) \times \frac{1000\ L}{1\ m^3} \times \frac{1\ g}{1x10^6\ ug}$$

$$Rainfall\ Volume_{ClayTile}\ \left(\frac{m^3}{yr}\right) = Surface\ Area\ _{ClayTile}(m^2) \times Rainfall\ Depth\ \left(\frac{m}{yr}\right)$$

$$Loading_{ClayTile}\ \left(\frac{g}{yr}\right) = Rainfall\ Volume_{ClayTile}\ \left(\frac{m^3}{yr}\right) \times Release\ Rate_{ClayTile}\ \left(\frac{g}{m^3}\right)$$

Zinc Loading

The surface area of roofing materials and the estimated Zn released from each material are shown in Table C-5. The roofing materials that contribute the most Zn are metal (173 lb/yr), EPDM (48 lb/yr), and PVC (14 lb/yr).

Copper Loading

The estimated Cu released from roofing materials are shown in Table C-6. The roofing materials that contribute the most Cu are asphalt shingles with algae resistance (147 lb/yr), wood shingles (20 lb/yr), and asphalt shingles without algae resistance (12 lb/yr).

Table C-5. Potential zinc loading from roofing materials.

Roof Material	Roof Area			Zinc Loading (lb/yr)				
	(ft^2)	(m^2)	(%)	Min	Median	Mean	Max	%
Asphalt Shingle	4,245,611	394,430	23.8%	na	na	na	na	na
PVC	4,206,162	390,765	23.6%	-15	10	14	159	5.56%
TPO	3,108,902	288,826	17.4%	nd	nd	nd	nd	nd
Asphalt Shingle with AR	2,714,407	252,177	15.2%	na	na	na	na	na
Metal	2,381,423	221,241	13.3%	50	131	173	669	76.0%
Built Up	729,343	67,758	4.1%	5.7	nd	nd	735	nd
EPDM	403,054	37,445	2.3%	6.1	32	48	224	18.3%
Clay Tile	41,499	3,855	0.2%	0.051	0.16	nd	7.2	0.09%
Wood Shingle	16,043	1,490	0.1%	-0.08	0.09	0.10	0.35	0.05%
Asbestos Shingle	2,504	233	0.01%	na	na	na	na	na
Total	**17,848,948**	**1,658,222**		**47**	**173**	**235**	**1795**	

AR = algae-resistance, PVC = polyvinyl chloride, TPO = thermoplastic polyolefin,
EPDM = ethylene propylene diene terpolymer; na = not applicable, nd = no data

Table C-6. Potential copper loading from roofing materials.

Roof Material	Roof Area			Copper Loading (lb/yr)				
	(ft^2)	(m^2)	(%)	Min	Median	Mean	Max	%
Asphalt Shingle	4,245,611	394,430	23.8%	-1.6	6.6	12	116	5.89%
PVC	4,206,162	390,765	23.6%	na	na	na	na	na
TPO	3,108,902	288,826	17.4%	nd	nd	nd	nd	nd
Asphalt Shingle with AR	2,714,407	252,177	15.2%	8.6	90	147	1215	80.4%
Metal	2,381,423	221,241	13.3%	na	na	na	na	na
Built Up	729,343	67,758	4.1%	0.57	nd	nd	106	nd
EPDM	403,054	37,445	2.3%	na	na	na	na	na
Clay Tile	41,499	3,855	0.2%	0.024	0.016	nd	0.60	0.01%
Wood Shingle	16,043	1,490	0.1%	4.9	15	20	59	13.7%
Asbestos Shingle	2,504	233	0.01%	na	na	na	na	na
Total	**17,848,948**	**1,658,222**		**12.5**	**112**	**178**	**1496**	

AR = algae-resistance, PVC = polyvinyl chloride, TPO = thermoplastic polyolefin,
EPDM = ethylene propylene diene terpolymer; na = not applicable, nd = no data

Other Considerations

There are some negative minimum loading values (Tables C-5 and C-6). These values are the result of slightly negative release rates from Winters et al. (2014). Negative release rates indicate more Cu or Zn contribution from atmospheric deposition than from roofing material leaching.

Winters et al. (2014) deployed glass roofing panels as an experimental control. The release rates reported from the roofing panels in their study are calculated using the difference in metals concentrations between the roofing material panels and the control panel.

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Appendix D. Herbicides and Fungicides

Overview

The estimated Zn loading from the use of moss control products is 2,527 lb/yr. That is 43.1% of the total Zn release estimate for the urban CuZn study area (Table 2, Figure 4). The estimated Cu loading from fungicide use is 0.021 lb/yr. This represents 0.003% of the total Cu release estimated for the study area (Table 1, Figure 3).

The information available regarding pesticide, herbicide, and fungicide use for non-agricultural purposes is limited. The estimates made for the use of moss control and fungicide products incorporate (1) one shelf survey at a home improvement megastore and (2) the moss control manufacturer-recommended application frequency and quantity.

Agricultural land use accounts for only 1.8% of the study area. The contribution of Cu and Zn related to agricultural use is not estimated.

Previous Studies

The *Puget Sound Toxics Loading Assessment* (PSTLA) reported that the largest source of Cu to Puget Sound may be the use of lawn and garden herbicides and fungicides (Norton et al., 2011). However, the estimate of the quantity of Cu released from herbicide and fungicide use is variable and uncertain (Roberts et al., 2011).

McLain (2014) performed a follow-up study surveying Washington residences and businesses about their use of copper-containing pesticides and herbicides. She reports that Cu use has declined over the last 10-20 years and is now used minimally. Zinc herbicides are used but account for a small portion of herbicides on the market. The majority of herbicides currently on the market are emerging pesticides using organic active ingredients (McLain, 2014).

Store Surveys

The fiscal sales data for Cu and Zn containing products were provided by one home improvement megastore and two farm and garden stores located near the CuZn study area (Table D-1). Sales data for Cu and Zn products sold by local feed stores are not available.

Fungicide products using Cu octanoate as the active ingredient are typically sold in liquid form and contain 0.017% Cu. The mass of Cu present in liquid fungicides is determined using the specific gravity of 1.1 for a Cu octanoate-containing fungicide (Bonide, 2005) and the density of water (1000 kg/m^3 or 1.0 g/mL) to calculate a density for the fungicide.

$$Density_{water}\ \left(\frac{g}{mL}\right) = 1000\ \frac{kg}{m^3} \times \frac{1000\ g}{1\ kg} \times \frac{1\ m^3}{1000\ L} \times \frac{1\ L}{1000\ mL} = 1.0\frac{g}{mL}$$

$$Density_{fungicide} = Specific\ Gravity_{fungicide} \times Density_{water}\ \left(\frac{g}{mL}\right) = 1.1\ \frac{g}{mL}$$

$$Fungicide\ (g) = Fungicide\ (mL) \times\ Density_{fungicide} = Fungicide\ (mL) \times 1.1\,\frac{g}{mL}$$

Fungicides using Cu sulfate as the active ingredient are typically sold in bulk as a powder and contain 53% Cu. Moss control products using Zn sulfate as the active ingredient are typically sold as a powder and contain 36% Zn.

It is difficult to estimate which stores residents and business owners in the study area purchase these products from. One home improvement store is located in the study area. The sales data from one home improvement store are used to estimate fungicide use by the study area residents.

Table D-1. Copper and zinc products sold in fiscal year 2016.

Store	Category	Product Quantity	Copper Content	Zinc Content	mL / kg	Units Sold	Copper (lb/yr)	Zinc (lb/yr)
Hardware	Fungicide	946	0.16	na	mL	40	0.016	na
Hardware	Fungicide	709	0.12	na	mL	17	0.0050	na
Hardware	Moss Control	1.3	na	0.47	kg	3697	na	1730
Hardware	Moss Control	2.7	na	0.97	kg	862	na	838
Hardware	Moss Control	2.3	na	0.82	kg	74	na	60
Farm/Garden	Moss Control	227	na	81.65	kg	bulk	na	82
Farm/Garden	Fungicide	22.7	12.02	na	kg	bulk	12	na
Farm/Garden	Moss Control	22.7	na	8.16	kg	166	na	1355
Farm/Garden	Moss Control	1.3	na	0.47	kg	10	na	4.68
Total							**12**	**4070**

Hardware = home improvement megastore; na = not applicable (does not contain copper or zinc)

Roofing Professional Interviews

Six roofing professionals were interviewed for this study (Appendix C). Three of these professionals estimated the number of houses treated with moss control products by their company each year (Table D-2). One roofing professional estimated that on average 25 pounds of Zn sulfate are applied to each household treated. These moss control estimates are used to calculate the quantity of Zn applied to roofs by three local roofing companies (Table D-2). There are more than three roofing companies that service the urban CuZn study area.

Table D-2. Roofing company application of zinc sulfate for moss control

Company	Households per year	Quantity per Household (lb)	Zinc Sulfate (lb/yr)	Zinc (lb/yr)
Roof #1	200	25	5000	1800
Roof #2	60	nd	1500	540
Roof #3	60	nd	1500	540
Total			**8000**	**2880**

Zinc sulfate contains 36% zinc; nd = no data

Copper Loading

The estimated quantity of Cu released in the urban CuZn study area due to fungicide use is 0.021 lb/yr. This is the quantity of Cu sold by the home improvement megastore surveyed (Table D-1). One home improvement store is located in the study area. Residents may go outside the study area to purchase fungicide products. For this study, it is assumed that residents shopped at the store located closest to their home.

The majority of fungicides currently on the market use organic compounds, not Cu (McLain, 2016). This was confirmed by the shelf survey.

Zinc Loading

The estimated average quantity of Zn released by the use of moss control products is 2,527 lb/yr. The estimate of Zn loading from moss control products ranges from 1,264 to 6,318 lb/yr (Table D-5). This estimate is calculated using the moss control manufacturer-recommended frequency of treatment and quantity applied per roof area.

The average release rate for moss control products containing Zn sulfate is 1.76 g/m^2/yr (Table D-3). The recommended frequency of moss control products is every two years (OSU, 2017). Three products sold by the local home improvement store recommend identical application rates of 0.001 lb/ft^2 (4.88 g/m^2). Researchers at Oregon State University cite a maximum application rate of 0.005 lb/ft^2 (24.4 g/m^2) (OSU, 2017). The minimum, mean, and maximum Zn release rates calculated from these four recommended application rates are provided in Table D-4. Not enough data are available to calculate a median release rate. The quantity of Zn released due to application of moss control products is shown in Table D-5.

Table D-3. Recommended application rates of zinc sulfate for moss control.

Reference	Zinc Sulfate ($ZnSO_4$)			Zinc (g/m^2)	Zinc Release Rate (g/m^2/yr)
	Rate (g/m^2)	Frequency (yr)	Zinc (%)		
Product #1	4.88	2	36%	1.76	0.88
Product #2	4.88			1.76	0.88
Product #3	4.88			1.76	0.88
OSU	24.4			8.79	4.39
Mean	9.76			3.52	**1.76**

OSU = Oregon State University Bryophyte Science (OSU, 2017)

Table D-4. Zinc release rates for zinc sulfate moss control products.

Zinc Release Rate				Units
Min	Median	Mean	Max	
0.88	nd	1.76	4.39	g/m^2/yr

The total surface area of roofs that may be treated for moss in the urban CuZn study area is 7.02 million ft^2 (652,185 m^2). The building roofs included in the calculation of moss control product application are steep-sloped and have one of the following roofing materials installed: asbestos shingle, asphalt shingle (with and without algae-resistance), clay tile, or wood shingle (Table D-5). These are the roofing materials that typically require moss control treatment. The surface area of various roof materials in the study area are calculated in Appendix B.

The moss control product industry is moving toward use of iron compounds (e.g., iron phosphate) instead of Zn sulfate (McLain, 2016).

Table D-5. Potential zinc loading from moss control products.

Roof Material	**Roof Area**			**Zinc Loading (lb/yr)**				
	(ft^2)	**(m^2)**	**(%)**	**Min**	**Median**	**Mean**	**Max**	**%**
Asphalt Shingle	4,245,611	394,430	23.8%	764	nd	1528	3821	60.5%
Asphalt Shingle with AR	2,714,407	252,177	15.2%	489	nd	977	2443	0.39
Clay Tile	41,499	3,855	0.2%	7.5	nd	14.9	37.3	0.01
Wood Shingle	16,043	1,490	0.1%	2.9	nd	5.8	14.4	0.00
Asbestos Shingle	2,504	233	0.01%	0.45	nd	0.90	2.25	0.00
Total	**7,020,064**	**652,185**		**1264**		**2527**	**6318**	

AR = algae resistance, nd = no data

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Appendix E. Vehicle Tire and Brake Wear

Overview

The estimated Zn loading from vehicle tire and brake wear is 862 lb/yr. That is 14.7% of the total Zn release estimate for the urban CuZn study area (Table 2, Figure 4). The estimated Cu loading from vehicle brake wear is 469 lb/yr. This represents 58.8% of the total Cu release estimated for the study area (Table 1, Figure 3).

The loading from vehicle wear is calculated as the product of the vehicle component release rate and the average annual kilometers traveled.

$$Loading_{Vehicle}\left(\frac{g}{yr}\right) = Release\ Rate\left(\frac{g}{km-vehicle}\right) \times Vehicle\ Kilometers\ Traveled\left(\frac{km}{yr}\right)$$

The release rates are compiled from literature values for the metals content and wear rates of vehicle tires and brakes. Current information on the Cu and Zn content of vehicle brakes is provided by brake manufacturers via the Better Brakes Rule (Ecology, 2017).

The vehicle kilometers traveled in the study area are collected using traffic counts for major roadways and are calculated for minor roadways.

Release Rates

The Cu and Zn release rates for vehicle tire and brake wear are compiled from various studies (Table E-1). They are separated into vehicle classes (motorcycle, passenger car, light duty vehicles, and heavy duty vehicles) to account for the variations in vehicle wear for vehicles with different weights and number of tires. Vehicle wear release rates are reported in quantity of metal per vehicle kilometer traveled (mg/vehicle/km).

Table E-1. Vehicle brake and tire wear release rates (mg/vehicle/km)

Category	**Source**	**Copper Release Rate**				**Zinc Release Rate**			
		Min	**Median**	**Mean**	**Max**	**Min**	**Median**	**Mean**	**Max**
Brakes	Motorcycles	0.145	nd	0.248	0.330	0.037	nd	0.062	0.083
	Passenger Cars	0.290	nd	0.495	0.660	0.073	nd	0.125	0.166
	Light Duty Vehicles	0.581	nd	0.77	0.96	0.146	nd	0.194	0.241
	Heavy Duty Vehicles (disc)	1.55	nd	2.16	2.77	0.390	nd	0.543	0.697
	Heavy Duty Vehicles (drum)	0.125	nd	0.173	0.223	0.102	nd	0.143	0.183
Tires	Motorcycles	na	na	na	na	0.252	nd	0.276	0.318
	Passenger Cars	na	na	na	na	0.402	nd	0.642	0.972
	Light Duty Vehicles	na	na	na	na	0.528	nd	1.01	1.30
	Heavy Duty Vehicles	na	na	na	na	1.36	nd	2.70	5.39

nd = no data, na = not applicable (copper or zinc not present)

Vehicle brake release rates are derived from the metals content of brakes and the brake wear rates determined in previous studies. As of January 2017, the average Cu and Zn content of all brake friction materials certified in Washington State is 3.30% Cu and 0.83% Zn. Brake pad Cu and Zn concentrations are rapidly declining due to brake manufacturer compliance with the Better Brakes Rule (Ecology, 2017).

The brake certification data provided under the Better Brakes Rule are for the latest manufactured brake pads. It will take time for the currently installed brakes to be replaced. The release rates used in this study approximate a scenario where all disc brakes are certified as low Cu brakes.

The majority of passenger and light duty vehicles (LDV) use disc brakes. Approximately 95% of heavy duty vehicles (HDV) use drum brakes. Drum brakes maintain lower temperatures and thus contain low concentrations of Cu and Zn. The drum brakes used in the majority of HDV contain 0.27% Cu and 0.22% Zn (Wesley and Whiley, 2013). For this study, HDV are separated into vehicles using drum and disc brakes. The release rates for brakes from each category of HDV are applied accordingly (Table E-1).

The brake wear rates used for this study were compiled from various studies and reported by Ntziachristos and Boulter (2003). The wear rates are reported in mg/vehicle/km and multiplied by the current concentration of Cu and Zn in brake pads to obtain the vehicle brake release rates (Table E-1). The wear rate of motorcycles brakes has not been studied. Ntziachristos and Boulter (2003) estimate the wear rate for motorcycles to be half the wear rate of passenger cars.

$$\mathrm{Release}_{\mathrm{Brakes}}\left(\frac{\mathrm{g\ Cu}}{\mathrm{km}}\right) = \mathrm{Brake\ Wear}\left(\frac{\mathrm{g}}{\mathrm{km-vehicle}}\right) \times \mathrm{Brake\ Copper\ (\%)}$$

$$\mathrm{Release}_{\mathrm{Brakes}}\left(\frac{\mathrm{g\ Zn}}{\mathrm{km}}\right) = \mathrm{Brake\ Wear}\left(\frac{\mathrm{g}}{\mathrm{km-vehicle}}\right) \times \mathrm{Brake\ Zinc\ (\%)}$$

The Zn release rates for vehicle tires are calculated from the Zn content of vehicle tires and the literature wear rates of tires. The concentration of Zn in vehicle tires vary by manufacturer and tire type. The average Zn content of tires from multiple studies is 1.0% (Ntziachristos and Boulter, 2003). The tire wear rates for different classes of vehicles are summarized by Ntziachristos and Boulter (2003). The average Zn content and range of tire wear rates are used to calculate the Zn release rate of vehicle tires (Table E-1).

$$\mathrm{Release}_{\mathrm{Tires}}\left(\frac{\mathrm{g\ Zn}}{\mathrm{km}}\right) = \mathrm{Tire\ Wear}\left(\frac{\mathrm{g}}{\mathrm{km-vehicle}}\right) \times \mathrm{Tire\ Zinc\ (\%)}$$

There is not a significant quantity of Cu in vehicle tires.

Vehicle Classes

The Washington State Department of Transportation (WSDOT) annually reports state-wide travel activity by vehicle type. The 2016 data are shown in Table E-2 (WSDOT, 2017).

For this urban CuZn study, WSDOT vehicle types are simplified to match the vehicle classes used in the vehicle wear literature. The vehicle classes used here are:

- Motorcycle
- Passenger car: cars and pickup trucks
- Light duty vehicle (LDV): buses and single unit trucks
- Heavy duty vehicle (HDV): combination trucks, with drum brakes or disc brakes

The 2016 Washington travel activity by vehicle type data are summarized into these vehicle classes (Table E-3).

For brake wear calculations, the HDV traffic volumes are separated into vehicles with disc and drum brakes. Wesley and Whiley (2013) estimate that 95% of HDV use drum and 5% of HDV use disc brakes. This estimate is used to separate the total HDV traffic volumes.

Table E-2. Washington DOT travel activity by vehicle type (2016)

Functional Class	Motorcycles	Cars	Pickup Trucks	Buses	Single Unit Trucks	Combination Trucks
Rural Interstate	0.20%	58.06%	27.12%	0.36%	3.00%	11.27%
Rural Other Arterial	0.42%	54.89%	33.96%	0.30%	4.07%	6.36%
Other Rural	0.99%	54.70%	36.40%	0.27%	4.77%	2.87%
Urban Interstate	0.21%	66.25%	25.68%	0.34%	2.38%	5.15%
Urban Other Arterial	0.29%	61.19%	31.59%	0.29%	3.85%	2.80%
Other Urban	0.33%	56.91%	35.65%	0.24%	4.37%	2.49%
Statewide	**0.26%**	**63.22%**	**27.82%**	**0.31%**	**2.94%**	**5.45%**

Table E-3. Washington travel activity by simplified vehicle class (2016)

Motorcycle	Passenger	Light Duty	Heavy Duty (disc)	Heavy Duty (drum)
0.26%	91.0%	3.25%	0.27%	5.18%

Traffic Volumes

The total annual vehicle traffic in the urban CuZn study area is 274 million miles (440 million kilometers). The traffic volume for the study area is a combination of measured and estimated traffic volumes. The total traffic volume is separated into the simplified vehicle classes (Table E-4).

Table E-4. Average annual vehicle kilometers traveled in the CuZn study area

Vehicle Class	Travel Activity	Traffic Volume (km)
Motorcycle	0.26%	1,128,635
Passenger Car	91.0%	401,362,052
Light Duty	3.25%	14,337,193
Heavy Duty (Disc)	0.27%	1,202,261
Heavy Duty (Drum)	5.18%	22,842,958
Total		**440,873,099**

The average annual daily traffic (AADT) volumes in the study area are measured via traffic counts for major roadways. The AADT is calculated for major roadways with outdated traffic data and minor roadways where no traffic count data have been collected. The traffic volume data and calculations are discussed in more detail below.

Traffic Volume Data

The 2015 traffic volumes measured at milepost 110 on Interstate 5 are used for the 6.8 kilometers of freeway passing through the center of the CuZn study area (WSDOT, 2015). The latest available traffic count data are used for major arterial and collector roadways where available (Lacey, 2015).

For major roadways with traffic count data collected before 2013, a correction factor of 15% is applied to update the traffic volumes. This correction factor is the average difference between old and new traffic counts for 18 roadway sections in the study area (Table E-5).

$$\mathrm{AADT_{update}}\left(\frac{\mathrm{miles}}{\mathrm{day}}\right)=\mathrm{AADT_{<2013}}\left(\frac{\mathrm{miles}}{\mathrm{day}}\right)+\left(0.15\times \mathrm{AADT_{<2013}}\left(\frac{\mathrm{miles}}{\mathrm{day}}\right)\right)$$

Table E-5. Comparison of traffic count data in the urban CuZn study area

Location	**Average Annual Daily Traffic (miles)**			
	2013-2015	**pre-2013**	**Diff**	**%Diff**
College St south of Martin Way	31500	30130	1371	4.4%
Martin west of I-5	47000	38930	8070	17.2%
Martin Way west of Desmond Dr	35000	25784	9216	26.3%
Martin Way west of Carpenter Rd	27500	25784	1716	6.2%
Martin Way east of Carpenter Rd	25000	24159	841	3.4%
Martin Way west of Marvin Rd	27500	23789	3711	13.5%
Martin Way east of Marvin Rd	20000	16815	3185	15.9%
Carpenter Rd south of Martin Way	16500	10192	6308	38.2%
Carpenter Rd north of Martin Way	6500	5503	997	15.3%
Carpenter Rd north of I-5	5000	4624	376	7.5%
Marvin Rd north of Martin Way	26000	30872	-4872	-18.7%
Galaxy Dr	11500	10643	857	7.5%
Martin Way west of Meridian Rd	16000	15522	478	3.0%
Meridian Rd north of Martin Way	10000	7124	2876	28.8%
Marvin Rd north of I-5	30000	24788	5212	17.4%
Marvin Rd north of Hawks Prairie Rd	8500	6481	2019	23.8%
Hawks Prairie Rd west of Marvin Rd	5500	3969	1531	27.8%
31st east of Marvin Rd	4000	3000	1000	25.0%
Mean			**2494**	**14.6%**
Median			**1624**	**15.6%**

Diff = difference, %Diff = percent difference

The traffic volumes for minor roadways, where traffic counts have not been performed, are calculated as the product of the road length and the number of vehicles daily travelling that roadway. The number of vehicles travelling any given roadway is estimated using a few different methods.

$$\text{Traffic Volume}\left(\frac{\text{vehicle}-\text{km}}{\text{day}}\right)=\text{Road Length (km)}\times\text{AADT}\left(\frac{\text{vehicles}}{\text{day}}\right)$$

Traffic Volume – Household Method

Residential traffic volumes are calculated using the latest commuter trends and the number of households per roadway. Surveys of United States commuters found that the on average single-family households own two vehicles and apartment renters own one vehicle (NMHC, 2016; Santos et al., 2011). Residents are likely to leave and return to their homes at least once per day. To calculate the minimum trips travelled per road section, the number of households is multiplied by the number of vehicles per household and the trips per vehicle per day.

$$\text{AADT}_{\text{H,house}}\left(\frac{\text{vehicles}}{\text{day}}\right)=\text{Households}\times 2\ \frac{\text{Vehicles}}{\text{household}}\times 2\ \frac{\text{trips}}{\text{day}}$$

$$\text{AADT}_{\text{H,apartment}}\left(\frac{\text{vehicles}}{\text{day}}\right)=\text{Households}\times 1\ \frac{\text{Vehicles}}{\text{household}}\times 2\ \frac{\text{trips}}{\text{day}}$$

The number of single-family and condominium households per road section are counted using aerial imagery (BingMaps, 2017; Ecology, 2012; GoogleMaps, 2017). The number of apartment housing units are counted using aerial imagery or collected from apartment complex websites.

The 2010 census household data are used for a few road sections. Census households are grouped into census blocks (Ecology, 2010). Census blocks may be accessed by multiple roads, so it can be difficult to determine which households use each roadway. When a census block is accessed entirely by one roadway, then the number of housing units in that census block can be used to determine the number of households using that road.

Traffic Volume – Business Method

Traffic volumes for businesses are estimated by counting the number of vehicles parked at businesses using historical satellite imagery and extrapolating to an average daily traffic volume. Ten years of historical satellite imagery (Google, 2015) for businesses in the CuZn study area are used to perform the parking lot vehicle counts. Vehicle counts are collected on days when the satellite image resolution is adequate to count individuals vehicles. For the 79 businesses evaluated, the average number of satellite images (2006-2016) with adequate resolution is 11.

The vehicle counts are compiled by day of the week and summarized as a weighted daily average traffic volume. One satellite image is a snap shot of business traffic. It is assumed that each satellite image represents an hour of traffic. This hourly traffic volume is converted to daily traffic using the typical hours of business for each business type (Table E-6). If a business type has only employee traffic, the hours for that business are set to one. The daily traffic volume is converted to an average daily traffic volume by calculating a weekly weighted average traffic volume for all the business traffic counts.

$$\text{Traffic}_{\,hourly}\left(\frac{\text{vehicles}}{\text{hour}}\right)=\text{vehicles in parking lot (from satellite imagery)}$$

$$\text{Traffic}_{\,daily}\left(\frac{\text{vehicles}}{\text{day}}\right)=\text{Traffic}_{\,hourly}\left(\frac{\text{vehicles}}{\text{hour}}\right)\times\frac{Business\ hours}{day}\times Trips$$

$$\text{AADT}_{Business}\left(\frac{\text{vehicles}}{\text{day}}\right)=\frac{\left(\text{Traffic}_{\,weekdayaverage}\left(\frac{\text{vehicles}}{\text{day}}\right)\times 5\text{ days}\right)+\left(\text{Traffic}_{\,weekendaverage}\left(\frac{\text{vehicles}}{\text{day}}\right)\times 2\text{ days}\right)}{\text{7 days in the week}}$$

Table E-6. Daily business hours and vehicle trips

Business Type	Hours Open	Daily Trips
Retail	12	2
Service	8	2
Manufacturing	1	3
Industry	1	3

The business method likely underestimates the total traffic volume for a business. Satellite image snap shots represent only one moment in time and do not represent all the variability in daily business traffic volumes.

Traffic Volume – School Method

The traffic volumes for schools in the CuZn study area are calculated using school demographic and bus ridership data. The school populations, bus fleet, and bus ridership data were provided by the North Thurston School District (NorthThurston, 2017) and are shown in Table E-7.

The daily traffic at a school is calculated as the sum of personal vehicles and buses traveling to the school daily. The number of personal vehicles used to transport students is calculated by subtracting the students riding on buses from the total student population. The total personal vehicle use is calculated by adding the student personal vehicles to the staff population. The daily school traffic is the sum of the total number of buses and personal vehicles multiplied by two trips per day. This method assumes that no students or staff are ridesharing (i.e., carpooling) and that no one leaves the school campus for lunch or other trips.

Table E-7. School populations, bus fleets, bus ridership, and daily traffic volume estimates (2016)

School	**Population**		**Buses**	**Students on Buses**	**Personal Vehicles**			**Total Vehicles**	**AADT (vehicles/day)**
	Students	**Staff**			**Students**	**Staff**	**Total**		
Olympic View Elementary	523	59	14	335	188	59	494	508	**363**
Salish Middle School	692	67	32	565	127	67	388	420	**300**
River Ridge High School	1203	116	38	674	529	116	1290	1328	**949**

AADT: average annual daily traffic

The daily traffic volume is converted to an average daily traffic volume by calculating a weekly weighted average.

$$\text{Personal Vehicles} = (\text{Student Population} - \text{Students on Buses}) + \text{Staff Population}$$

$$\text{Traffic}_{\text{School}}\left(\frac{\text{vehicles}}{\text{day}}\right) = (\text{Buses} + \text{Personal Vehicles}) \times 2\ \frac{\text{trips}}{\text{day}}$$

$$\text{AADT}_{\text{School}}\left(\frac{\text{vehicles}}{\text{day}}\right) = \frac{\left(\text{Traffic}_{\text{School}}\left(\frac{\text{vehicles}}{\text{day}}\right) \times 5\ \text{weekdays}\right)}{7\ \text{days in the week}}$$

Traffic Volume – Estimation Method

In some situations, traffic volumes from a neighborhood or business are uncertain. It is difficult to know which road drivers may take to exit a business or enter their neighborhood. In these situations, total traffic volumes are calculated and split among the various routes using local knowledge to educate the split. This method is used only when no other traffic data are available.

For example, a grocery store may have three parking lot exits. The first exits into a small neighborhood. The second exits onto a major arterial road, but a driver can only turn right. The third exit enters onto a two-way road with a traffic-light controlled intersection allowing drivers to turn either direction onto the major arterial. The estimated split of traffic leaving this grocery store is 5% by Exit #1, 25% by Exit #2, and 70% by Exit #3 (Figure E-1).

Figure E-1. Traffic estimation example (GoogleMaps, 2017)

Traffic Volume – Method Overview

The majority of traffic volume data (96.2%) in the CuZn study area is from up-to-date traffic count data (Lacey, 2015; WSDOT, 2015). The traffic volumes for minor roadways and streets with outdated traffic count data are calculated and estimated using the above traffic volume methods (Table E-8).

The combination method listed in Table E-8 denotes sections of roadway where traffic volumes are a combination of two or more traffic volume methods (e.g., household, school, and business). The school method is primarily used in combination with other traffic volume methods. Only one road section accessing River Ridge High School uses traffic volume solely from the school method.

The estimation method results are often combined with other traffic volume methods (e.g., business estimate, school estimate). These traffic volumes are listed with the estimation results in Table E-8.

Table E-8. Traffic volume summary by method.

Method	Road Length	AADT	Traffic Volume	
	(km)	(km/day)	(km/yr)	(%)
2015 Traffic Counts	48.7	1,017,400	424,036,775	96.2%
Updated Traffic Counts	5.3	21,300	7,610,774	1.7%
Estimation	10.8	54,310	6,071,198	1.4%
Household	37.3	52,207	2,180,450	0.49%
Business	2.3	9,747	502,465	0.11%
Combination	1.4	11,496	449,486	0.10%
School	0.1	949	21,951	0.005%
Total	**105.8**	**1,167,409**	**440,873,099**	

AADT = average annual daily traffic

Copper Loading

The estimated quantity of Cu released in the CuZn study area due to vehicle brake wear is 469 lb/yr. The Cu loading from brake wear ranges from 280 to 623 lb/yr. The majority of Cu (93%) is from passenger car brake wear (Table E-9).

Table E-9. Potential copper loading from vehicle brake wear.

Vehicle Type	Vehicle (km/yr)	Copper Loading (lb/yr)				
		Min	Median	Mean	Max	%
Passenger Cars	401,362,052	257	nd	438	584	93.3%
Heavy Duty (drum)	22,842,958	0.33	nd	0.46	0.59	0.10%
Light Duty	14,337,193	18	nd	24	30	5.2%
Heavy Duty (disc)	1,202,261	4.1	nd	5.7	7.3	1.2%
Motorcycle	1,128,635	0.36	nd	0.62	0.82	0.13%
All	**440,873,099**	**280**	**nd**	**469**	**623**	

nd = no data

Zinc Loading

The Zn estimated to be released in the study area from vehicle tire and brake wear is 862 lb/yr. Tire wear represents 744 lb/yr (86%) and brake wear contributes 118 lb/yr (14%). The estimated Zn loading from brake wear ranges from 70 to 157 lb/yr. The potential Zn loading from brake wear is contributed primarily by passenger cars (Table E-10). The estimate of Zn loading from tire wear ranges from 445 to 1188 lb/yr. The majority of potential Zn loading from tire wear is due to passenger cars and HDV (Table E-11).

Table E-10. Potential zinc loading from vehicle brake wear.

Vehicle Type	Vehicle (km/yr)	Zinc Loading (lb/yr)				
		Min	Median	Mean	Max	%
Passenger Cars	401,362,052	65	nd	110	147	93.1%
Heavy Duty (drum)	22,842,958	0.27	nd	0.38	0.49	0.32%
Light Duty	14,337,193	5	nd	6	8	5.2%
Heavy Duty (disc)	1,202,261	1.0	nd	1.4	1.8	1.2%
Motorcycle	1,128,635	0.09	nd	0.15	0.21	0.13%
All	**440,873,099**	**70.6**	**nd**	**118**	**157**	

nd = no data

Table E-11. Potential zinc loading from vehicle tire wear.

Vehicle Type	Vehicle (km/yr)	Tire Zinc Loading (lb/yr)				
		Min	Median	Mean	Max	%
Passenger Cars	401,362,052	356	nd	568	860	76.4%
Heavy Duty	24,045,219	72.2	nd	143.1	285.6	19.2%
Light Duty	14,337,193	17	nd	32	41	4.3%
Motorcycle	1,128,635	0.63	nd	0.69	0.79	0.09%
All	**440,873,099**	**445**	**nd**	**744**	**1188**	

nd = no data

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Appendix F. Chain-Link Fence

Overview

The average estimated Zn loading from chain-link fencing is 242 lb/yr. That is 4.1% of the total Zn release estimate for the urban CuZn study area (Table 2, Figure 4).

The potential Zn loading from chain-link fencing is calculated for painted and unpainted fencing.

$$Loading_{Chainlink1}\left(\frac{g}{yr}\right) = Chainlink\ Area_{painted}\ (m^2) \times Release\ Rate_{paintedmetal}\ (\frac{g\ Zn}{m^2 - yr})$$

$$Loading_{Chainlink2}\left(\frac{g}{yr}\right) = Chainlink\ Area_{galvanized}\ (m^2) \times Release\ Rate_{galvanized}\ (\frac{g\ Zn}{m^2 - yr})$$

The release rates and surface area calculations for chain-link fencing are discussed below.

Release Rates

The release rates for painted and galvanized steel are used to calculate the quantity of Zn leached from chain-link fences in the study area (Table F-1).

Table F-1. Release rates for painted and galvanized steel

Source	Zinc Release Rate (g/m^2/yr)			
	min	median	mean	max
Painted Metal	0.10	0.27	0.54	1.37
Galvanized Steel	0.73	2.24	2.0	2.74

The release rate for painted metal is a combination of release rates reported in two experimental roofing panel studies (Persson and Kucera, 2001; Winters et al., 2014). The minimum, maximum, and median release rates were determined from Winters et al. (2014). The mean release rate is the average of the mean release rates reported in both studies.

The release rate for galvanized steel is a statistical summary of release rates reported by multiple studies (Bertling, 2005; Legret and Pagotto, 1999; Persson and Kucera, 2001; Taylor Associates, 2004). The minimum and maximum release rates for galvanized steel is the minimum and maximum across all four studies (Table F-1). The median release rate for galvanized steel is the median of all mean values reported (n = 4). The mean release rate for galvanized steel is the average of all mean values reported (n = 4). This method results in a median release rate slightly greater than the mean release rate.

Persson and Kucera (2001) and Bertling (2005) collected runoff from small scale roofing panels exposed to the environment of Stockholm, Sweden. They reported release rates in mg/m^2/yr, which are converted to g/m^2/yr for use in this urban CuZn study. Winters et al. (2014) measured stormwater runoff from experimental roofing panels in the study area. They reported release rates in g/m^2/yr.

Legret and Pagotto (1999) approximate Zn release from galvanized guardrails along a highway in France to be 950 g/km/yr. This release rate is converted to g/m^2/yr using an estimated area per kilometer of guardrail of 480.3 m^2/km. The 480.3 m^2/km is calculated for a W-beam style guardrail, the most common style of guardrail used in the study area (see Appendix K).

$$Release_{Guardrail}\left(\frac{g}{m^2-yr}\right)=\frac{Release_{LegretPagotto}\left(\frac{g}{km-yr}\right)}{480.3\ \frac{m^2}{km}}$$

Taylor Associates (2004) collected consecutive runoff samples from repeated synthetic rainwater rinsing of a galvanized guardrail in SeaTac, Washington. For the purpose of calculating a release rate, the first four of 12 samples are ignored and only the steady-state Zn leaching concentrations are used. Zinc concentrations reported in mg/L are converted to g/m^2/yr. This conversion is accomplished by estimating the surface area washed, calculating the mass of Zn leached, and dividing the mass by the surface area. This Zn runoff rate is converted to an annual release rate using the average annual rainfall depth to estimate the number of equivalent wash events per year.

$$Surface\ Area\ (m^2)=\frac{Sample\ Volume\ (in^3)}{Event\ Rainfall\ Depth\ (in)}\times\frac{1\ m^2}{1550\ in^2}$$

$$Zinc\ (g)=Zinc\ \left(\frac{mg}{L}\right)\times Sample\ Volume\ (L)\times\frac{1\ g}{1000\ mg}$$

$$Zinc\ Runoff\ \left(\frac{g}{m^2}\right)=\frac{Zinc\ (g)}{Surface\ Area\ (m^2)}$$

$$Release_{TaylorGuardrail}\left(\frac{g}{m^2-yr}\right)=Zinc\ Runoff\ \left(\frac{g}{m^2}\right)\times\frac{Average\ Annual\ Rainfall\ \left(\frac{in}{yr}\right)}{Event\ Rainfall\ Depth\ (in)}$$

The event rainfall depth is reported to be 0.09 inches (Taylor Associates, 2004). The average annual rainfall is 37.43 in/yr (0.95 m/yr) for Seattle-Boeing Field (USClimateData, 2017).

Chain-link Area

The area of chain-link fence in the CuZn study area is calculated using fence lengths and heights.

$$Chainlink\ Area\ (m^2)\ =Fence\ Length\ (m)\times Fence\ Height\ (m)$$

Aerial and street view imagery (BingMaps, 2017; Ecology, 2012; Ecology, 2015; GoogleMaps, 2017) is used to digitize the fence length, estimate fence height, and identify any coatings used on the commercial chain-link fencing in the study area. The study area was scanned street-by-street using aerial and street view imagery to identify and digitize all commercial chain-link fencing. Residential chain-link fence is not included in this analysis.

Chain-link Materials

The exposed surface area of galvanized materials for a known area of chain-link fence is calculated using the typical wire mesh spacing, wire gauge, and post diameters for residential, commercial, and industrial use (Table F-2). Post size, mesh spacing, and wire gauge vary with location, fence height, icing, and wind speed (CLFMI, 2011). Hence, simplified chain-link dimensions are used to account for variations in fence materials.

Table F-2. Chain-link fence dimensions used for surface area calculations.

Fence Height	Line Post OD		Top Rail OD		Wire Mesh Spacing (inch)	Mesh & Tension Wire Gauge	Mesh Wire OD	
(feet)	(inch)	(meter)	(inch)	(meter)			(inch)	(meter)
3 to 6	1.900	0.048	1.66	0.042	2	9	0.148	0.0038
6 to 8	2.375	0.060						
10 to 12	2.875	0.073						
> 12	3.500	0.089						
>12 Terminal Post	4.000	0.102	na	na	na	na	na	na

Data compiled from CLFMI (2011); OD = outer diameter, na = not applicable

For the following calculations, the top-rail-with-bottom-tension-wire style of chain-link fence was modeled (Figure F-1). There are many variations of chain-link fence in use (CLFMI, 2011). The top-rail-with-bottom-tension-wire fence provides a conservative estimate of Zn loading, since it has a top rail pipe with more exposed surface area then a top tension wire.

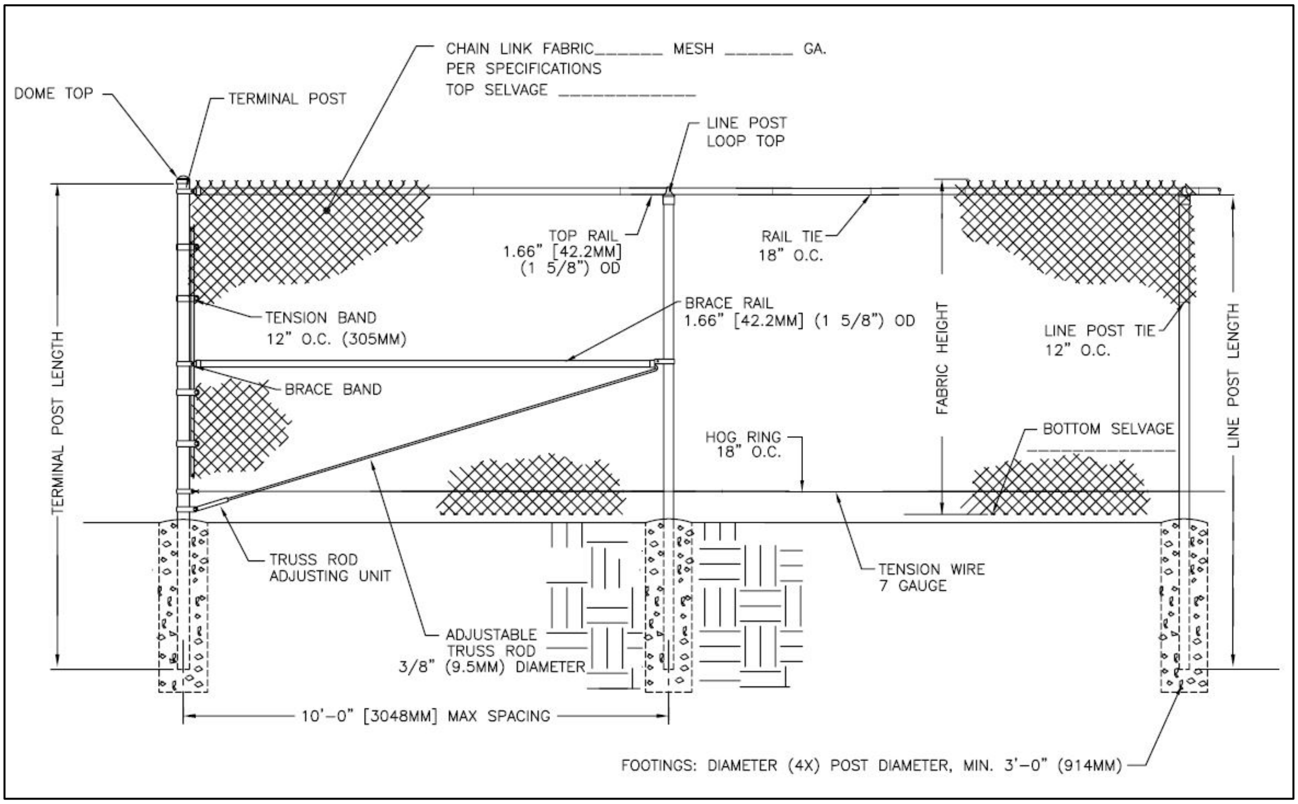

Figure F-1. Top rail, bottom tension wire chain-link fence style (CLFMI, 2011).

Wire Mesh Surface Area

The surface area of chain-link fabric for a given area of fencing is calculated by determining the area of mesh wire per fence surface area. The length of mesh wire in four mesh squares (23cm x 23cm) is calculated by measuring one length of wire, counting the number of wires in that area, and multiplying the number of wires by the length of each wire. The exposed surface area of the wire mesh is calculated using the lateral area of a cylinder.

$$Total\ Length_{WireMesh}\ (in)\ = Wire\ Length\ (in) \times Number\ of\ Wires$$

$$Wire\ Area_{WireMesh}\ (in^2)\ = 2\pi\ \times Wire\ Radius\ (in) \times Total\ Length\ (in)$$

$$Wire\ Area_{WireMesh}\ (in^2)\ = \pi \times Wire\ Diameter\ (in) \times Total\ Length\ (in)$$

The total wire length and surface area within a 23-cm by 23-cm test area of 2-inch spacing chain-link mesh (Figure F-2) are calculated below. There are 10 wire mesh strands measuring 23 centimeters (9.055 inches) long.

$$Total\ Length_{TestArea}\ (in)\ = 9.055\ in \times 10 = 90.55\ in$$

$$Wire\ Area_{TestArea}\ (in^2)\ = \pi \times 0.148\ in \times 90.55\ in = 42.10\ in^2$$

The wire mesh surface area calculated inside the area of four mesh squares (23cm x 23cm = 529 cm^2 = 82 in^2) is used to determine the exposed surface area per linear meter for different height fences (Table F-2). The calculation of the surface area of one linear inch of 6-foot high chain-link fence is shown below.

$$Wire\ Area_{Fence}\ (in^2)\ = Wire\ Area_{TestArea}\ (m^2) \times \frac{Fence\ Area\ (Test\ Area)}{Fence\ Area\ (1in\ x\ 72in)}$$

$$Wire\ Area_{Fence}\ (in^2)\ = 42.10\ in^2 \times \left(\frac{82\ in^2}{72\ in^2}\right) = 36.97\ in^2 per\ linear\ inch$$

Golding (2006) estimated the exposed surface area of a 6-foot, industrial chain-link fence (6-gauge wire) to be 87 in^2 per linear inch which is twice the area calculated above. The larger gauge used by Golding (2006) does not account for the difference in surface areas. No other fencing dimensions used to estimate chain-link surface area (e.g., mesh spacing) were provided by Golding (2006).

Figure F-2. Chain-link fence test area (2-inch mesh spacing).

Fence Post Surface Area

The total surface area of chain-link fence posts is calculated using the typical diameter of terminal posts, line posts, and top rails (Table F-2). The diameter of terminal posts are generally one size larger than the line posts (CLFMI, 2011). The surface area of fence posts is calculated using the lateral area of a cylinder. Fence posts are typically capped, so the surface area calculated is the exterior area. The total area of fence posts is the product of individual post area and the number of posts of that size.

$$Area_{IndividualPost}\ (m^2) = \pi \times Post\ Diameter\ (m) \times Fence\ Height\ (m)$$

$$Area_{LinePost}\ (m^2) = Post\ Area_{OneLinePost}\ (m^2) \times Number\ of\ Line\ Posts$$

The number of chain-link fence posts are calculated differently for each type of post. The number of terminal posts is calculated in GIS as the number of vertices (i.e., line corners) per fence line. The line vertices are calculated after digitizing the fence lines and simplifying the resultant line to remove line vertices not corresponding to fence corners. The number of posts between the fence corners (i.e., line posts) is calculated by dividing the total fence length by the maximum line post spacing and subtracting the number of terminal posts for that length of fence. The maximum line post spacing of 10 feet (3.048 m) is used to calculate the number of line posts between terminal posts (CLFMI, 2011). The length of top rail is equal to the total length of fence.

$$Terminal\ Posts = Fence\ Corners = GIS\ Fence\ Line\ Vertices$$

$$Line\ Posts = \left(\frac{Fence\ Length\ (m)}{3.048\ m}\right) - Terminal\ Posts$$

$$Top\ Rail\ Length\ (m) = Fence\ Length\ (m)$$

Table F-3. Exposed surface area of chain-link fence per linear meter.

Fence Height	Fence Area	Wire Mesh Surface Area		
(feet)	(in^2 per inch)	(in^2 per inch)	(in^2 per meter)	(m^2 per meter)
3	36	18.49	728	0.4695
4	48	24.65	970	0.6260
5	60	30.81	1213	0.7825
6	72	36.97	1456	0.9390
7	84	43.13	1698	1.0955
8	96	49.29	1941	1.2521
9	108	55.46	2183	1.4086
10	120	61.62	2426	1.5651
11	132	67.78	2668	1.7216
12	144	73.94	2911	1.8781
13	156	80.10	3154	2.0346
14	168	86.26	3396	2.1911
15	180	92.43	3639	2.3476
16	192	98.59	3881	2.5041
17	204	104.75	4124	2.6606
18	216	110.91	4367	2.8171
19	228	117.07	4609	2.9736
20	240	123.23	4852	3.1301

Bottom Tension Wire Surface Area

The surface area of chain-link bottom tension wire is calculated using the typical diameter of wire mesh (9 gauge = 0.0038 m) and the equation for the lateral area of a cylinder.

$$\boxed{Tension\ Wire\ Area\ (m^2)\ = \pi \times Post\ Diameter\ (m) \times Fence\ Length\ (m)}$$

Total Chain-link Exposed Surface Area

The total exposed surface area of chain-link fence is the sum of the wire mesh, fence posts, top rail, and bottom tension wire surface areas.

$$\boxed{\begin{aligned} Chainlink\ Area\ (m^2) = {} & Wire\ Area_{WireMesh}\ (m^2) + Post\ Area_{Terminal}\ (m^2) + \\ & Post\ Area_{Line}\ (m^2) + Top\ Rail\ Area\ (m^2) + Tension\ Wire\ Area\ (m^2) \end{aligned}}$$

Zinc Loading

The quantity of Zn released from commercial chain-link fences is 242 lb/yr in the CuZn study area and ranges from 86 to 345 lb/yr. On average, galvanized chain-link fence contributes 231 lb/yr of Zn and painted chain-link leaches 11 lb/yr (Table F-4).

Table F-4. Chain-link fence surface area and zinc loading in the study area.

Fence Type	**Total Area (m^2)**	**Zinc Loading (lb/yr)**				
		min	**median**	**mean**	**max**	**%**
Galvanized	52,385	84	259	231	316	97.9%
Painted	9,292	2.1	5.5	11	28	2.1%
All Chain-link	**61,678**	**86**	**264**	**242**	**345**	

The chain-link fence heights, lengths, and calculated exposed surface areas for galvanized steel and painted steel fencing in the study area are provided in Tables F-5 and F-6, respectively.

Table F-5. Quantity of unpainted, galvanized steel chain-link fence in the urban CuZn study area.

Fence Height		**Terminal Posts**		**Line Posts**		**Top Rail Area (m^2)**	**Bottom Wire Area (m^2)**	**Fence Length (m)**	**Wire Mesh Area (m^2)**	**Total Area (m^2)**
(feet)	**(meter)**	**Posts**	**Area (m^2)**	**Posts**	**Area (m^2)**					
4	1.22	255	59	2444	452	1090	97	8227	5150	6848
5	1.52	179	52	1931	446	851	76	6427	5029	6455
6	1.83	680	236	9256	2566	4012	358	30287	28441	35612
8	2.44	55	31	150	69	83	7.4	625	782	973
10	3.05	12	10	116	266	52	4.6	390	610	943
12	3.66	0	0	0	0	0	0	0	0	0
16	4.88	24	37	141	192	66	5.9	501	1254	1555
20	6.10	0	0	0	0	0	0	0	0	0
Galvanized Total		1205	425	14038	3992	6154	549	46456	41267	**52385**

Table F-6. Quantity of painted, steel chain-link fence in the urban CuZn study area.

Fence Height		**Terminal Posts**		**Line Posts**		**Top Rail Area (m^2)**	**Bottom Wire Area (m^2)**	**Wire Mesh**		**Total Area (m^2)**
(feet)	**(meter)**	**Posts**	**Area (m^2)**	**Posts**	**Area (m^2)**			**Length (m)**	**Area (m^2)**	
4	1.22	176	41	2148	397	945	84	7137	4468	5935
5	1.52	52	15	325	75	152	14	1147	897	1153
6	1.83	37	13	397	110	175	16	1323	1243	1556
8	2.44	0	0	0	0	0	0	0	0	0
10	3.05	4	3.4	4	9.2	3.4	0.30	26	40	56
12	3.66	2	2.3	10	10	4.8	0.43	37	69	86
16	4.88	0	0	0	0	0	0	0	0	0
20	6.10	7	14	36	61	17	1.6	131	411	505
Painted Total		278	88	2920	663	1298	116	9800	7128	**9292**

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Appendix G. Vehicle Exhaust, Vehicle Leaks, and Road Wear

Overview

The estimated Zn loading from vehicle exhaust, leaks, and road wear is 56.7 lb/yr. That is 0.97% of the total Zn release estimate for the urban CuZn study area (Table 2, Figure 4). The estimated Cu loading from vehicle exhaust, vehicle leaks, and road wear is 22.4 lb/yr. This represents 2.8% of the total Cu release estimated for the study area (Table 1, Figure 3).

The potential loading from vehicle emissions, vehicle leaks, and road wear are calculated in relation to the total vehicle kilometers travelled in the study area. Release rates for the metals released due to these sources have been determined using data from previous studies.

$$Loading\ \left(\frac{g}{yr}\right) = \ Release\ Rate\ \left(\frac{g}{km-vehicle}\right) \times Vehicle\ Kilometers\ Traveled\left(\frac{km}{yr}\right)$$

Vehicle Classes

The Washington State travel activity by vehicle class is used to categorize the total vehicle kilometers in the study area (Table G-1). The development of the vehicle class system and calculation of vehicle kilometers travelled are discussed in Appendix E.

Table G-1. Average annual vehicle kilometers traveled in the urban CuZn study area

Vehicle Class	Travel Activity	Traffic Volume (km)
Motorcycle	0.26%	1,128,635
Passenger Car	91.0%	401,362,052
Light Duty	3.25%	14,337,193
Heavy Duty (Disc)	0.27%	1,202,261
Heavy Duty (Drum)	5.18%	22,842,958
Total		**440,873,099**

Release Rates

The Cu and Zn release rates for vehicle exhaust emissions are given in Table G-2. The vehicle emission release rates are reported in ug/vehicle/km for light duty vehicles (Kennedy et al., 2002). For this study, the light duty vehicle release rates for vehicle emissions are used for all vehicle classes.

Kennedy et al. (2002) also report release rates in ug/vehicle/km for vehicle leaks from light and heavy duty vehicles (Table G-3). The light duty release rates for vehicle leaks are used for motorcycles, passenger cars, and light duty vehicles in CuZn study.

The release rates for asphalt road wear are calculated as the product of asphalt metals content and the asphalt road wear rates reported in the literature. The concentration of Cu and Zn in 50% bitumen asphalt are 46.3 mg/kg Cu and 53.5 mg/kg Zn (Kennedy and Gadd, 2003). This is likely an overestimate of the quantity of Cu and Zn in road materials in the study area. The majority of roadways in the study area are made of asphalt-concrete with an asphalt content between 4.6% and 6.7% (Lacey, 2017; Willoughby and Mahoney, 2007). The asphalt road wear rates used are the average wear rates from two international emissions inventories (Ntziachristos and Boulter, 2016; von der Gon et al., 2008). The resultant road wear release rates are given in mg/vehicle/km (Table G-3).

All of the above release rates are separated into vehicle classes (motorcycle, passenger car, light duty vehicles, and heavy duty vehicles).

Copper Loading

The estimated quantity of Cu released from vehicle exhaust emissions is 18.2 lb/yr in the study area. The majority of that Cu (72%) is from passenger car emissions (Table G-2). The potential Cu loading from vehicle oil and lubricant loss is 0.0024 lb/yr (Table G-3). The average Cu release from road material wear is 4.25 lb/yr (Table G-4).

Zinc Loading

The estimated quantity of Zn released from vehicle exhaust emissions is 49.1 lb/yr. The majority of Zn (82%) is from passenger car emissions (Table G-2). The potential Zn loading from vehicle oil and lubricant loss is 2.78 lb/yr (Table G-3). The average Zn release from roadway asphalt wear is 4.91 lb/yr (Table G-4).

Table G-2. Average potential copper and zinc loading from vehicle exhaust emissions.

Vehicle Type	Vehicle-km/yr	Release Rate (ug/vehicle/km)		Loading (lb/yr)	
		Copper	Zinc	Copper	Zinc
Passenger cars	401,362,052	14.7	45.5	13.01	40.3
Heavy Duty	24,045,219	88.0	136.6	4.66	7.2
Light Duty	14,337,193	14.7	45.5	0.46	1.4
Motorcycle	1,128,635	14.7	45.5	0.037	0.11
All	**440,873,099**			**18.2**	**49.1**

Table G-3. Average potential copper and zinc loading from vehicle oil and lubricant loss.

Vehicle Type	CuZn **-km/yr**	Release Rate (ug/vehicle/km)		Loading (lb/yr)	
		Copper	Zinc	Copper	Zinc
Passenger cars	401,362,052	0.0025	2.90	2.21E-03	2.57
Heavy Duty	24,045,219	0.0019	2.10	1.01E-04	0.11
Light Duty	14,337,193	0.0025	2.90	7.90E-05	0.09
Motorcycle	1,128,635	0.0025	2.90	6.22E-06	0.007
All	**440,873,099**			**0.0024**	**2.78**

Table G-4. Average potential copper and zinc loading from roadway asphalt wear.

Vehicle Type	Vehicle-km/yr	Release Rate (ug/vehicle/km)		Loading (lb/yr)	
		Copper	Zinc	Copper	Zinc
Passenger cars	401,362,052	0.0036	0.0041	3.18	3.67
Heavy Duty	24,045,219	0.018	0.021	0.95	1.10
Light Duty	14,337,193	0.0036	0.0041	0.11	0.13
Motorcycle	1,128,635	0.0018	0.0020	0.004	0.005
All	**440,873,099**			**4.25**	**4.91**

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Appendix H. Roof Gutters

Overview

The estimated Zn loading from roof gutters and downspouts is 64.5 lb/yr. That represents 1.1% of the total Zn release estimated for the urban CuZn study area (Table 2, Figure 4).

The potential loading from roof gutters and downspouts is calculated as the product of the surface area and the appropriate release rate.

$$Loading_{Gutter}\left(\frac{g}{yr}\right) = Area_{Gutter}\,(m^2) \times Release\ Rate\left(\frac{g}{m^2 - yr}\right)$$

The total surface area of gutters and downspouts is 574,354 ft^2 (53,359 m^2). Steep-sloped roofs contain 570,086 ft^2 and low-sloped roofs contain 4,269 ft^2 (Table H-3). Low-sloped roofs typically use roof drains and overflow scuppers on top of the roof, instead of gutters running along the edge of the roof.

The surface area of gutters and downspouts are calculated using building perimeter length, wall height, and the cross-sectional areas of gutters and downspouts. Surface area calculations are discussed in further detail below.

The methods for determining building perimeter and wall heights are discussed in relation to building siding materials (Appendix B).

The release rates used to estimate Cu and Zn leaching from roof gutters and downspouts are described below.

Gutter and Downspout Material

Gutters and downspouts for steep-sloped roofs are made of steel, which is epoxy-coated by the manufacturer. Interviews with six local roofing professionals indicate that the use of epoxy-coated gutters has been constant since before the early 1980s. For this study, it is assumed that all gutters and steep-sloped downspouts are made of coated metal.

The downspouts for low-sloped roofs can be made of galvanized steel, polyvinyl chloride (PVC), or acrylonitrile butadiene styrene (ABS) pipe (IPC, 2012a). For this study, it is assumed that all low-sloped roof downspouts are made of galvanized steel. This will produce a conservative estimate of Zn leached from low-sloped roof downspouts, since PVC and ABS pipe contain less Zn and are likely to leach less Zn.

Release Rates

The release rates for painted metal and galvanized steel are used to calculate the potential Zn loading from gutters and downspouts. The painted metal release rates are used for steep-sloped roof gutters and downspouts. The galvanized steel release rates are used for low-sloped roof downspouts. The release rates are given in Table H-1.

The development of the release rates for painted and galvanized steel is discussed in Appendix F. Copper has not been shown to be present in significant quantities in painted metal or galvanized steel.

Table H-1. Release rates for painted and galvanized steel

Source	Zinc Release Rate (g/m²/yr)			
	min	median	mean	max
Painted Metal	0.10	0.27	0.54	1.37
Galvanized Steel	0.73	2.24	2.0	2.74

Gutter Area

The gutter area for a roof is calculated as the product of the gutter inner circumference and the roof gutter length. This method assumes that the entire inner area of gutter is exposed and wetted during storm events. The total estimated gutter area is 438,073 ft^2 (40,698 m^2) for a total gutter length of 1.44 million feet (133,971 meters) in the CuZn study area (Table H-3).

$$Area_{Gutter}\ (m^2) = Gutter\ Inner\ Circumference\ (m) \times Roof\ Gutter\ Length\ (m)$$

The most commonly installed gutter is a 5-inch wide, K-style gutter (Gutters, 2017). The cross-section of a 5-inch K-style gutter is shown in Figure H-1. The inside circumference of a 5-inch K-style gutter is 11.96 inches (0.3038 meters).

The inner circumference of steep-sloped roof gutters is calculated using the most common gutter dimensions. Roof gutters are sized to accommodate roof area and the regional 5-minute maximum rainfall intensity (ThisOldHouse, 2017). The size of roof gutters could be determined according to the total surface area of each roof. For this study, it is assumed that all steep-sloped roof gutters are 5-inch K-style gutters.

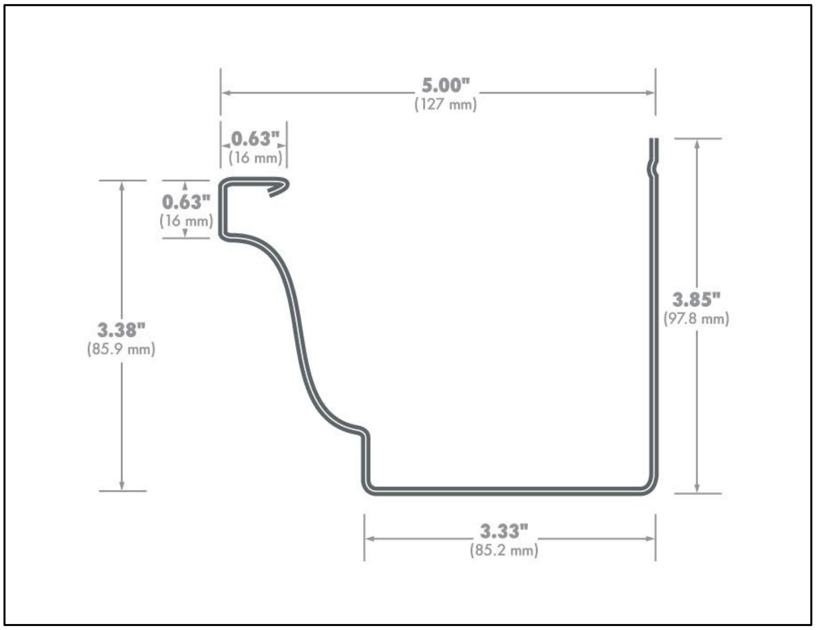

Figure H-1. Cross-section of 5-inch K-style gutter.

The gutter length for each steep-sloped roof is calculated by multiplying the roof perimeter length by the roof width-to-length ratio.

$$Gutter\ Length\ (m) = Roof\ Perimeter\ (m) \times \frac{Roof\ Width\ (m)}{Roof\ Length\ (m)}$$

For this study, it is assumed that gutters on steep-sloped roofs are installed only along the length of the roof. This is generally the case, since the width of steep-sloped roofs are often gabled, not hipped (Figure H-2). So, the rainfall flows toward the length-wise drip edge of the roof. However, building roofs come in many different shapes. The width-to-length ratio is used to account for the different shapes of building roofs.

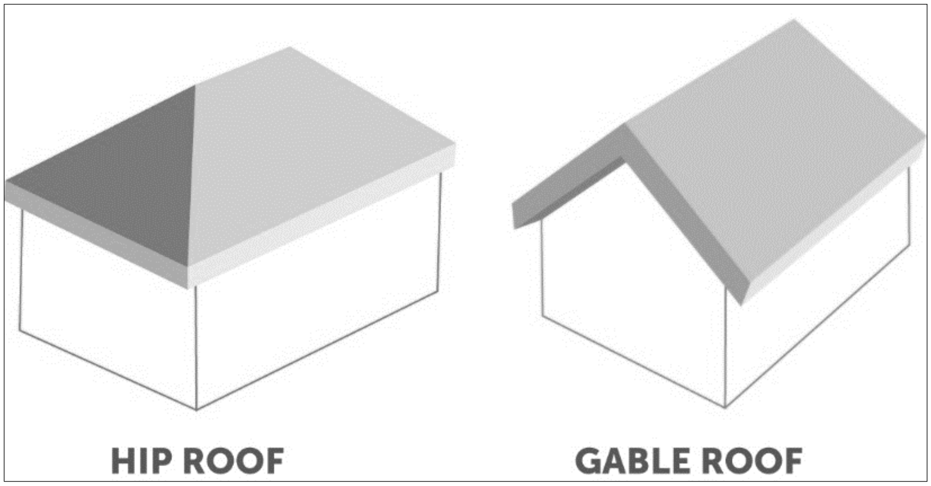

Figure H-2. Examples of hip and gable roofs

Width-to-length ratios are calculated for each building roof using GIS. To accomplish this, the minimum bounding rectangle for each building footprint is created. Then the width-to-length ratio is calculated from the width and length of each building's minimum bounding rectangle. This ratio is then multiplied by the building footprint perimeter length to estimate the gutter length.

Two other methods for calculating gutter length were tested. The first method calculates gutter length as twice the maximum building length. This method does not accommodate all variations in roof shape. For instance, a roof may be L-shaped and the maximum length not representative of the roof drip edges. The second method calculates gutter length using the average width-to-length ratio for all buildings in the CuZn study area. The average width-to-length ratio is 65.8% and ranges from 8.75% to 100%. Using the average width-to-length ratio does not treat each roof individually, so the resultant gutter length for odd shaped, or sized, buildings may not be accurately represented.

All three methods for calculating gutter length estimated very similar total gutter lengths for the study area (Table H-2).

Table H-2. Comparison of total gutter lengths determined by three methods

Method	Total Length (m)
Width-to-Length	134,002
Average Width-to-Length	137,621
Twice Length	128,247

Downspout Area

The downspout area is calculated as the product of the inner downspout circumference and the building wall height. The total estimated downspout area is 136,281 ft^2 (12,661 m^2) for an estimated 12,236 downspouts in the CuZn study area (Table H-3).

$$Area_{Downspout}\ (m^2) = Downspout\ Inner\ Circumference\ (m) \times Wall\ Height\ (m)$$

Commercial building wall heights were provided by Thurston County (Thurston, 2016). For buildings without wall heights recorded (e.g., residential structures), a wall height of 10 feet (3.048 meters) per story was used (Appendix B).

For 5-inch K-style gutters, a 2-inch by 3-inch square cross-section downspout is typically used (Gutters, 2017). This size of downspout is assumed for all steep-sloped roofs in the study area. The inside circumference of a 2-inch by 3-inch square downspout is 10.0 inches (0.2540 meters). The area of a 10-foot (3.048 meter) tall, 2-inch by 3-inch square downspout is calculated below.

$$Area_{2x3Downspout}\ (m^2) = 0.2540\ m \times 3.048\ m = 0.77\ m^2$$

The number of gutter downspouts for steep-sloped buildings is calculated as the gutter length divided by 40 feet (12.2 meters). The typical gutter downspout spacing is 40 feet (ThisOldHouse, 2017). If the resultant number of downspouts for a building is zero (e.g., structures with roofs smaller than 318 ft^2), then one downspout was assigned.

$$Downspouts_{steep-slope} = \frac{Gutter\ Length\ (m)}{12.2\ m}$$

For this study, it is assumed that all low-sloped roof downspouts are 4-inch diameter galvanized steel pipe. The IPC (2012b) requires a downspout diameter of 4 inches for every 10,600 ft^2 (985 m^2) of low-slope roof in western Washington (maximum rainfall intensity of 1.0 in/hr). The number of downspouts on each low-sloped roof is calculated by dividing the total roof area by 10,600 ft^2 (985 m^2).

$$Downspouts_{low-slope} = \frac{Area_{Roof}\ (m^2)}{985\ m^2}$$

The inside area of circular downspout pipe is calculated using the lateral area of a cylinder. The nominal inner diameter of a 4-inch pipe is 4.0 inches (0.102 meters). The area of a 10-foot (3.048 meter) tall 4-inch diameter downspout pipe is calculated below.

$$Area_{4inchDownspout}\ (m^2) = \pi \times Inner\ Diameter\ (m) \times Wall\ Height\ (m)$$

$$Area_{4inchDownspout}\ (m^2) = \pi \times 0.102\ m \times 10\ m = 0.98\ m^2$$

Table H-3. Quantity and exposed surface area of roof gutters and downspouts

Roof Material	Roofs	Downspouts		Gutters		Total Area	
		Quantity	Area (m^2)	Length (m)	Area (m^2)	(m^2)	(%)
Asphalt Shingle Asphalt Shingle with AR	3,215	9,190	9,753	110,865	33,679	3,215	81.4%
Metal	646	1,863	2,423	22,059	6,701	646	17.1%
Clay Tile	17	57	61	688	209	17	0.5%
Wood Shingle	9	26	25	317	96	9	0.2%
Asbestos Shingle	2	3	2	43	13	2	0.03%
Steep Slope Total	**3,889**	**11,139**	**12,264**	**133,971**	**40,698**	**3,889**	**99.3%**
Built Up	119	246	149	na	na	119	0.3%
PVC TPO	109	781	210	na	na	109	0.4%
EPDM	23	66	36	na	na	23	0.07%
Metal	2	4	2	na	na	2	0.004%
Low Slope Total	**253**	**1,097**	**397**	na	na	**253**	**0.7%**
All	**4,142**	**12,236**	**12,661**	**133,971**	**40,698**	**4,142**	

AR = algae-resistance, PVC = polyvinyl chloride, TPO = thermoplastic polyolefin, EPDM = ethylene propylene diene terpolymer; na = not applicable

Zinc Loading

The estimated quantity of Zn released from roof gutters and downspouts is 64.5 lb/yr and ranges from 12.7 to 162 lb/yr. This is a conservative estimate of Zn release, since it is assumed that all of the inner surface area of gutters and downspouts are wetted during storm events.

The majority of Zn (80%) is from steep-sloped, asphalt shingle roofs (Table H-4). This is the most abundant roof type in the CuZn study area, comprising 81% of the roofs (Table H-3).

Table H-4. Potential zinc loading from roof gutters and downspouts

Roof Material	Zinc Loading (lb/yr)				
	Min	Median	Mean	Max	%
Asphalt Shingle Asphalt Shingle with AR	9.86	25.76	51.43	131.18	79.7%
Metal	2.07	5.41	10.81	27.56	16.8%
Clay Tile	0.061	0.16	0.32	0.81	0.5%
Wood Shingle	0.027	0.072	0.14	0.37	0.2%
Asbestos Shingle	0.0035	0.0091	0.018	0.047	0.03%
Steep Slope Total	**12.0**	**31.4**	**62.7**	**160**	**97.2%**
Built Up	0.24	0.73	0.66	0.90	1.0%
PVC TPO	0.34	1.04	0.94	1.27	1.5%
EPDM	0.057	0.18	0.16	0.21	0.2%
Metal	0.0035	0.011	0.010	0.013	0.01%
Low Slope Total	**0.64**	**1.96**	**1.77**	**2.40**	**2.8%**
All	**12.7**	**33.4**	**64.5**	**162**	

AR = algae-resistance, PVC = polyvinyl chloride, TPO = thermoplastic polyolefin, EPDM = ethylene propylene diene terpolymer; na = not applicable

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Appendix I. Heating, Cooling, and Air-Conditioning Units

Overview

The estimated Zn loading from rooftop heating, cooling, and air-conditioning (HVAC) components is 58.8 lb/yr. This represents 1.0% of the total Zn release estimated for the urban CuZn study area (Table 2, Figure 4).

The potential loading from HVAC components is calculated as the product of the component surface area and the appropriate release rate.

$$Loading_{HVAC}\left(\frac{g}{yr}\right) = Area_{HVAC}\ (m^2) \times Release\ Rate\ \left(\frac{g}{m^2 - yr}\right)$$

The total surface area of rooftop HVAC components is 290,177 ft^2 (26,958 m^2). HVAC unit housings account for 202,194 ft^2, which is 70% of the total HVAC exposed area in the study area (Table I-3). The other rooftop HVAC components that may leach Zn are HVAC unit mounting curbs, ducting, and vent pipes. The surface area calculations for the various rooftop HVAC components are discussed below.

The release rates for painted metal and galvanized steel (Appendix F) are used to estimate Zn leaching from rooftop HVAC components. HVAC packaged unit housings are constructed of painted steel. The other HVAC components are made of galvanized steel. The release rates used for each HVAC component are shown in Table I-3.

HVAC Components

The typical rooftop HVAC system is comprised of the packaged rooftop unit, the mounting curb, ducting, and vents (Figure I-1). The HVAC unit contains condenser coils that help remove excess heat and cool air. The mounting curb is a structural support frame installed between the roof and the unit. Ducting circulates air in and out of the building. Ducting is typically installed inside the building to maintain HVAC efficiency. Vents remove excess heat from the building (Brandemuehl, 2017).

HVAC Materials

HVAC components are constructed using a variety of materials. The majority of components are either painted or galvanized steel. The rooftop packaged unit outer housing is epoxy-coated steel. The unit condensing coils can be made of stainless or galvanized steel. This study does not address the possible Zn contribution of condensing coils. The mounting curb and ducting are galvanized steel. Vents can be constructed from many different materials (e.g., plastic, painted steel, galvanized steel). For this study, it is assumed that all vents are made of galvanized steel. This will provide a conservative estimate for the quantity of Zn released from rooftop vents, since galvanized steel leaches more Zn than the other materials.

HVAC Component Area

The exposed surface area of rooftop HVAC components is calculated using surface areas measured from aerial imagery (Ecology, 2012; Ecology, 2015) and the industry standard dimensions for each component. The component dimensions vary, so average or typical dimensions are assumed.

Figure I-1. Rooftop HVAC components including packaged unit, mounting curb, and vents

HVAC Packaged Rooftop Unit

The exposed surface area of HVAC packaged unit housings is calculated from the surface areas of the top and sides of the unit. The top surface area is measured from aerial imagery using GIS. The side areas are calculated using the GIS measured unit perimeter and the average height for the size category of the packaged unit. This method may overestimate the total exposed surface area of packaged units, since not all surfaces are solid painted steel (Figure I-1).

$$\text{Total Area}_{\text{Unit}}\ (\text{m}^2) = \text{Top Area}_{\text{Unit}}\ (\text{m}^2)\ + (Perimeter\ Length_{Unit}\ (m) \times Height_{Unit}\ (m))$$

Rooftop HVAC packaged units come in various sizes depending on the manufacturer and the unit capacity. The top surface area of the packaged units in the CuZn study area are measured using GIS. The height of each unit is estimated using packaged unit size categories. The HVAC unit size categories were determined through interviews with four HVAC suppliers (Table I-1) and a survey of HVAC units on the Washington Department of Ecology Headquarters building in this study area.

The industry average HVAC packaged unit dimensions are shown in Table I-1. The average packaged unit height is 49.43 inches (1.26 meters). To account for variability in HVAC unit size, the dimensions of HVAC units are separated into four categories and related to the top surface area (Table I-2). The height of the rooftop HVAC packaged units in the study area are estimated using the HVAC size category top areas listed in Table I-2.

The total estimated surface area of HVAC package unit housing is 202,194 ft^2 (18,784 m^2) in the study area (Table I-2). Nearly half the HVAC units in the study area are in the 4-to-12 m^2 top area category with a height of 1.3 meters.

Table I-1. HVAC packaged unit average industry dimensions (by capacity)

Capacity (ton)	Width (in)	Length (in)	Height (in)	Top Area	
				(ft^2)	(m^2)
2 to 5	42.18	62.62	44.16	18.75	1.74
7.5 to 12.5	60.67	94.50	55.77	40.97	3.81
25	74.25	109.79	50.79	60.07	5.58
All	**54.36**	**82.19**	**49.43**	**33.88**	**3.15**

Table I-2. HVAC packaged unit size categories and total exposed surface areas

HVAC Size Categories		HVAC Units	Area	
Top Area (m^2)	Height (m)		(m^2)	(%)
> 2	1.1	167	1,050	5.6%
2 to 4	1.4	326	4,274	22.8%
4 to 12	1.3	446	9,257	49.3%
>12	2.4	58	4,204	22.4%
All		**997**	**18,784**	

HVAC Mounting Curb

Mounting curbs are the structural support for HVAC packaged units. The curb is attached to the roof supports and distributes the weight of the packaged unit mounted on top of the curb (Figure I-1). The mounting curb may be blocked from direct rainfall by the packaged unit. Rainfall will run down sides of the packaged unit and through the condenser coils, so the outer surface of the mounting curb is calculated as the exposed surface.

The exposed surface area of HVAC mounting curbs is calculated as the product of the packaged unit perimeter length and the typical mounting curb height.

$$\boxed{\text{Curb Area}_{\text{HVAC}}\ (\text{m}^2) = \text{Perimeter Length}_{\text{HVAC}}\ (\text{m}) \times \text{Curb Height}_{\text{HVAC}}\ (\text{m})}$$

Interviews with local HVAC professionals indicate that the typical exposed height of an HVAC mounting curb is 4 inches (0.102 meters).

The total estimated surface area of HVAC mounting curbs is 10,037 ft^2 (932 m^2) in the CuZn study area (Table I-3).

Building Square Vents

Square-shaped vents on low-sloped building roofs are usually for air ventilation. The size of square-shaped vents varies; some are elevated above the roof surface and some are flush. For this study, all square-shaped vents are assumed to be flush with the roof (height equal to zero). The surface area of square vents is measured in GIS using aerial imagery.

$$\mathrm{Area}_{\mathrm{SquareVent}}\ (\mathrm{m}^2) = \mathrm{Top\ Area}_{SquareVent}\ (\mathrm{m}^2)$$

The total estimated surface area of square vents is 73,839 ft^2 (6,860 m^2) in the CuZn study area (Table I-3).

Building Pipe Vents

Pipe vents on low-sloped building roofs are usually for dry venting of plumbing fixtures. The exposed surface of pipe vents is calculated using the equation for the lateral surface area of a cylinder.

$$\mathrm{Area}_{\mathrm{PipeVent}}(\mathrm{m}^2) = \pi \times \mathrm{Diameter}_{\mathrm{PipeVent}}\ (\mathrm{m}) \times \mathrm{Height}_{\mathrm{PipeVent}}(\mathrm{m})$$

The outer diameter of pipe vents in the CuZn study area are measured in GIS using aerial imagery. The International plumbing code (IPC, 2012) requires a minimum dry vent height above the roof surface of 6 inches (0.1524 meters) and a maximum height of 24 inches (0.381 meters). For this study, a pipe vent height of 19.7 inches (0.5 meters) is assumed for all pipe vents in the study area.

The total estimated surface area of pipe vents is 1,840 ft^2 (171 m^2) in the study area (Table I-3).

Ducting

The exposed surface area of HVAC ducting is calculated using the GIS-measured top area of rooftop ducting and an assumed ducting height of 39.4 inches (1.0 meter).

$$\mathrm{Area}_{\mathrm{duct}}\ (\mathrm{m}^2) = (\mathrm{Width}_{\mathrm{duct}}\ (\mathrm{m}) \times \mathrm{Height}_{\mathrm{duct}}\ (\mathrm{m})) + (\mathrm{Length}_{\mathrm{duct}}(\mathrm{m}) \times \mathrm{Height}_{\mathrm{duct}}\ (\mathrm{m}))$$

The total estimated surface area of ducting is 2,268 ft^2 (211 m^2) in the study area (Table I-3).

Zinc Loading

The estimated quantity of Zn released from rooftop HVAC components is 58.8 lb/yr and ranges from 17.4 to 106 lb/yr. Square vents (52.2%) and packaged units (37.8%) contribute the majority of the Zn released by HVAC components in the study area (Table I-3).

Table I-3. Potential zinc loading from rooftop HVAC components

HVAC Component	Area		Zinc Release Rates ($g/m^2/yr$)				Zinc Loading (lb/yr)				
	(m^2)	(%)	Min	Median	Mean	Max	Min	Median	Mean	Max	%
Packaged Unit	18,784	69.7%	0.10	0.27	0.54	1.37	4.27	11.1	22.2	56.7	37.8%
Mounting Curb	932	3.5%	0.73	2.24	2.03	2.74	1.50	4.60	4.17	5.63	7.1%
Square Vents	6,860	25.4%	0.73	2.24	2.03	2.74	11.0	33.9	30.7	41.4	52.2%
Pipe Vents	171	0.6%	0.73	2.24	2.03	2.74	0.28	0.84	0.76	1.03	1.3%
Ducting	211	0.8%	0.73	2.24	2.03	2.74	0.34	1.04	0.94	1.27	1.6%
Total	**26,958**						**17.4**	**51.5**	**58.8**	**106**	

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Appendix J. Treated Lumber

Overview

The estimated copper loading from treated lumber is 49.5 lb/yr. This represents 6.2% of the total copper release estimated for the urban CuZn study area (Table 1, Figure 3). Residential decks release 32.7 lb/yr, building mud sills contribute 14.5 lb/yr, and guardrail posts leach 2.33 lb/yr (Table J-2). Utility poles in the study area are treated with pentachlorophenol, which does not contain Cu or Zn.

The Cu loading from treated lumber is calculated using the literature release rates for treated wood and the exposed surface area of treated lumber.

$$Loading_{Lumber}\left(\frac{g}{yr}\right) = Area_{Lumber}\,(m^2) \times Release\ Rate\left(\frac{g}{m^2 - yr}\right)$$

The total surface area of treated lumber in the study area is 395,816 ft^2 (36,773 m^2). Outdoor decks account for 233,056 ft^2 (58.9%), guardrail posts have 96,395 ft^2 (24.4%), and residential building mud sills comprise 66,366 ft^2 (16.8%) of the treated lumber in the study area (Table J-2). The surface area calculations for treated lumber are described below.

The release rates used are discussed below.

Wood Preservatives

The two main preservatives used to treat lumber are chromated copper arsenate (CCA) and alkaline copper quaternary (ACQ) (Freeman and McIntyre, 2008). The use of CCA-treated lumber was phased out for residential use in 2004 (USEPA, 2017). After 2004, ACQ became the predominant wood preservative used to treat lumber intended for residential use (Freeman and McIntyre, 2008; Hasan, 2010).

For this study, residential structures built before 2004 are separated from those built after 2004. The release rate for CCA-treated wood is applied to lumber used for pre-2004 buildings, and the ACQ-treated release rate is used for post-2004 lumber.

Release Rates

The release rates for CCA-treated and ACQ-treated lumber are given in Table J-1.

Table J-1. Copper release rates for treated lumber

Preservative	**Copper Release Rate (g/m^2/yr)**			
	Min	**Median**	**Mean**	**Max**
Chromated Copper Arsenate (CCA)	0.09	0.20	0.36	0.82
Alkaline Copper Quaternary (ACQ)	--	--	3.20	--

The treated lumber release rates are compiled from Hasan et al. (2010). They soaked treated southern yellow pine lumber in collected rainwater and analyzed the leachate for trace metals. In addition, they compared CCA-treated lumber release rates from two other studies (Kennedy and Collins, 2001; Taylor and Cooper, 2005).

The CCA-treated lumber release rates in Table J-1 are the average for all new and weathered CCA-treated lumber results reported by Hasan et al. (2010). The average does not include Cu release rates determined for high retention treated lumber. High retention lumber is intended for extreme environments (e.g., marine waters), so the Cu content and leaching from that lumber is much greater than the lower retention lumber used for other applications.

The release rate for ACQ-treated lumber was determined by Hasan et al (2010) for three samples of new ACQ-treated lumber. The Cu leached from ACQ-treated lumber is an order of magnitude greater than for CCA-treated lumber.

Hasan et al. (2010) reported the quantity of Cu released from various treated lumber in mg/m^2/day. For this urban CuZn study, the release rates are converted to g/m^2/yr.

Deck Area

The surface area of residential decks is provided by Thurston County (2016). The area of all outdoor, uncovered decks are compiled using GIS. The surface area of decks built before and after 2004 are summarized in Table J-2. For this study, all outdoor decks and porches are assumed to be made of treated lumber.

Mud Sill Area

The mud sill plate is the bottom, horizontal member of a wall or building to which vertical supports are attached. Mud sills are typically 2-inch by 6-inch lumber mounted flat between the building foundation and wall structure (Figure J-1). Mud sills are required to be constructed of treated lumber (Duffy, 2017; IRC, 2015).

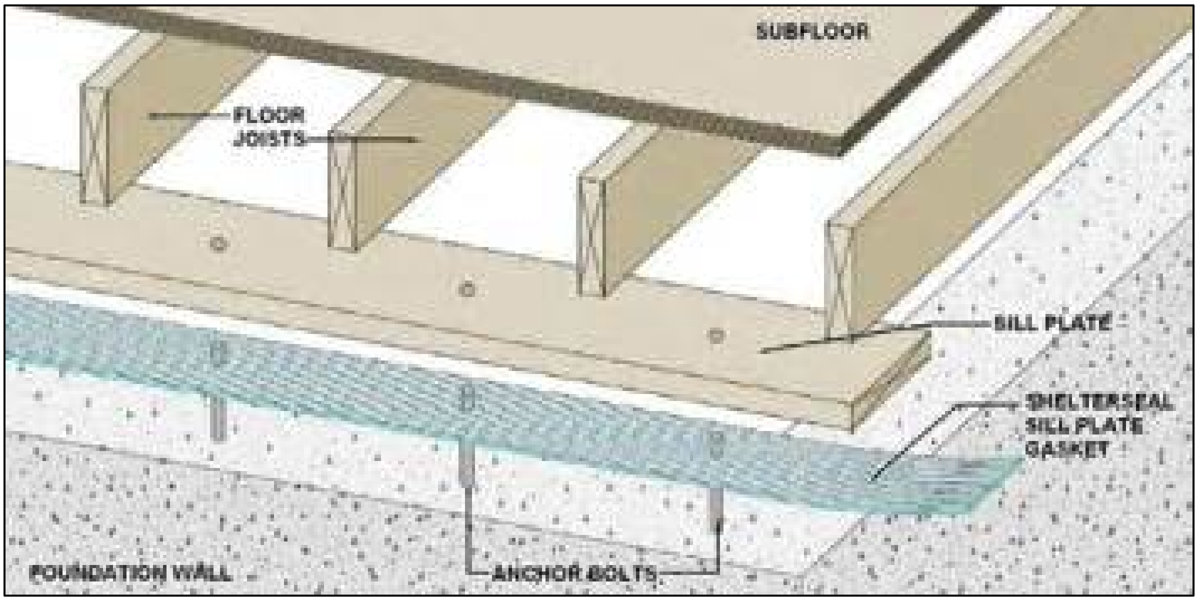

Figure J-1. Building floor diagram, showing mud sill (ShelterEnterprises, 2017).

Mud sills are typically covered by the building structure. The potential exposed area of treated lumber in a mud sill is the outer edge. The exposed surface area of residential mud sills is calculated as the product of the building perimeter and mud sill width.

$$Area_{Mud\ Sill}\ (m^2) = Building\ Perimeter\ (m) \times Mud\ Sill\ Width\ (m)$$

For this study, it is assumed that 2-inch by 6-inch treated lumber is used for all mud sills. The width of modern 2x6 lumber is 1.5-inch by 3.5-inch (38 mm by 140 mm).

The surface area of potentially exposed mud sills for structures built before and after 2004 are shown in Table J-2.

Copper Loading

The potential Cu loading from treated lumber used for residential mud sills, decks, and roadside guardrail posts is 49.5 lb/yr. Residential decks release 32.7 lb/yr, building mud sill plates contribute 14.5 lb/yr, and guardrail posts leach 2.33 lb/yr (Table J-2). The loading calculations for guardrail posts are discussed in Appendix K.

Table J-2. Treated lumber surface area and potential copper loading

Source	**Year Built**	**Area**			**Zinc Loading (lb/yr)**				
		(ft^2)	**(m^2)**	**(%)**	**Min**	**Median**	**Mean**	**Max**	**%**
Mud Sills	pre-2004	49,793	4,626	12.6%	0.93	8.34	3.65	2.05	7.4%
Mud Sills	post-2004	16,573	1,540	4.2%	nd	nd	10.87	nd	21.9%
Decks	pre-2004	206,229	19,159	52.1%	3.85	34.53	15.11	8.48	30.5%
Decks	post-2004	26,827	2,492	6.8%	nd	nd	17.59	nd	35.5%
Guardrail Posts	*	96,395	8,955	24.4%	0.59	1.31	2.33	5.32	4.7%
Total		**395,816**	**36,773**		**5.38**	**44.2**	**49.5**	**15.8**	

** Guardrail posts are industrial use lumber and can still be treated with CCA; nd = no data*

Other Considerations

Utility poles are a potential source of Cu. Utility poles are treated with pentachlorophenol (Penta), chromated copper arsenate (CCA), copper naphthenate (CuN), or ammoniacal copper zinc arsenate (ACZA) (WoodPoles, 2017). Mankowski et al. (2002) reports that 63% of utility poles in the United States are treated with Penta, 13% with CCA, 13% with CuN, and 3% with ACZA.

There are 446 utility poles in the CuZn study area. The majority of utility poles are made from Douglas Fir (DF) logs treated with Penta. Therefore, no Cu or Zn is released from utility poles in this study.

In a random survey of 12 utility poles in the study area, 10 are Douglas Fir and 2 are Cedar. All have brands and/or coloration indicating treatment with pentachlorophenol. The average base circumference is 45.7 inches (1.16 meters), base diameter is 14.5 inches (0.37 meters), and pole length is 51.0 feet (15.5 meters).

The utility poles surveyed represented a variety of pole heights and classes. The average dimensions are closest to the dimensions of a 50-foot long, Class 1 utility pole (ANSI, 2017; WoodPoles, 2017). The ANSI (2017) pole length, minimum circumference at 6-feet from butt, and minimum top circumference for log type and class can be used to calculate the exposed area of utility poles. Industry practice is to bury 10 percent of the pole plus 2-feet (10% + 2-feet). Using the equation for the area of a tapered cylinder, the exposed surface area of a utility pole can be calculated.

$$Area_{UtilityPole}\ (ft^2) = Area_{taperedcylinder} = 2 \times \pi \times Average\ Radius\ (ft) \times Height(ft)$$

$$Area_{UtilityPole}\ (ft^2) = \pi \times Average\ Diameter\ (ft) \times Height(ft)$$

$$Height\ (ft) = Pole\ Length\ (ft) - Length\ Buried\ (ft)$$

$$Length\ Buried\ (ft) = (0.10 \times Pole\ Length\ (ft)) + 2\ ft$$

$$Circumference\ (ft) = 2 \times \pi \times Radius\ (ft) = \pi \times Diameter\ (ft)$$

$$Diameter\ (ft) = \frac{Circumference\ (ft)}{\pi}$$

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Appendix K. Guardrails

Overview

The estimated Zn loading from roadside guardrails is 26.5 lb/yr. This represents 0.45% of the total Zn release estimated for the urban CuZn study area (Table 2, Figure 4). The Cu estimated to be released from treated wood guardrail posts is 2.33 lb/yr. That is 0.29% of the potential Cu loading in the study area.

The potential loading from guardrails and posts is calculated as the product of the exposed surface area and the release rate for the material.

$$Loading_{Guardrail}\left(\frac{g}{yr}\right) = Area_{Guardrail}\,(m^2) \times Release\ Rate_{Galvanized}\left(\frac{g}{m^2 - yr}\right)$$

The total surface area of roadside guardrails and posts is 96,395 ft^2 (8,955 m^2). The guardrails account for 64,615 ft^2 and guardrail posts account for 31,780 ft^2 (Table K-4). The surface area calculations for guardrails and posts are discussed below.

Release Rates

The release rates for galvanized steel are used to estimate Zn leaching from roadside guardrails. The release rate for chromated copper arsenate (CCA)-treated lumber is used to estimate the Cu loading from guardrail posts. CCA-treated lumber was banned for residential purposes in 2004 (Freeman and McIntyre, 2008). CCA-treated lumber is still used for industrial and commercial uses (e.g., guardrail posts). The release rates for galvanized steel and CCA-treated lumber are shown in Table K-1.

Table K-1. Release rates for galvanized steel and CCA-treated lumber

Source	**Metal**	**Release Rate (g/m^2/yr)**			
		Min	**Median**	**Mean**	**Max**
Galvanized Steel	Zinc	0.73	2.24	2.00	2.74
CCA-treated Lumber	Copper	0.09	0.20	0.36	0.82

Further details about the development of release rates for galvanized steel and CCA-treated lumber are provided in Appendices F and J, respectively.

Guardrails

Guardrails are installed alongside roadways to protect vehicles from driving off the roadway and impacting hazardous areas (e.g., steep road bank, oncoming traffic). Guardrails are installed only in critical areas. The length of guardrails in the CuZn study area is measured in GIS using aerial imagery (Ecology, 2012; Ecology, 2015). The type of guardrail used is identified using street view imagery (BingMaps, 2017; GoogleMaps, 2017).

There are two types of guardrails in use in the study area. The W-beam style of guardrail is the most common type of guardrail used. The cross-sectional view of a W-beam guardrail resembles the letter W (Figure K-1). The other type of guardrail is a Thrie-beam guardrail, which are used primarily in guardrail transition areas (e.g., beginning of a bridge, connection to a cement traffic barrier). The cross-section of a Thrie-beam guardrail looks like the letter W with an extra bump (Figure K-2).

The exposed surface area of guardrails is calculated as twice the cross-sectional height (front and back) multiplied by the horizontal length of the guardrail. The exposed area of any guardrail terminal sections is added to the surface area of the guardrail length. The area of the terminal section is calculated as the product of twice the cross-sectional height and the length of the terminal section.

$$\mathrm{Area_{guardrail}}(\mathrm{m}^2) = \Big(\big(2 \times \mathrm{Height}_{rail}\ (\mathrm{m})\big) \times \mathrm{Length}_{rail}\ (\mathrm{m})\Big) + \big(2 \times \mathrm{Area_{terminal}}(\mathrm{m}^2)\big)$$

$$\mathrm{Area_{terminal}}(\mathrm{m}^2) = \Big(\big(2 \times \mathrm{Height}_{terminal}\ (\mathrm{m})\big) \times \mathrm{Length}_{terminal}\ (\mathrm{m})\Big)$$

Figure K-1. Galvanized steel W-beam guardrail showing rail, posts, and spacers.

The cross-sectional heights of W-beam, Thrie-beam, and guardrail terminal sections are measured from engineering drawings (Table K-2). These "heights" are the total exposed length of the guardrail curvature. The most commonly used guardrail terminal section in the CuZn study area is the C-shaped terminal section (Figure K-3). For this study, it is assumed that all guardrail terminal sections are C-shaped.

Table K-2. Guardrail dimensions

Guardrail Type	Cross-section Height		Length	
	(in)	(m)	(in)	(m)
W-Beam	18.91	0.4803	varies	varies
Thrie Beam	27.90	0.7086	varies	varies
Terminal End	24.00	0.6096	24.00	0.9312

Figure K-2. Galvanized steel Thrie-beam guardrail showing transition section (upper right)

Guardrail Posts

The total exposed surface area of guardrail posts is calculated as the product of the number of posts and the above-ground surface area of each post and spacer.

$$\mathrm{Area_{TotalPosts}}\ (\mathrm{m}^2) = \mathrm{Posts} \times \left(\mathrm{Area_{Post}}\ (\mathrm{m}^2) + \mathrm{Area_{Spacer}}\ (\mathrm{m}^2)\right)$$

Guardrails are installed to the required height by the use of posts driven into the roadway shoulder. The guardrails are mounted to the posts using spacers (Figure K-1). The guardrail posts used are either 6-inch by 8-inch treated lumber or W6x9 galvanized steel I-beams. The guardrail spacers used for W-beam guardrails are 14 inches (0.356 meters) long and made with either W6x9 galvanized steel I-beams or 6-inch by 8-inch treated lumber. The guardrail spacers used for Thrie-beam guardrails are 22 inches (0.559 meters) long and made with either W6x9 galvanized steel I-beams or 8-inch by 10-inch treated lumber (WSDOT, 2016).

Figure K-3. Galvanized steel C-shaped guardrail terminal section

The majority of guardrail posts and spacers in the CuZn study area are treated lumber. For this study, it is assumed that all guardrail posts are treated 6-inch by 8-inch lumber. If the posts were all steel I-beams, then Zn would be released from guardrail posts instead of Cu. The dimensions for guardrail posts are given in Table K-3.

The exposed surface area of a guardrail post is calculated as the sum of the surface area of all above-ground post sides. Guardrails are required to be 33 inches (0.839 meters) above the road surface. On flat ground, the guardrail post must be a minimum of 29 inches (0.7366 meters) tall to elevate guardrails to the required height (WSDOT, 2016). Example equations for the surface area of guardrail posts and spacers are shown below.

$$\mathrm{Area}_{\mathrm{Post,Wood}}(\mathrm{m}^2) = (2 \times \mathrm{Area}_{\mathrm{width}}) + \left(2 \times \mathrm{Area}_{\mathrm{length}}\right) + \mathrm{Area}_{\mathrm{top}}$$

$$\mathrm{Area}_{\mathrm{Spacer}}(\mathrm{m}^2) = (2 \times \mathrm{Area}_{\mathrm{width}}) + \left(2 \times \mathrm{Area}_{\mathrm{length}}\right) + (2 \times \mathrm{Area}_{end})$$

Table K-3. Guardrail post dimensions and exposed surface area per post

Guardrail Type	Dimensions (inches)			Area per Post	
	Width	Length	Height	(in^2)	(m^2)
W-beam Post	6	8	29	860	0.55
W-beam Spacer	6	8	14	488	0.31
W-beam Total				1,348	**0.87**
Thrie-beam Post	6	8	29	860	0.55
Thrie-beam Spacer	6	8	22	712	0.46
Thrie-beam Total				1,572	**1.01**

The number of guardrail posts in a length of guardrail is calculated using the minimum post spacing. Standard guardrail post spacing is 75 inches (1.905 meters). Guardrail near critical areas and guardrail transition zones (e.g., bridges, concrete barriers) are called Type 11 guardrails. The post spacing for Type 11 guardrails is 37.5 inches (0.9525 meters), half the standard spacing (WSDOT, 2016). These post spacing values are used to estimate the number of guardrail posts in the CuZn study area (Table K-4).

$$\mathrm{Posts}_{Standard} = \frac{\text{Guardrail Length (m)}}{\text{Post Spacing (m)}} = \frac{\text{Guardrail Length (m)}}{1.905\ m}$$

$$\mathrm{Posts}_{\mathrm{Type11}} = \frac{\text{Guardrail Length (m)}}{\text{Post Spacing (m)}} = \frac{\text{Guardrail Length (m)}}{0.9525\ \mathrm{m}}$$

The total exposed surface area for guardrail posts is 31,780 ft^2 (2,952 m^2) in the study area (Table K-4).

Table K-4. Potential copper and zinc loading from guardrails and guardrail posts

Source	**Posts**	**Length (m)**	**Area**		**Copper Loading (lb/yr)**				**Zinc Loading (lb/yr)**			
			(m^2)	**(%)**	**min**	**median**	**mean**	**max**	**min**	**median**	**mean**	**max**
W-Beam Rail	na	5881	5,654	63.1%	na	na	na	na	9.10	27.9	24.9	34.2
W-Beam Post	3094	na	2,691	30.0%	0.54	1.2	2.1	4.9	na	na	na	na
Thrie Rail	na	246	349	3.9%	na	na	na	na	0.56	1.7	1.5	2.1
Thrie Post	258	na	262	2.9%	0.05	0.1	0.2	0.5	na	na	na	na
Total	**3352**	**6127**	**8,955**		**0.6**	**1.3**	**2.3**	**5.3**	**9.7**	**29.6**	**26.5**	**36.3**

na = not applicable

Copper Loading

The estimated quantity of Cu released from guardrail posts is 2.33 lb/yr and ranges 0.6 to 5.3 lb/yr (Table K-4). This quantity of Cu is added to the Cu from other treated lumber (Appendix J) to estimate the total Cu leached from treated wood in the study area.

Zinc Loading

The estimated quantity of Zn released from guardrails is 26.5 lb/yr and ranges from 9.7 to 36.3 lb/yr. The most common guardrail style is the W-beam guardrail. W-beam guardrails account for 94.2% of the potential Zn released from guardrails in the study area (Table K-4).

References for Appendix K

BingMaps. 2017. Aerial and Streetview imagery of Lacey, Washington. Microsoft. https://binged.it/2rs09OM

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Appendix L. Streetlights and Traffic Signals

Overview

The estimated Zn loading from streetlights and traffic signals is 33.6 lb/yr. This represents 0.57% of the total Zn release estimated for the urban CuZn study area (Table 2, Figure 4). Parking lot lights account for 21.8 lb/yr (64.8%), traffic signals contribute 8.67 lb/yr (25.8%), and streetlight poles release 3.15 lb/yr (9.4%) (Table L-4). The majority of streetlights in the study area are constructed of aluminum and do not release Cu or Zn.

The Zn loading from streetlights and traffic signals is calculated as the product of the exposed surface area and the release rate for either galvanized steel or painted metal.

$$Loading_{Streetlight}\left(\frac{g}{yr}\right) = Area_{Streetlight}\,(m^2) \times Release\ Rate\left(\frac{g}{m^2 - yr}\right)$$

The total surface area of streetlights and traffic signals in the study area is 365,506 ft^2 (33,957 m^2). Light poles in business parking lots account for 197,803 ft^2 (54.1%), streetlight poles have 143,175 ft^2 (39.2%), and traffic signal surface area is 24,528 ft^2 (6.7%) in the study area (Table L-4). The surface area calculations for streetlights and traffic signals are described below.

The release rates used are discussed below.

Materials

Streetlight poles in the CuZn study area are constructed with aluminum, painted metal, galvanized steel, and wood. The majority of streetlights are aluminum. Business parking lot light poles are made of painted metal. Traffic signal poles are mostly galvanized steel with a few traffic signals made with painted metal (Table L-4).

Aluminum and wood poles are not considered in this loading estimate. Aluminum does not contain significant quantities of Cu or Zn. The wood poles used in the study area are treated with pentachlorophenol, which does not contain Cu or Zn (Appendix J).

Release Rates

The release rates for painted and galvanized steel are given in Table L-1. Further information about the development of the release rates for painted and galvanized steel is provided in Appendix F.

Table L-1. Release rates for painted and galvanized steel

Source	Zinc Release Rate (g/m^2/yr)			
	min	median	mean	max
Painted Metal	0.10	0.27	0.54	1.37
Galvanized Steel	0.73	2.24	2.0	2.74

Streetlight Quantity

There are a total of 1,164 streetlights and 51 traffic signals in the CuZn study area (Lacey, 2017; Thurston, 2017). The number of streetlights includes traffic cameras and sensors installed on poles along Interstate 5. The type, shape, and size of the streetlights and traffic signals vary (Figure L-1). The geometry of the different poles is used to calculate the exposed surface areas.

There are an estimated 2,627 business parking lot lights in the study area. For this study, it is assumed that all parking lot lights are 25 feet (7.62 meters) tall and have straight poles.

The number of business parking lot lights is calculated using the median number of lights per parking lot area (pole/km^2) for 37 businesses in the study area. Parking lot lights were counted using aerial and street view imagery (BingMaps, 2017; Ecology, 2012; Ecology, 2015; GoogleMaps, 2017). There are a median of 1,151 lights per square kilometer of parking lot (Table L-2). This factor is multiplied by the total business parking lot area (2.28 km^2) to calculate the approximate number of parking lot lights in the study area. This may be an overestimate of the number of parking lot lights, since not all business parking lots have light poles.

$$\text{Lights}_{\text{Business}} = \text{Factor}_{\text{median}}\left(\frac{\text{lights}}{\text{km}^2}\right) \times \text{Area}_{\text{ParkingLot}}\ (\text{km}^2)$$

$$\text{Lights}_{\text{Business}} = 1{,}151\ \left(\frac{\text{lights}}{\text{km}^2}\right) \times 2.28\ (\text{km}^2) = 2{,}627\ \text{lights}$$

Table L-2. Business light pole survey results (poles per parking lot area)

Land Use	Parking Lot Lights (pole/km^2)			
	n	**Median**	**Mean**	**Std Dev**
Commercial Retail and Housing	28	1,154	1,288	776
Commercial Services	6	1,563	1,924	1,570
Government and Industrial	3	730	921	398
All Land Use Types	**37**	**1,151**	**1,361**	**932**

n = number of businesses, Std Dev = standard deviation

Streetlight Area

The exposed surface area of streetlight poles is calculated using the equations for the area of a tapered cylinder or the lateral area of a cylinder depending on the shape of each light pole. Streetlights and traffic signals have tapered poles. Parking lot lights have straight poles.

$$Area_{taperedcylinder}\ (m^2) = 2\pi \times Average\ Radius\ (m) \times Height\ (m)$$

$$Lateral\ Area_{cylinder}\ (m^2) = 2\pi \times Radius\ (m) \times Height\ (m)$$

Streetlights are constructed of one vertical pole and an arm to extend the light horizontally toward the roadway. There are pedestrian, dual function, single arm, and twin arm streetlights in use in the CuZn study area (Figure L-1).

The height of the vertical pole and the length of the arm(s) are recorded in the GIS data (Lacey, 2017; Thurston, 2017). The diameter of the streetlight arms is not recorded. The base diameter of streetlight arms is assumed to be equal to the top diameter of the streetlight pole. The end diameter of streetlight arms is assumed to be half the arm base diameter. The dimensions used for streetlights, traffic signals, and parking lot lights are given in Table L-3.

The dimensions for each traffic signal component are listed separately (Table L-3). The exposed surface area for a traffic signal is calculated by summing the total surface area for all the components present. The traffic signal mast-arm length is calculated as 12 feet (3.66 meters) per lane of traffic controlled by the signal (Figure L-2). For streetlights attached to traffic signals, the pole diameters for standalone streetlights with the same height as the traffic signal light are used.

Table L-3. Streetlight and traffic signal dimensions and surface areas

Light Pole Type	Pole Dimensions (m)			Arm Dimensions (m)			Surface Area (m^2)		
	Height	Base Diameter	Top Diameter	Length	Base Diameter	End Diameter	Pole	Arm	Total
Pedestrian Streetlight	4.57	0.381	0.102	n/a	0.102	0.051	6.93	na	6.93
Dual Function Streetlight	7.62	0.178	0.114	1.83	0.114	0.057	6.99	0.99	7.98
Dual Function Streetlight	9.14	0.178	0.114	1.83	0.114	0.057	8.39	0.99	9.38
Dual Function Streetlight	12.19	0.203	0.114	1.83	0.114	0.057	12.16	0.99	13.15
Straight Pole Streetlight	6.10	0.203	0.114	4.27	0.114	0.057	6.08	2.30	8.38
Straight Pole Streetlight	9.14	0.203	0.114	4.27	0.114	0.057	9.12	2.30	11.42
Straight Pole Streetlight	12.19	0.203	0.114	4.27	0.114	0.057	12.16	2.30	14.46
Single Arm Streetlight	4.57	0.178	0.114	na	na	na	4.20	na	4.20
Single Arm Streetlight	9.14	0.178	0.114	1.83	0.114	0.057	8.39	0.99	9.38
Single Arm Streetlight	9.14	0.178	0.114	2.44	0.114	0.057	8.39	1.31	9.70
Single Arm Streetlight	9.14	0.178	0.114	3.05	0.114	0.057	8.39	1.64	10.03
Single Arm Streetlight	9.14	0.178	0.114	3.66	0.114	0.057	8.39	1.97	10.36
Single Arm Streetlight	12.19	0.203	0.114	1.83	0.114	0.057	12.16	0.99	13.15
Single Arm Streetlight	12.19	0.203	0.114	1.83	0.114	0.057	12.16	0.99	13.15
Single Arm Streetlight	12.19	0.203	0.114	2.44	0.114	0.057	12.16	1.31	13.47
Single Arm Streetlight	12.19	0.203	0.114	3.05	0.114	0.057	12.16	1.64	13.80
Single Arm Streetlight	12.19	0.203	0.114	3.66	0.114	0.057	12.16	1.97	14.13
Twin Arm Streetlight	9.14	0.254	0.152	1.83	0.152	0.076	11.67	1.31	12.99
Twin Arm Streetlight	9.14	0.254	0.152	2.44	0.152	0.076	11.67	1.75	13.43
Twin Arm Streetlight	12.19	0.254	0.152	1.83	0.152	0.076	15.57	1.31	16.88
Twin Arm Streetlight	12.19	0.254	0.152	2.44	0.152	0.076	15.57	1.75	17.32
Traffic Signal Base Pole	6.40	0.457	0.305	na	na	na	15.32	na	15.32
Signal, 30' Streetlight	2.74	0.178	0.114	4.27	0.114	0.057	2.52	2.30	4.82
Signal, 40' Streetlight	5.79	0.203	0.114	2.44	0.114	0.057	5.78	1.31	7.09
Signal, 40' Streetlight	5.79	0.203	0.114	4.27	0.114	0.057	5.78	2.30	8.07
Signal, Mast Arm (1 lane)	na	na	na	3.66	0.191	0.119	na	3.56	3.56
Signal, Mast Arm (2 lane)	na	na	na	7.32	0.216	0.130	na	7.94	7.94
Signal, Mast Arm (3 lane)	na	na	na	10.97	0.241	0.114	na	12.26	12.26
Signal, Mast Arm (4 lane)	na	na	na	14.63	0.279	0.109	na	17.86	17.86

na = not applicable; traffic signal components listed separately

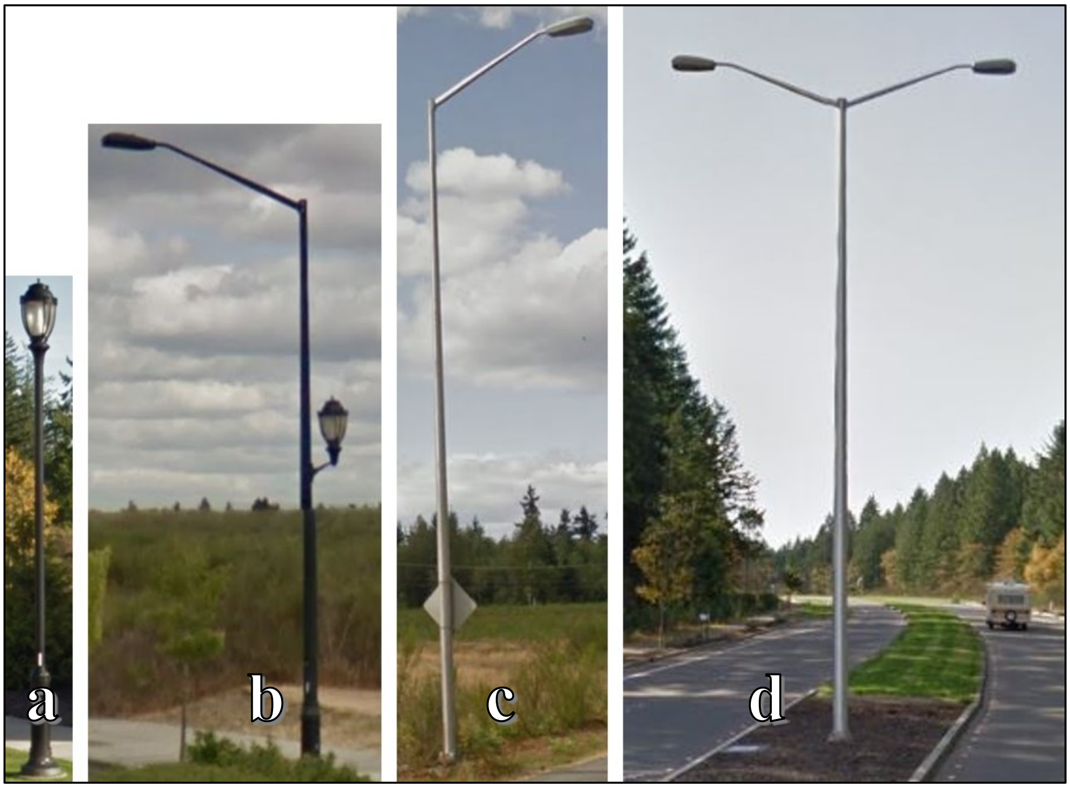

Figure L-1. Streetlight types in the urban CuZn study area.
(a = pedestrian, b = dual function, c = single arm, d = twin arm)

Figure L-2. Traffic signal with 40-foot streetlight controlling four lanes of traffic.

Zinc Loading

The potential Zn loading from streetlights and traffic signals is 33.6 lb/yr and ranges from 7.97 to 74.7 lb/yr. Parking lot lights account for 21.8 lb/yr (64.8%), traffic signals contribute 8.67 lb/yr (25.8%), and streetlight poles release 3.15 lb/yr (9.4%) (Table L-4).

Table L-4. Potential zinc loading from streetlights and traffic signals

Category	Material	Surface Area			Zinc Loading (lb/yr)				
		(m^2)	(ft^2)	(%)	min	median	mean	max	%
Streetlight Poles	Painted	1,809	19,477	5.3%	0.41	1.07	2.14	5.47	6.4%
	Galvanized	225	2,425	0.7%	0.36	1.11	1.01	1.36	3.0%
	Aluminum	11,258	121,183	33.2%	na	na	na	na	na
	Wood	8	90	0.02%	na	na	na	na	na
Parking Lot Lights	Painted	18,376	197,803	54.1%	4.17	10.90	21.76	55.50	64.8%
Traffic Signals	Painted	465	5,001	1.4%	0.11	0.28	0.55	1.40	1.6%
	Galvanized	1,814	19,527	5.3%	2.92	8.95	8.12	10.96	24.2%
Total		**33,957**	**365,506**		**7.97**	**22.3**	**33.6**	**74.7**	

na = not applicable

References for Appendix L

BingMaps. 2017. Aerial and Streetview imagery of Lacey, Washington. Microsoft. https://binged.it/2rs09OM

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Lacey. 2017. Streetlights in Lacey, Washington. February 28, 2017. City of Lacey.

Thurston. 2017. Streetlights in Thurston County, Washington. March 2, 2017.

Appendix M. Signs

Overview

The estimated Zn loading from signs is 12.4 lb/yr. This represents 0.21% of the total Zn release estimated for the urban CuZn study area (Table 2, Figure 4). The majority of sign posts are made of painted metal or galvanized steel. Signs are made of aluminum and do not contain Cu or Zn.

The Zn loading from sign posts is calculated as the product of the exposed surface area and the release rate for either galvanized steel or painted metal.

$$Loading_{SignPost}\left(\frac{g}{yr}\right) = Area_{SignPost}\,(m^2) \times Release\ Rate\left(\frac{g}{m^2 - yr}\right)$$

The total surface area of sign posts and support structures in the study area is 48,976 ft^2 (4,550 m^2). Parking lot signs account for 13,156 ft^2 (26.9%) and street signs have 23,419 ft^2 (47.8%) in the study area (Table M-7). The surface area calculations for signs are described below.

The release rates used are discussed below.

Materials

Signs are constructed of aluminum and do not contain Cu or Zn (WSDOT, 2016). Sign posts in the CuZn study area are constructed with galvanized steel, painted metal, plastic, and wood. For this study, it is assumed that sign posts are made of either painted metal or galvanized steel. Wood and plastic sign post use is limited in the study area.

The sign posts used by the City of Lacey are 2-3/8 inch (0.0603 meter) diameter round posts coated with a clear, acrylic finish (Lacey, 2017). Thurston County and WSDOT use 2-1/2 inch (0.0635 meter) square, perforated posts made of galvanized steel. The support structures for billboards and overhead highway signs are constructed with painted steel (BingMaps, 2017; GoogleMaps, 2017).

Release Rates

The release rates for painted and galvanized steel are given in Table M-1. More information about the development of release rates for painted and galvanized steel is provided in Appendix F.

Table M-1. Release rates for painted and galvanized steel

Source	Zinc Release Rate (g/m^2/yr)			
	min	median	mean	max
Painted Metal	0.10	0.27	0.54	1.37
Galvanized Steel	0.73	2.24	2.0	2.74

Sign Quantity

There are a total of 3,764 standard-sized signs in the CuZn study area. Standard-sized signs are the typical street or parking lot sign with one to three sign posts (Figure M-1). These signs include regulatory (e.g., stop, speed), warning (e.g., caution, curve ahead), and guide (e.g., street name, airport) signs. The height, shape, and number of posts per sign vary (Table M-3). The geometry of the different sign posts is used to calculate the exposed surface areas.

Figure M-1. Standard-sized street warning and guide sign.

There are an estimated 2,056 business parking lot signs in the study area. The number of business parking lot signs is calculated using the median number of signs per parking lot area (sign/km^2) for 41 businesses in the study area (Table M-2).

Parking lot signs are counted using aerial and street view imagery (BingMaps, 2017; Ecology, 2012; Ecology, 2015; GoogleMaps, 2017). There are a median of 900 signs per square kilometer of parking lot (Table M-2). This factor is multiplied by the total business parking lot area (2.28 km^2) to calculate the approximate number of parking lot signs in the study area.

$$\mathrm{Signs}_{\mathrm{Business}} = \mathrm{Factor}_{\mathrm{median}} \left(\frac{\mathrm{signs}}{\mathrm{km}^2}\right) \times \mathrm{Area}_{\mathrm{ParkingLot}}\ (\mathrm{km}^2)$$

$$\mathrm{Signs}_{\mathrm{Business}} = 900 \left(\frac{\mathrm{lights}}{\mathrm{km}^2}\right) \times 2.28\ (\mathrm{km}^2) = 2{,}056\ \mathrm{lights}$$

Table M-2. Business parking lot sign survey results (signs per parking lot area).

Land Use	Parking Lot Signs (sign/km^2)			
	n	Median	Mean	Std Dev
Commercial Retail and Housing	29	910	1021	520
Commercial Services	11	692	825	371
Government and Industrial	1		583	
All Land Use Types	**41**	**900**	**958**	**484**

n = number of businesses, Std Dev = standard deviation

There are 17 billboards in the CuZn study area. Fourteen billboards have 30-foot (9.14 meter) tall, unipole support structures with parallel sign frames. Two billboards have 20-foot tall, two-pole support structures with parallel sign frames. One billboard is a 30-foot (9.14 meter) tall, unipole support structure with a V-shaped sign frame (Figure M-2).

Figure M-2. Billboard structures.
a. 30-foot, unipole with parallel sign frames, b. 30-foot, unipole with V-shape sign frames.

There are three overhead highway signs on Interstate 5 in the study area. One is an electronic reader sign with a T-shaped, monotube support structure. The other two are exit signs with L-shaped monotube support structures (Figure M-3).

Standard-sized Sign Post Area

The exposed surface area of standard-sized sign posts is calculated using the equation for the lateral area of a cylinder for round posts and by calculating the solid surface area of square posts and subtracting the perforated area. There are 12 holes per foot on each side of the square, perforated sign post. The surface areas calculated by these methods are doubled, because most sign posts are not capped and rainfall can contact both the interior and exterior of the sign posts. The dimensions and surface area of various standard-sized sign posts are given in Table M-3.

$$Area_{RoundPost}\ (m^2) = 2 \times \left(2\pi\ \times Radius\ (m) \times Height\ (m)\right)$$

$$Area_{SquarePost}\ (m^2) = 2 \times \left((4 \times Side\ Length\ (m) \times Height\ (m)) - Area_{Perforated}\ (m^2)\right)$$

$$Area_{Perforated}\ (m^2) = Area_{Hole}\ \left(\frac{m^2}{m}\right) \times Height\ (m)$$

$$Area_{Hole}\ \left(\frac{m^2}{m}\right) = 4 \times Area_{Circle}\ (m^2) \times \frac{Holes}{1\ m} = 4 \times \left(\pi\ \times \left(Radius\ (m)\right)^2\right) \times \frac{Holes}{1\ m}$$

$$\frac{Holes}{1\ m} = 4 \times \left(\frac{12\ holes}{1\ ft} \times \frac{1\ ft}{0.3048\ m}\right) = 157\ \frac{holes}{m}$$

Figure M-3. Overhead highway signs.

Table M-3. Standard-sized sign post dimensions, surface areas, and quantity

Sign Post Type	Height (m)	Posts	Post Surface Area (m^2)	Sign Quantity	Total Area (m^2)
2-3/8" Round	3.05	1	1.16	1,100	1,271
1-3/4" Square	1.83	1	0.59	2,056	1,222
2-1/2" Square	1.83	1	0.87	23	20
2-1/2" Square	2.44	1	1.16	59	69
2-1/2" Square	3.05	1	1.46	492	716
2-1/2" Square	1.83	2	1.75	2	3
2-1/2" Square	2.44	2	2.33	7	16
2-1/2" Square	3.05	2	2.91	18	52
2-1/2" Square	3.66	2	3.49	2	7
2-1/2" Square	2.44	3	3.49	2	7
2-1/2" Square	3.05	3	4.37	2	9
2-1/2" Square	3.66	3	5.24	1	5
Total				**3,764**	**3,398**

The typical above-ground post height for standard-sized signs is 10 feet (3.05 meters). Post heights from 4 to 12 feet (1.22 to 3.66 meters) are estimated using street view imagery (BingMaps, 2017; GoogleMaps, 2017). The business signs in the CuZn study area vary from 4 to 8 feet tall (1.22 to 2.44 meters). For this study, it is assumed that all business parking lot signs are 6 feet (1.83 meters) tall and use 1-3/4 inch (0.0445 meter) square, perforated posts. In addition, all WSDOT sign posts on Interstate 5 are assumed to be 2.5 inch square, perforated posts. The taller signs with two or three posts may use larger posts.

Overhead Highway Sign Area

The exposed surface area of overhead highway signs is calculated as the sum of the monotube and sign support brace areas. The dimensions of monotube, sign braces, and the number of support braces are estimated using street view imagery (BingMaps, 2017; GoogleMaps, 2017). The monotube used is 2-foot (0.610 meter) square tube approximately 25 feet (7.62 meter) tall with a 25-foot long cross beam. There are nine 7-foot (2.13 meter) long sign braces on the T-shaped structure and six 10-foot (3.05 meter) sign braces on the L-shaped structures. The sign braces are assumed to be constructed from W4x13 painted steel I-beam. The dimensions and surface areas for the large structure sign systems are provided in Table M-4.

The exposed surface area for the I-beam sign braces are calculated per meter of I-beam length by summing the area of all sides in one meter (Figure M-4). The surface area of each sign brace is calculated by multiplying the area per meter length by the total length of the sign brace. The dimensions of W4x13 I-beam are provided by EngineersEdge (2017).

$$\text{Area}_{\text{SignBrace}}(\text{m}^2) = \text{Area}_{\text{perMeter}}\left(\frac{\text{m}^2}{\text{m}}\right) \times \text{Length (m)}$$

$$\text{Area}_{\text{perMeter}}\left(\frac{\text{m}^2}{\text{m}}\right) = \left(2 \times \text{Area}_{\text{bf}} + 4 \times \text{Area}_{\text{tf}} + 4 \times \text{Area}_{\text{x}} + 2 \times \text{Area}_{\text{y}} + \text{Area}_{\text{ST,top}}\right)$$

$$\text{Area}_{\text{bf}}(\text{m}^2) = \text{bf (m)} \times 1\text{ m};\ \ \text{Area}_{\text{tf}}(\text{m}^2) = \text{tf (m)} \times 1\text{ m};$$
$$\text{Area}_{\text{x}}(\text{m}^2) = (\text{bf (m)} - \text{tw(m)}) \times 1\text{ m};\ \ \text{Area}_{\text{y}}(\text{m}^2) = \left(\text{d (m)} - (2 \times \text{tf (m)})\right) \times 1\text{ m};$$
$$\text{Area}_{\text{top}}(\text{m}^2) = \left(2 \times (\text{bf (m)} \times \text{tf (m)})\right) + \left(\text{tw (m)} \times \left(\text{d (m)} - (2 \times \text{tf (m)})\right)\right)$$

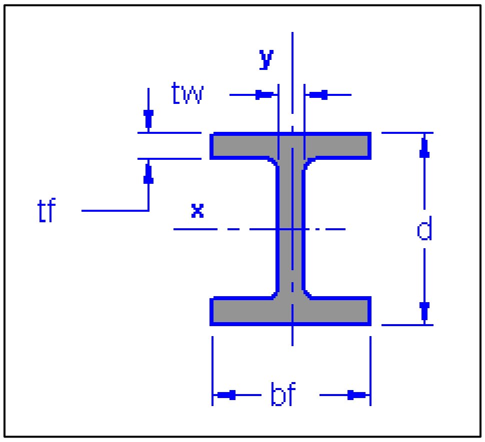

Figure M-4. Cross-sectional view of steel I-beam

Table M-4. Overhead highway sign support system dimensions and surface areas

Monotube Geometry	Monotube Dimensions			Sign Brace (W4x13 I-Beam)				Total Area (m^2)
	Length (m)	Width (m)	Area (m^2)	Area (m2) / m	Qty	Length (m)	Area (m^2)	
T-shaped	15.24	0.610	37.2	0.80	9	2.13	15.36	52.5
L-shaped	15.24	0.610	37.2	0.80	6	3.05	14.63	51.8

Qty = quantity; Area (m2) / m = I-beam surface area per meter of length

Billboard Support Area

The exposed surface area of billboard support structures is calculated as the sum of the surface areas for the pole(s), catwalk(s), and sign frame braces. The dimensions of pole, catwalks, sign braces, and the number of braces are estimated using street view imagery (BingMaps, 2017; GoogleMaps, 2017).

The sign braces are assumed to be constructed from W6x15 painted steel I-beam. The surface area of W6x15 are calculated using the same method described for overhead highway sign braces. The dimensions of W6x15 I-beam are provided by EngineersEdge (2017).

The billboard access catwalks are estimated to be 2 feet (0.61 meters) wide for the 30-foot, unipole parallel sign billboards and 3 feet (0.91 meters) wide for the 30-foot, unipole V-shaped signs billboard. There are no catwalks on the 20-foot, two-pole billboards. The open space of grating catwalks vary from 50-70% of the total area of a catwalk (McNichols, 2017). For this study, it is assumed that all catwalks have an open space of 60%. The exposed surface area of a grating catwalk is calculated by subtracting the area of open space from twice the total area of the catwalk. The catwalk area is doubled to account for the top and bottom of the grating.

$$Exposed\ Area_{catwalk}\ (m^2) = Area_{catwalk}\ (m^2) - Area_{space}\ (m^2)$$

$$Area_{space}\ (m^2) = 0.60 \times Area_{catwalk}\ (m^2)$$

$$Area_{catwalk}\ (m^2) = 2 \times (Length_{catwalk}\ (m) \times Width_{catwalk}\ (m))$$

The billboard support structure dimensions and surface areas are shown in Tables M-5 and M-6.

Table M-5. Billboard catwalk and sign support brace dimensions and surface areas

Pole Geometry	Catwalks				Sign Braces		
	Qty	Length (m)	Width (m)	Area (m^2)	Qty	Length (m)	Area (m^2)
30' unipole, V-shaped	6	12.19	0.91	53.51	6	5.18	37.20
30' unipole, V-shaped	-	-	-	-	8	28.56	34.18
20' unipole, parallel	2	4.57	0.61	4.46	2	4.88	35.01
20' two-pole, parallel	na	na	na	na	2	4.88	35.01

Qty = quantity; na = not applicable

Table M-6. Billboard pole dimensions and surface areas

Billboard Geometry	Vertical Pole			Horizontal Pole			Total Pole Area (m^2)	Total Billboard Area (m^2)
	Height (m)	Diameter (m)	Area (m^2)	Length (m)	Diameter (m)	Area (m^2)		
30' unipole, V-shaped	9.14	0.91	26.27	12.19	0.61	23.35	49.62	174.51
20' unipole, parallel	6.10	0.46	8.76	4.57	0.30	4.38	13.13	52.61
20' two-pole, parallel	6.10	0.30	5.84	na	na	na	5.84	40.85

na = not applicable

Zinc Loading

The estimated Zn loading from sign posts and sign support structures is 12.39 lb/yr and ranges from 3.97 to 20.17 lb/yr. Parking lot signs account for 5.47 lb/yr (44.2%), street signs contribute 5.55 lb/yr (44.8%), billboards leach 1.16 lb/yr (9.38%), and overhead highway signs release 0.20 lb/yr (1.64%) (Table M-7).

Table M-7. Potential zinc loading from sign posts and sign support structures

Sign Category	**Material**	**Surface Area**			**Zinc Loading (lb/yr)**				
		(m^2)	**(ft^2)**	**(%)**	**min**	**median**	**mean**	**max**	**%**
Street	Painted	1,271	13,679	27.9%	0.29	0.75	1.50	3.84	12.15%
	Galvanized	905	9,740	19.9%	1.46	4.47	4.05	5.47	32.69%
Parking Lot	Galvanized	1,222	13,156	26.9%	1.97	6.03	5.47	7.38	44.15%
Overhead Hwy	Painted	171	1,842	3.8%	0.04	0.10	0.20	0.52	1.64%
Billboards	Painted	981	10,560	21.6%	0.22	0.58	1.16	2.96	9.38%
Total		**4,550**	**48,976**		**3.97**	**11.94**	**12.39**	**20.17**	

References for Appendix M

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Appendix N. Cellular Towers

Overview

The estimated Zn loading from cellular towers is 1.48 lb/yr. This represents 0.03% of the total Zn release estimated for the urban CuZn study area (Table 2, Figure 4). Four cellular towers are located in the study area. Two are made of galvanized steel and two are painted metal. All four cellular towers are monotube style towers.

The Zn loading from cellular towers is calculated as the product of the exposed surface area and the release rate for either galvanized steel or painted metal.

$$Loading_{CellTower}\left(\frac{g}{yr}\right) = Area_{CellTower}\,(m^2) \times Release\ Rate\left(\frac{g}{m^2 - yr}\right)$$

The total surface area of cellular towers in the study area is 5,600 ft^2 (524 m^2). The surface area calculation for cellular towers is described below.

Release Rates

The cellular towers in the study area are constructed from either galvanized steel or painted metal. The release rates for painted and galvanized steel are given in Table N-1. Further information about the development of the release rates for painted and galvanized steel is provided in Appendix F.

Table N-1. Release rates for painted and galvanized steel

Source	**Zinc Release Rate (g/m^2/yr)**			
	min	**median**	**mean**	**max**
Painted Metal	0.10	0.27	0.54	1.37
Galvanized Steel	0.73	2.24	2.0	2.74

Cellular Tower Area

The exposed surface area of cellular towers is calculated using the equation for the area of a tapered cylinder. The style and dimensions of cellular towers vary. All cellular towers in the study area are the monotube style tower. The surface area of self-supporting and guyed towers are not addressed in this report (Figure N-1).

For this study, the dimensions of a 148-foot (45.1 meter) tall, monotube cellular tower are used to estimate the surface area of all cellular towers in the study area (Horn, 2011). For monotube towers, each tower section tapers to fit inside the section below it. The bottom diameter of the upper tower section is slightly smaller than the top diameter of the lower tower section. The average of the bottom and top diameters is used to calculate the surface area for a 148-foot cellular tower (Table N-2).

$$\begin{aligned}\text{Area}_{\text{CellTower}}\ (\text{m}^2) &= 2\pi\ \times \text{Average Radius (m)} \times \text{Height (m)}\\ &= \pi \times \text{Average Diameter (m)} \times \text{Height (m)}\end{aligned}$$

$$\text{Area}_{\text{CellTower}}\ (\text{m}^2) = \pi \times \left(\frac{0.56\ \text{m} + 1.29\ \text{m}}{2}\right) \times 45.1\ \text{m} = 131\ \text{m}^2$$

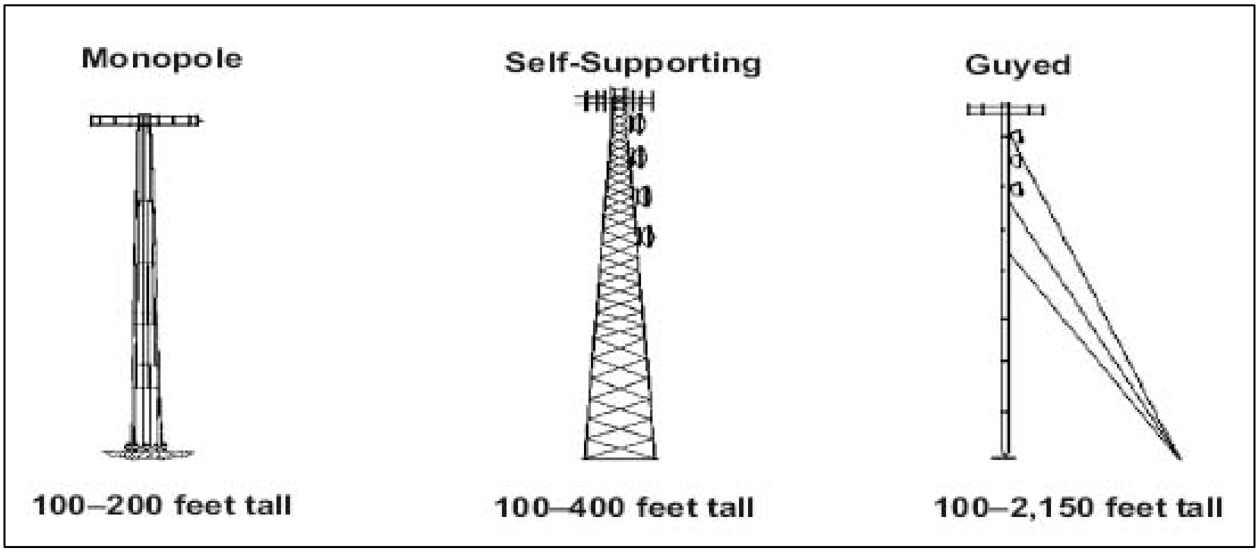

Figure N-1. Monopole, self-supporting, and guyed tower designs.

Table N-2. Dimensions for 148-foot monopole cellular tower (Horn, 2011).

Tower Section	Diameter (m)	Length (m)	Section Area (m2)
1, bottom 1, top	0.56 0.75	11.28	23.21
2, bottom 2, top	0.72 0.93	12.19	31.60
3, bottom 3, top	0.89 1.10	12.19	38.14
4, bottom 4, top	1.06 1.29	13.72	50.53
Tower, bottom **Tower, top**	**0.56** **1.29**	**45.11**	**130.99**

Zinc Loading

The estimated Zn loading from cellular towers is 1.48 lb/yr and range from 0.48 to 1.45 lb/yr. Galvanized towers release 1.17 lb/yr (79.1%) and painted metal towers contribute 0.31 lb/yr (20.9%) in the study area (Table N-3).

Table N-3. Potential zinc loading from cellular towers

Category	Material	Surface Area			Zinc Loading (lb/yr)				
		m2	ft2	%	min	max	mean	median	%
Cell Tower	Painted	262	2,820	50.0%	0.06	0.79	0.31	0.16	20.9%
	Galvanized	262	2,820	50.0%	0.42	1.58	1.17	1.29	79.1%
Total		**524**	**5,640**		**0.48**	**2.37**	**1.48**	**1.45**	

Reference for Appendix N

Horn, D. 2011. Technical memo 1: Design of monopole bases.
http://www.towernx.com/downloads/Technical_Manual_MP_BasePL.pdf
http://www.towernx.com/downloads/example2.pdf

Appendix O. Metal Salvage

Overview

The estimated Zn loading from metal salvage operations is 27.7 lb/yr. That is 0.47% of the total Zn release estimate for the urban CuZn study area (Table 2, Figure 4). The estimated Cu loading from metal salvage operations is 3.92 lb/yr. This represents 0.49% of the total Cu release estimated for the study area (Table 1, Figure 3).

The Cu and Zn loading from metal salvage is calculated as the product of the metal salvage tax parcel area and the release rates for metal scrap and auto wrecking yards.

$$Loading_{Salvage}\left(\frac{g}{yr}\right) = Parcel\ Area_{Salvage}\ (m^2) \times Release\ Rate\ \left(\frac{g}{m^2 - yr}\right)$$

The total surface area of metal salvage businesses is 253,743 ft^2 (23,574 m^2) in the study area (Table O-2). There is one scrap metal business (92,055 ft^2) and one auto wrecking business (161,689 ft^2) in the study area. The tax parcel area for each business is calculated from Thurston County parcel data (Thurston, 2016) using GIS.

Release Rates

The release rates for metal salvage operations are used to calculate the quantity of Cu and Zn released from metal scrap and auto wrecking businesses in the study area (Table O-1).

Table O-1. Release rates for metal salvage operations.

Metal	Release Rates (g/m2/yr)			
	Min	Median	Mean	Max
Copper	0.155	1.24	75.3	269
Zinc	0.183	29.0	534	2467

The release rates for metal salvage operations are calculated using stormwater metals concentrations and business site areas from two previous studies. Line et al. (1997) collected first-flush stormwater samples from industrial facilities across North Carolina. They monitored two auto wrecking yards and three metal scrap and recycling facilities. Blondeel et al. (2014) collected stormwater samples from three metal scrap yards in Belgium.

The release rates are calculated from the results reported by the above studies. The Cu and Zn concentrations from both studies are reported in ug/L. The mass of metal released from each business is calculated by multiplying the metal concentration by the rainfall volume potentially impacting each business. The rainfall volume is calculated as the product of the event rainfall depth and the site area. The release rate for each storm event (g/m^2) is derived by dividing the mass of metal by the site area.

Annual release rates ($g/m^2/yr$) are derived by multiplying each storm-event release rate (g/m^2) by the estimated number of equivalent storm events per year. The annual number of equivalent storm events is determined using the storm event rainfall depths and the regional annual average rainfall depths for North Carolina (CurrentResults, 2017) and Belgium (ClimateData, 2017; TimeDate, 2017).

Line et al. (1997) report rainfall depths for the five storm events monitored. The number of equivalent storm events is calculated for each sampled event using an average annual rainfall depth of 51.6 inches (1310 mm). The annual number of events for the Line et al. (1997) metal salvage results ranges from 32 to 128 storms. Blondeel et al. (2014) monitored one storm event with a rainfall depth of 0.074 inches (1.9 mm). Annual average rainfall for Belgium is 29.7 inches (753 mm). The annual number of equivalent events for the Blondeel et al. (2014) metal salvage results is 396 storms.

Example calculations for metal salvage release rates are shown below.

$$Rainfall\ Volume\ (L) = (Rainfall\ Depth\ (m) \times Site\ Area\ (m^2)) \times \frac{1000\ L}{1\ m^3}$$

$$Mass\ (g) = \left(Copper\ \left(\frac{ug}{L}\right) \times Rainfall\ Volume\ (L)\right) \times \frac{1\ g}{10^6\ ug}$$

$$Storms\ (\frac{events}{year}) = \frac{Average\ Annual\ Rainfall\ (mm)}{Event\ Rainfall\ Depth\ (mm)}$$

$$Release\ \left(\frac{g}{m^2 - yr}\right) = \left(\frac{Mass\ (g)}{Site\ Area\ (m^2)}\right) \times\ Storms\ (\frac{events}{year})$$

The release rates used in this study (Table O-1) are the summary of all storm events sampled by Line et al. (1997) and Blondeel et al. (2014).

Stormwater effluent from multiple metal salvage operations was monitored in California (Hiemstra, 2014). The Cu and Zn concentrations reported are similar to those reported by Line et al. (1997) and Blondeel et al. (2014). Hiemstra (2014) does not provide rainfall depths or site areas. Release rates for metal salvage operations in California are not calculated.

Zinc Loading

The estimated Zn loading from metal salvage operations is 27.7 lb/yr and ranges from 0.0095 to 128 lb/yr. Auto wrecking releases 17.7 lb/yr (63.7%) and scrap metal contributes 10.0 lb/yr (36.3%) in the study area (Table O-2).

Copper Loading

The estimated Cu loading from metal salvage operations is 3.92 lb/yr and ranges from 0.0080 to 14.0 lb/yr. Auto wrecking releases 2.49 lb/yr (63.7%) and scrap metal contributes 1.42 lb/yr (36.3%) in the study area (Table O-2).

Table O-2. Potential copper and zinc loading from metal salvage operations

Salvage Type	**Area**		**Copper Loading (lb/yr)**				**Zinc Loading (lb/yr)**			
	(m^2)	**(%)**	**Min**	**Median**	**Mean**	**Max**	**Min**	**Median**	**Mean**	**Max**
Scrap Recycling	8,552	36.28%	0.0029	0.023	1.42	5.07	0.0035	0.55	10.1	46.5
Auto Wrecking	15,021	63.72%	0.0051	0.041	2.49	8.91	0.0061	0.96	17.7	81.7
Total	**23,574**		**0.0080**	**0.064**	**3.92**	**14.0**	**0.0095**	**1.51**	**27.7**	**128**

Other Considerations

The above estimate of Cu and Zn loading from metal salvage operations is likely an underestimate.

Scrap metal operations demolish, crush, and stack scrap metal. This process exposes more metal surface area and may release fluids from appliances and automobiles. In addition, the tax parcel areas used to calculate potential metals loading do not account for any topographic changes on the actual land parcels in the CuZn study area. Topography may add surface area to the total parcel area.

The release rates used in this study are derived from stormwater samples (Blondeel et al., 2014; Hiemstra, 2014; Line et al., 1997). Stormwater pollutant concentrations are notoriously variable. The release rates calculated from eight salvage yards and six storm events may not fully incorporate all the variability in metals runoff from salvage operations.

References for Appendix O

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Appendix P. Parking Lots

Overview

The estimated Zn loading from parking lots is 790 lb/yr. That is 13.5% of the total Zn release estimate for the urban CuZn study area (Table 2, Figure 4). The estimated Cu loading from parking lots is 52.5 lb/yr. This represents 6.6% of the total Cu release estimated for the study area (Table 1, Figure 3).

The Cu and Zn loading from parking lots is calculated as the product of the parking lot area and the release rates for parking lots.

$$Loading_{ParkingLots}\left(\frac{g}{yr}\right) = Area_{ParkingLots}\,(m^2) \times Release\ Rate\left(\frac{g}{m^2 - yr}\right)$$

The total surface area of parking lots in the study area is 2,281,697 m^2 (2.28 km^2). The parking lots are digitized and the lot areas calculated using GIS.

Release Rates

The release rates for parking lots are calculated using washoff concentrations from parking lot test plots in Austin, Texas. Mahler et al. (2004) washed a variety of parking lot test plots (e.g., asphalt sealed with different sealants) with a synthetic rainwater mixture and analyzed the runoff. The resultant Cu and Zn concentrations were multiplied by the runoff volume (100 liters) to calculate the mass of metal released. The mass was divided by the test plot area (50 m^2) and multiplied by the annual number of equivalent storm events to determine an annual release rate (mg/m^2/yr). The annual number of equivalent storm events is calculated by dividing the annual average rainfall depth (0.87 meters) for Austin, Texas (USClimateData, 2017) by the equivalent rainfall depth (0.0020 meters) for each washoff event. The annual number of equivalent events for the Mahler et al. (2004) parking lot results is 434 storms.

$$Mass\ (mg) = \left(Copper\left(\frac{mg}{L}\right) \times Wash\ Volume\ (L)\right)$$

$$Event\ Rainfall\ Depth\ (m) = \frac{Runoff\ Volume\ (m^3)}{Test\ Plot\ Area\ (m^2)}$$

$$Storms\ (\frac{events}{year}) = \frac{Average\ Annual\ Rainfall\ (m)}{Event\ Rainfall\ Depth\ (m)}$$

$$Release\left(\frac{mg}{km^2 - yr}\right) = \left(\frac{Mass\ (mg)}{Site\ Area\ (km^2)}\right) \times Storms\ (\frac{events}{year})$$

The release rates used in this urban CuZn study (Table P-1) are the summary of all parking lot test plots sampled by Mahler et al. (2004).

Table P-1. Release rates for parking lots

Metal	**Release Rates (mg/m2/yr)**			
	Min	**Median**	**Mean**	**Max**
Copper	0.352	2.83	10.4	71.8
Zinc	3.98	39.8	157	1034

Zinc Loading

The estimated Zn loading from parking lots is 790 lb/yr and ranges from 20.0 to 5199 lb/yr (Table P-2).

Copper Loading

The estimated Cu loading from parking lots is 52.5 lb/yr and ranges from 1.77 to 361 lb/yr (Table P-2).

Table P-2. Potential copper and zinc loading from parking lots

Metal	**Area**		**Loading (lb/yr)**			
	(m^2)	**(km^2)**	**Min**	**Median**	**Mean**	**Max**
Copper	2,281,697	2.28	1.77	14.2	52.5	361
Zinc			20.0	200	790	5199

References for Appendix P

Mahler, B. J., P. C. Van Metre and J. T. Wilson. 2004. Concentrations of polycyclic aromatic hydrocarbons (PAHS) and major and trace elements in simulated rainfall runoff from parking lots, Austin, Texas, 2003. United States Geological Survey. 2004-1208. https://pubs.usgs.gov/of/2004/1208/pdf/ofr2004-1208_version3.pdf

USClimateData. 2017. Climate data for Austin, Texas. U.S. Climate Data. http://www.usclimatedata.com/climate/texas/united-states/3213

Appendix Q. Release Rates

Release rates for potential sources of Cu and Zn are compiled from previous studies. The Cu and Zn loading values are calculated using minimum, median, mean, and maximum release rates. For some sources, only a mean release rate is available. The release rates for building materials (Table Q-1) and vehicle wear (Table Q-2) are summarized below. The studies that provided the release rates are summarized in Table Q-3.

Table Q-1. Building material release rates.

Category	Source	Copper Release Rate				Zinc Release Rate				Units
		Min	Median	Mean	Max	Min	Median	Mean	Max	
Roofing	Wood Shakes (treated)	1.50	4.68	6.02	17.9	-0.0251	0.0287	0.0313	0.107	g/m2/yr
	Asphalt Shingle with AR	0.016	0.162	0.264	2.186	na	na	na	na	g/m2/yr
	Asphalt Shingle	-0.002	0.008	0.013	0.133	na	na	na	na	g/m2/yr
	Painted Galvanized	na	na	na	na	0.103	0.269	0.537	1.37	g/m2/yr
	PVC	na	na	na	na	-0.017	0.011	0.016	0.185	g/m2/yr
	EPDM	na	na	na	na	0.074	0.383	0.584	2.71	g/m2/yr
	Built Up	0.0009	nd	nd	0.166	0.009	nd	nd	1.155	g/m3
	Clay Tile	0.0028	0.0019	nd	0.071	0.006	0.0185	nd	0.85	g/m3
Siding	Concrete wall	<1	0.000016	0.000035	0.00017	0.00022	0.0014	0.00012	0.0019	g/m2/yr
	Brick	0.0012	0.0044	0.0091	0.0540	0.0050	0.1388	0.4047	4.4326	g/m2/yr
	Painted Wood	<1	0.0066	0.0154	0.0540	0.0069	0.3084	0.5396	1.6189	g/m2/yr
	Metal	<1	<1	0.0003	0.0009	0.0050	0.0231	0.1330	0.4818	g/m2/yr
	Unpainted Wood	0.0008	0.0044	0.0231	0.0617	0.0108	0.0385	0.0636	0.1407	g/m2/yr
	Vinyl	0.0008	0.0015	0.0031	0.0067	0.0046	0.0127	0.0116	0.0175	g/m2/yr
Material	Galvanized	na	na	na	na	0.73	2.24	2.0	2.74	g/m2/yr
	Painted Galvanized	na	na	na	na	0.103	0.269	0.537	1.37	g/m2/yr
	CCA-treated Wood	0.09	0.20	0.36	0.82	na	na	na	na	g/m2/yr
	ACQ-treated Wood	nd	nd	16.55	nd	na	na	na	na	g/m3/yr
Salvage	Metal Salvage	0.352	2.83	10.4	71.8	3.98	39.8	157	1034	mg/m2/yr

AR = algae-resistance, PVC = polyvinyl chloride, EPDM = ethylene propylene diene terpolymer; na = not applicable, nd = no data
CCA = chromated copper arsenate, ACQ = alkaline copper quaternary

Table Q-2. Vehicle wear release rates.

Category	Source	Copper Release Rate				Zinc Release Rate				Units
		Min	Median	Mean	Max	Min	Median	Mean	Max	
Brakes	Motorcycles	0.145	nd	0.248	0.330	0.037	nd	0.062	0.083	mg/km-vehicle
	Passenger Cars	0.290	nd	0.495	0.660	0.073	nd	0.125	0.166	mg/km-vehicle
	Light Duty Vehicles	0.581	nd	0.77	0.96	0.146	nd	0.194	0.241	mg/km-vehicle
	Heavy Duty Vehicles (disc)	1.55	nd	2.16	2.77	0.390	nd	0.543	0.697	mg/km-vehicle
	Heavy Duty Vehicles (drum)	0.125	nd	0.173	0.223	0.102	nd	0.143	0.183	mg/km-vehicle
Tires	Motorcycles	na	na	na	na	0.252	nd	0.276	0.318	mg/km-vehicle
	Passenger Cars	na	na	na	na	0.402	nd	0.642	0.972	mg/km-vehicle
	Light Duty Vehicles	na	na	na	na	0.528	nd	1.01	1.30	mg/km-vehicle
	Heavy Duty Vehicles	na	na	na	na	1.36	nd	2.70	5.39	mg/km-vehicle
Roadway	Motorcycles	nd	0.0018	nd	nd	nd	0.0020	nd	nd	mg/km-vehicle
	Passenger Cars	nd	0.0036	nd	nd	nd	0.0041	nd	nd	mg/km-vehicle
	Light Duty Vehicles	nd	0.0036	nd	nd	nd	0.0041	nd	nd	mg/km-vehicle
	Heavy Duty Vehicles	nd	0.0180	nd	nd	nd	0.0208	nd	nd	mg/km-vehicle
Leaks	Motorcycles	nd	nd	0.0025	nd	nd	nd	2.9	nd	ug/km-vehicle
	Cars & Light Duty Vehicles	nd	nd	0.0025	nd	nd	nd	2.9	nd	ug/km-vehicle
	Heavy Duty Vehicles	nd	nd	0.0019	nd	nd	nd	2.1	nd	ug/km-vehicle
Exhaust	Light Duty Vehicles	nd	nd	14.7	nd	nd	nd	45.5	nd	ug/km-vehicle
	Heavy Duty Vehicles	nd	nd	88	nd	nd	nd	136.6	nd	ug/km-vehicle
Parking	Parking Lots	0.155	1.24	75.3	269	0.183	29.0	534	2467	g/m2/yr

na = not applicable, nd = no data

Table Q-3. Literature references for copper and zinc release rates.

Source	**Reference**
Roofing	Barron (2006); Good (1993); Mitchell and Sources (2003); Persson and Kucera (2001); Winters and Graunke (2014); Winters et al. (2014)
Siding	Davis et al. (2001)
Construction Materials	Legret and Pagotto (1999); Persson and Kucera (2001); Bertling (2005); Taylor Associates (2004); Winters et al. (2014); Freeman and McIntyre (2008); Hasan et al. (2010), Kennedy and Collins (2001); Taylor and Cooper (2005)
Metal Salvage	Line et al. (1997); Blondeel et al. (2014)
Brakes	Ntziachristos and Boulter (2003); Wesley and Whiley (2013); Ecology (2017)
Tires	Ntziachristos and Boulter (2003)
Roadway	von der Gon et al. (2008); Ntziachristos and Boulter (2016)
Vehicle Leaks	Kennedy et al. (2002)
Vehicle Exhaust	Gertler et al. (2002); Kennedy et al. (2002)
Parking Lots	Mahler et al. (2004)

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Appendix R. Glossary, Acronyms, and Abbreviations

Glossary

CuZn study area: A portion of the lower Woodland Creek watershed primarily within the City of Lacey and part of Thurston County, Washington.

Effluent: An outflowing of water from a natural body of water or from a man-made structure. For example, the treated outflow from a wastewater treatment plant.

Mean: A mathematical expression denoting the average value of a population of observed values. The mean is calculated by dividing the sum of all values by the quantity of values.

Median: A mathematical expression denoting the value lying at the midpoint of a population of observed values. There is an equal probability of falling above or below the median value.

Range: A mathematical expression denoting the variability of all observed values. The range is calculated as the minimum value subtracted from the maximum value.

Standard Deviation: A mathematical expression denoting the amount of variation or dispersion of a set of data values. Standard deviation is calculated as the square root of the variance. For this study, the range rule of thumb is used to calculate the standard deviation as the range of data values divided by four.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

ACQ	Alkaline copper quaternary
BMP	Best management practice
CCA	Chromated copper arsenate
Cu	Copper
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
LCR	Lead and Copper Rule
USGS	U.S. Geological Survey
WSDOT	Washington State Department of Transportation
Zn	Zinc

Units of Measurement

ft^2	square feet, a unit of area
g	gram, a unit of mass
$g/m^2/yr$	gram per square meter per year, annual release rate per area
g/km/yr	gram per kilometer per year, annual release rate per kilometer traveled
in^2	square inch, a unit of area
kg	kilograms, a unit of mass equal to 1,000 grams
km	kilometer, a unit of length equal to 1,000 meters
km^2	square kilometer, a unit of area
lb/yr	pounds per year, unit of chemical release
m	meter
m^2	square meter, a unit of area
mg	milligram
mg/Kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
$mg/m^2/yr$	milligram per square meter per year, annual release rate per area
mL	milliliters
ug	micrograms
ug/L	micrograms per liter (parts per billion)