Evaluating Sources of Zinc in the Los Cerritos Watershed

A Report to the Los Cerritos Channel Watershed Group
and the State Water Resources Control Board

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Executive Summary

In Southern California, zinc is a difficult stormwater pollutant to mitigate. Zinc from anthropogenic sources builds up on the expanding number of impermeable surfaces in cities, and is then picked up by stormwater during rain events which can result in negative effects depending on its ultimate transportation and fate. For example, vehicle tires typically contain zinc which gets transferred to road surfaces as tires wear down. In metropolitan settings, traffic congestion leads to extra braking and idling, causing more zinc to accumulate on roadways. During first flush or any rainfall event, the zinc is then picked up and discharged into receiving waters including the Pacific Ocean. Although in theory, zinc can be removed using filtration systems, the massive volume of water that flows from urban landscapes during rain events makes this approach a challenging option for treatment.

Our project focused on identifying sources of zinc pollution in the Los Cerritos Channel Watershed, which has historically exceeded water quality standards for the metal and currently has a federal Clean Water Act Total Maximum Daily Load (TMDL) implemented to restore water quality for the channel. Common sources of zinc cited in literature include tire debris, industrial stormwater runoff and galvanized metal surfaces, such as roofs. Originally, we undertook a three-pronged approach using modeling, remote sensing, and Geographic Information Systems (GIS) to map out and analyze where sources or potential sources of zinc were located within the watershed. Over the course of the project, all three approaches faced challenges, such as insufficient data and low resolution imagery, which hindered effective analysis and development of noteworthy conclusions that would be useful for source prevention and monitoring within the watershed. Eventually, both modeling and remote sensing, at least using current publicly available data or imagery proved not to be an efficient way of identifying or tracking zinc source distribution. With the publicly available data we did have access to, we could not definitively come to any significant conclusions about zinc pollution in the watershed or the distribution of its sources, but we were able to form preliminary suggestions about which subbasins within the Los Cerritos Channel are of highest concern and warrant further investigation, and to provide a set of potential future steps based on the analysis we have done.

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List of Acronyms

µg/L - Micrograms per liter
AC - Air Conditioning
AVIRIS - Airborne Visible/Infrared Imaging Spectrometer
BMPs - Best Management Practices
CEDEN - California Environmental Data Exchange Network
CWA - Clean Water Act
DDT - Dichlorodiphenyltrichloroethane
EPA - Environmental Protection Agency
ESA - European Space Agency
GI - Green Infrastructure
GIS - Geographic Information Systems
IGP - Industrial General Permit
LID - Low Impact Development
LCC - Los Cerritos Channel
LCCWMP - Los Cerritos Channel Watershed Management Program
LCCCIMP - Los Cerritos Channel Coordinated Integrated Monitoring Program
MBAS - Methylene Blue Active Substances
MS4 - Municipal Separate Stormwater Sewer Systems
NAIP - National Agriculture Imagery Program
NASA - National Aeronautics and Space Administration
NPDES - National Pollutant Discharge Elimination System
PAHs - Polycyclic Aromatic Hydrocarbons
PCBs - Polychlorinated Biphenyls
RGB - Red, Green, Blue
S2A - Sentinel 2A
SB - Subbasin
SMARTS - Stormwater Multiple Application and Report Tracking System
TIGER - Topographically Integrated Geographic Encoding and Referencing
TMDL - Total Maximum Daily Load
TSS - Total Suspended Solids
WLA - Waste Load Allocation
WMP - Water Management Program
WQBELs - Water Quality-Based Effluent Limitations

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I. Introduction

The Los Cerritos Channel Watershed is a densely populated area of mixed residential, commercial, and industrial development located between Long Beach and Seal Beach in southern Los Angeles County, California. It covers 27.7 square miles in southern Los Angeles County, California and extends slightly north of the I-105 freeway in Downey, south to Atherton Street in Long Beach. It is a small-scale watershed, with nothing upstream that is bringing pollution into the channel. The Los Cerritos Channel, which drains into Alamitos Bay on the Pacific Ocean, is heavily polluted by a variety of pollutants, including metals such as zinc, as a result of stormwater runoff from the surrounding land uses.

Expansion of urban areas has drastically increased the amount of impervious cover in our landscapes. These impervious surfaces, such as streets and sidewalks, rooftops, and parking lots, not only increase the amount of surface runoff that occurs during rain events, but also collect contaminants such as metals and sediment, which are then transported to receiving waters when these rain events occur. A particular pollutant of interest in the Los Cerritos Watershed is zinc, which is toxic to aquatic life. Major sources of zinc in stormwater include man-made products such as gutters, roofs, fencing, light poles and sign posts, and pipes, which use a galvanized coating on their surfaces to prevent oxidation or rust. Tires also have zinc embedded in their rubber, which transfers to roadway asphalt through wear, especially during heavy traffic conditions.

Zinc is of particular concern for the Los Cerritos Channel as pollution levels have consistently been found to be at levels above water quality standards. A wide variety of health and environmental harm, including increased toxicity in aquatic systems, can result from discharges of stormwater contaminated with heavy metals such as zinc at levels higher than established water quality standards. While the natural concentrations of zinc within water bodies and soils are generally not harmful to living organisms, both of these environments can become toxic for zinc through anthropogenic additions. Even low increases in heavy metal concentrations can have major impacts, such as adversely affecting fish development and behavior, and increasing fish mortality (Giardina, Larson, Wisner, Wheeler, & Chao, 2009; Golding, 2008).

The federal Clean Water Act (CWA) regulates water quality standards and discharges of pollutants into waters of the U.S. from any point source - which are defined or discrete conveyances such as a pipe or drainage ditch. Under the CWA, stormwater is considered a point source, which means that cities, which operate municipal separate stormwater sewer systems (MS4s) to manage stormwater and industrial facilities that generate stormwater runoff are subject to stringent regulations and must obtain permits through the CWAs National Pollutant Discharge Elimination System (NPDES) program for discharge of the runoff. For many states, the state issues a “General Permit” for industrial sites, and individual facilities can register under the permit, agreeing to meet its stormwater management requirements. One problem with this system, however, comes from some industrial sites in the city not registering themselves, and therefore lacking a way to regulate and monitor their discharge.

To protect and restore water quality, Total Maximum Daily Loads, or TMDLs, are implemented. TMDLs set the maximum amount of pollutant a waterbody can receive and still safely achieve water quality standards, and they have also been set within the Los Cerritos Channel to regulate water quality standards. In fact, 68% of samples taken in the channel tested for dissolved zinc exceeded both acute and chronic criteria ("Total Maximum Daily Loads for Metals, March 2010," n.d.). As a result, the U.S. Environmental Protection Agency (EPA) has developed an additional, wet-weather TMDL for zinc. In order to come into compliance with the TMDL, the levels of zinc must be reduced. Table 1 provides a summary of the TMDL load limitations, along with storm volumes, calculated loads, and exceedance factors for storm events from 2011 through 2013. Because of the negative effects that zinc has on aquatic environments when biologically available and the frequency of zinc exceeding water quality standards in the watershed, there have been efforts to reduce and mitigate its levels in stormwater runoff.

		TMDL Load Limits* (ug/L)								
		Total Copper	Total Lead	Total Zinc						
		9.8	55.8	95.6						
		TMDL Load Limits (kg/day)			Total Measured Loads (kg/day)			Exceedance Factors		
Storm Season	Total Flow (L)	Total Copper	Total Lead	Total Zinc	Total Copper	Total Lead	Total Zinc	Total Copper	Total Lead	Total Zinc
2011-2012	2.07E+08	2	11.6	19.8	16.2	7.7	116	8.0	0.7	5.9
	2.99E+08	2.9	16.7	28.6	11.6	7.8	86	4.0	0.5	3.0
	2.36E+08	2.3	13.2	22.6	4.5	2.2	31	1.9	0.2	1.4
	1.80E+08	1.8	10.1	17.2	10.4	7.7	70	5.9	0.8	4.1
2012-2013	2.60E+08	2.6	14.5	24.9	13.3	12	102	5.2	0.8	4.1
2013-2014	6.47E+07	0.63	3.6	6.2	3.3	1.3	21	5.2	0.4	3.4
	2.72E+07	0.27	1.5	2.6	1.5	0.34	9.4	5.6	0.2	3.6
	3.98E+08	3.9	22.2	38.0	14	8	100	3.6	0.4	2.6
	1.11E+08	1.1	6.2	10.6	5.4	3	43	5.0	0.5	4.1
2014-2015	1.11E+08	1.1	6.2	10.6	13.3	5.2	122	12.2	0.8	11.5
	4.67E+08	4.57	26.0	44.6	14.0	7.5	107	3.1	0.3	2.4
	7.22E+08	7.08	40.3	69.1	52.0	33.2	347	7.3	0.8	5.0
	1.12E+08	1.1	6.2	10.7	5.9	3.4	47	5.4	0.5	4.4

* = See Table 6-2, pg. 35 in USEPA, "Los Cerritos Channel Total Maximum Daily Loads for Metals". March 2010.
TMDL Load Limits calculation: TMDL (kg/day) = daily storm volume (liters) X TMDL Load Limit (µg/L) / 1,000,000,000
TMDL Measured Load calculation: TMDL (kg/day) = daily storm volume (liters) X sample result (µg/L) / 1,000,000,000
Exceedance Factor Calculations = Total Measured Load / TMDL Load Limit
GREEN indicates exceedance factors of less than 1
RED indicates exceedance factors greater than 1

Table 1: TMDL Load Limitations and Measured Loads at the Los Cerritos Monitoring Site during Storm Events (City of Long Beach Stormwater Monitoring Report 2014/15 (July 2015))

Both traditional gray infrastructure and Low Impact Development (LID) best management practices (BMPs) have been used to try to meet stormwater management goals for the channel. BMPs are used to prevent, intercept, and treat stormwater at the source and near points of discharge (US EPA, 2018b). LID is also an effective method to reduce and mitigate pollutants in stormwater and such practices are designed to mimic natural hydrologic processes that infiltrate, retain, and filter stormwater, effectively removing a variety of pollutants, including heavy metals. These infrastructural changes can help improve water quality and water treatment of stormwater, but removing zinc from stormwater is incredibly difficult because of the sheer volume of stormwater. Instead, it is more effective to prevent zinc from entering water bodies in the first place. However, the many different possible sources of zinc make it challenging to identify what contribute the most and determine their locations.

This project will focus on developing a methodology to identify the distribution of zinc within the Los Cerritos Channel Watershed by using remote methods such as satellite imagery and Geographic Information Systems (GIS). In doing so, we hope to determine a way to be able to apply this methodology to other watersheds that may similarly see high levels of zinc pollution, or even other types of pollutants in stormwater. As already mentioned, zinc is of particular interest to the Los Cerritos Channel Watershed because this area has historically high levels. In order to meet regulations, these levels must be brought down.

II. Background

Background of the Los Cerritos Watershed

The Los Cerritos Channel Watershed covers an area of approximately 17, 711 acres on the Los Angeles Coastal Plain in southern Los Angeles County, and drains to the Pacific Ocean. Figure 1 shows the cities the Watershed encompasses. The majority of the land use (93%) in the watershed consists of urban development; approximately 60% of the land use is residential, 9% mixed urban, 15% commercial, and 9% industrial. The Los Cerritos Channel is an open flood control channel in which water is free to flow through the channel and drain into other bodies of water.

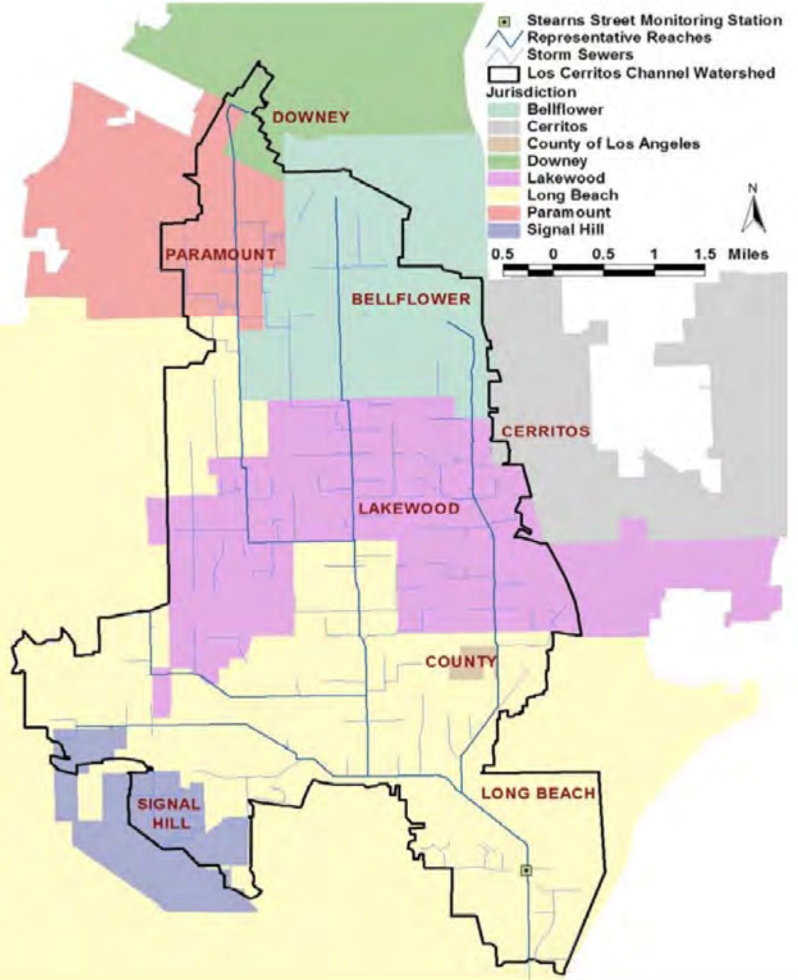


Figure 1: Cities of the Los Cerritos Channel Watershed

Stormwater

Stormwater, defined by the EPA, is runoff generated by rainfall and snowmelt in which the water flows over land and impervious surfaces such as paved streets, parking lots, and rooftops without being soaked into the ground (OW US EPA, 2015). As the runoff covers these surfaces, it may pick up contaminants and pollutants. Components of stormwater pollution can include: oil, pathogenic bacteria and viruses, nutrients, sediments and heavy metals; with a variety and range of adverse effects on humans and the environment (Ma, Egodawatta, McGree, Liu, & Goonetilleke, 2016). As a result, stormwater pollution is a concern due to the negative effects it can have on the environment and public health.

Metal Pollutants

Heavy metals are defined as naturally occurring elements with at least five times the density of water and high atomic weight (Tchounwou, Yedjou, Patlolla, & Sutton, 2012). Some heavy metals, such as manganese and iron at low concentrations, are beneficial and necessary in performing biological functions (Jaishankar, Tseten, Anbalagan, Mathew, & Beeregowda, 2014). However, they may also be considered pollutants when found in the environment. Lead, cadmium, copper and zinc are some of the most studied heavy metals found in stormwater pollution. because they are known to be toxic to human and biological health when found in high concentrations (Pitt, n.d.). Impacts can range from adversely affecting fish development, to reducing water quality by making it toxic, to causing stomach and cholesterol concerns and carcinogenic effects in humans (Young, Kochenkov, McIntyre, Stark, & Coffin, 2018).

Stormwater in the Los Cerritos Channel

Los Cerritos Channel had been listed as impaired for copper, lead, and zinc under the CWA and has also been listed as impaired for changes in pH and other pollutants that do not have TMDL requirements that need to be met (2017). For stormwater and pollutants, TMDLs must take into account both wet and dry weather conditions, as runoff from both weather conditions contribute to water quality degradation. Dry weather runoff in the Los Cerritos Channel comes partially from discharges to MS4s from bad residential or commercial practices such as overwatering (LCCWMP, 2017). Wet weather runoff comes from rain events, and can include a vast array of pollutants, one of which is metals. The sources of these metals in stormwater are normally attributed to metals left on land – either from anthropogenic or natural sources – which then accumulates and is swept up when it rains (2017). Despite this, wet weather monitoring only finds exceedances for copper and zinc, and dry weather monitoring is ongoing with no current metals exceedances (2017).

Water Quality in the Los Cerritos Channel

Those with MS4 permits must clearly state the quality priorities that will be addressed by a Water Management Program (WMP), which would include effluent limitations in the context of the existing water quality conditions and stormwater discharges into a body of water (LCCWMP, 2017). There are three Clean Water Act MS4 permits associated with the Los Cerritos Channel Watershed: the Long Beach MS4 Permit, Los Angeles County MS4 Permit, and the Caltrans Permit. The CIMP divides pollutants into three categories by priority; Category 1 is for Highest Priority, Category 2 for High priority, and Category 3 for Medium priority (2017). Category 1 pollutants are copper, lead, zinc, dichlorodiphenyltrichloroethane (DDT), chlordane, polychlorinated biphenyls (PCBs), and Polycyclic aromatic hydrocarbons (PAHs) (LCCCIMP, 2015). Category 2 pollutants are ammonia, bisethylhexylphthalate, *E. coli*, and pH (2015). Category 3 pollutants are methylene blue active substances (MBAS) and enterococcus (2015). Both Category 1 and 2 pollutants have data about the quality impairment that they cause within water bodies, as well as effluent limitations, but Category 3 pollutants do not have sufficient data to indicate the degree of water quality impairment as well as receiving water limitations (2015).

Monitoring in the Los Cerritos Channel

The Los Cerritos Channel Cooperative Integrated Monitoring Program (CIMP) was created in order to monitor TMDL concentrations in receiving waters. Monitoring sites for the Los Cerritos Channel include Subbasins (SB) 4, 8, 9, and 10, shown in Figures 2 and 3. The main objectives of the program were to "assess the impacts of discharges on receiving waters, assess compliance with receiving water limitations and water quality-based effluent limitations (WQBELs), characterize pollutant loads in MS4 discharges, identify sources of pollutants in MS4 discharges, and measure and improve the effectiveness of pollutant controls implemented under the new MS4 permits" (Kinnetic Laboratories Incorporated, 2015). Data has been collected by the City of Long Beach and the Los Cerritos Channel Watershed Group at the Stearns Street mass emission monitoring station (designated as LCC1) dating back to 1999. Additional monitoring data from the subbasin (SB) sites, however, has only been collected more recently.

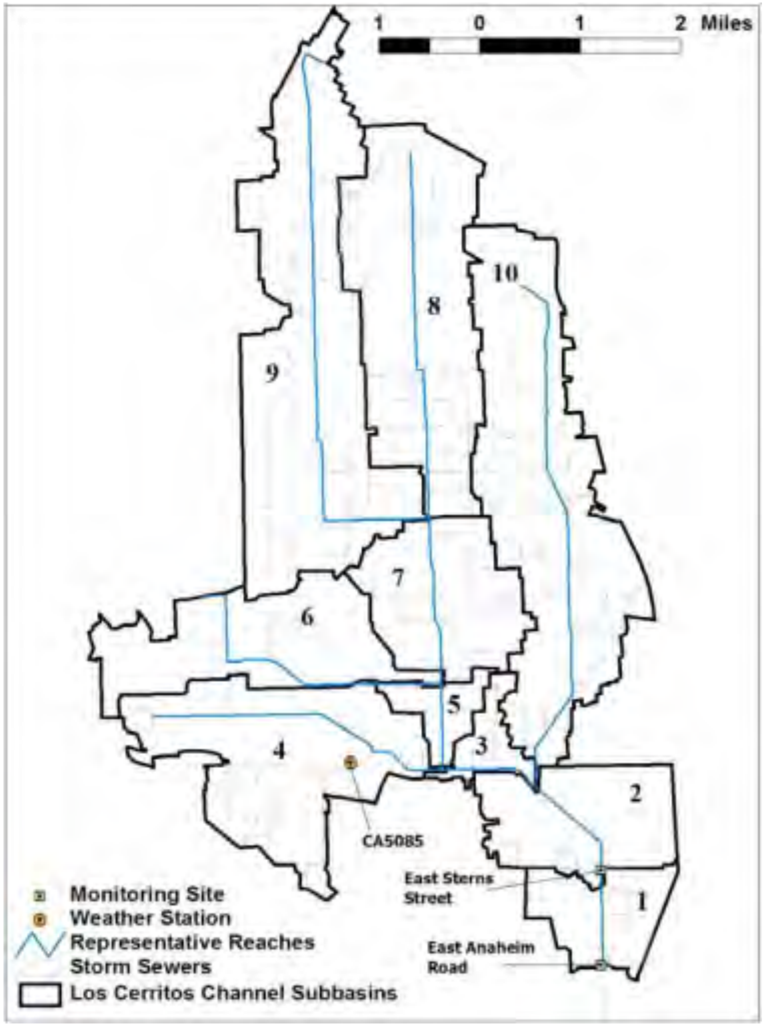
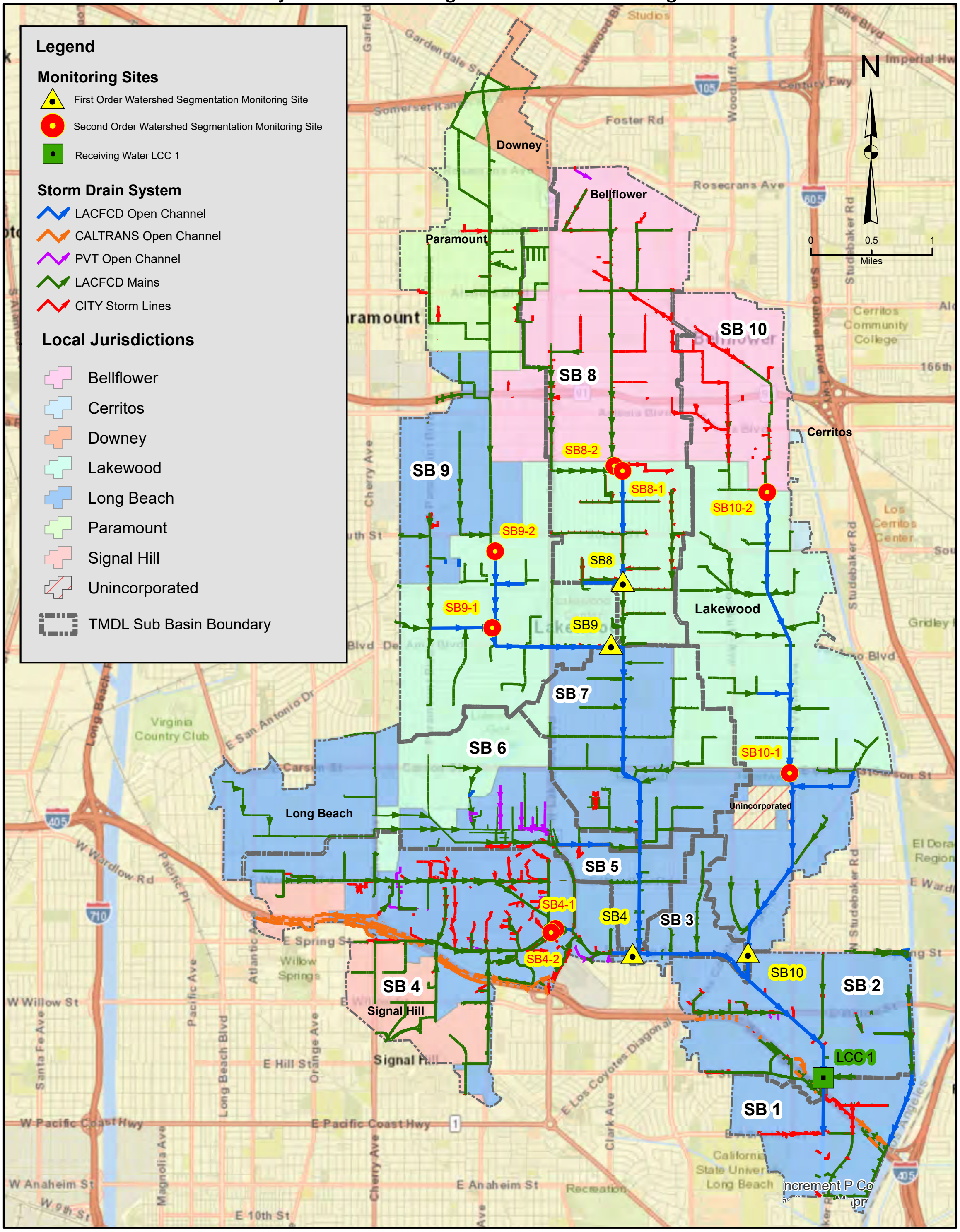


Figure 2: Subbasins of the Los Cerritos Channel Watershed

Los Cerritos Watershed

Primary Watershed Segmentation Monitoring Sites



Richard Watson & Associates, Inc.

Date: 2/10/2018

Figure 3: Locations of Monitoring Sites chosen by the Los Cerritos Channel Integrated Monitoring Program. These sites receive discharge from their respective subbasins.

Regulatory Background

The Federal Water Pollution Control Act, commonly known as the Clean Water Act (CWA), was passed in 1972 to regulate the discharge of pollutants into United States waters (CWA § 101). Section 402 of the Clean Water Act required the creation of a National Pollution Discharge Elimination System (NPDES) Permit which prohibits the discharge of pollutants from a point source into waters of the United States, generally navigable or otherwise protected surface waters, without a permit under the National Pollutant Discharge Elimination System program.. The EPA regulates point sources that enter bodies of water from an operating and permitted facility in order to set and meet limitations for toxic pollutants. Point sources are defined as discrete or confined conveyances such as pipes or ditches and may be stationary pollution sources. However, stormwater is included as a point source under the CWA and so a permit must be obtained to prevent discharges of pollutants in stormwater runoff. While the EPA is responsible for overseeing the CWA and regulating its implementation, many states have been delegated the authority to decide how they will be implemented and enforced. In California, the CWA is implemented by the State Water Resources Control Board (State Board) and nine Regional Water Quality Control Boards (Regional Board).

To meet water quality compliance levels under CWA, each state must develop Total Maximum Daily Loads (TMDLs) for waters that are impaired for any pollutant according to their priority rankings (US EPA, 2018c). TMDLs are a system put in place to restore impaired waters by setting levels for the maximum amounts of pollutants a body of water can handle to bring the water back into compliance with water quality standards (US EPA, 2018c). A TMDL is generally comprised of wasteload allocations (WLAs) for point sources, load allocations for nonpoint sources, and a margin of safety (US EPA, 2018c), and must accommodate for various weather conditions as well. The Los Cerritos Channel's most current wet weather TMDLs for zinc is Daily Storm Volume * 95.6 µg/L (LCCWMP, 2017).

The CWA mandates industrial facilities, construction sites, and municipal separate stormwater sewer systems (MS4s) to have permits in place to prevent polluted stormwater from being discharged into surrounding waterways. Polluted stormwater runoff and urban dry-weather runoff often travel through municipal separate storm sewer systems and drain untreated into local water bodies, often leaving them impaired. Various permits can be obtained to prevent harmful pollutants from entering MS4s. The Los Cerritos Channel Watershed Group, with the exception of the City of Long Beach, is covered by the Los Angeles County MS4 Permit which includes the following cities: Bellflower, Cerritos, Downey, Lakewood, Long Beach, Paramount, and Signal Hill.

Under the CWA, industrial facilities that discharge pollutants into stormwater or surface waters need to apply for an NPDES permit; rather than having each site apply for its own permit, in California the State Water Board has developed an Industrial General Permit (IGP). The IGP is categorized as a general permit because any "industrial" site can apply to be covered under this permit, but the application of the permit and specific controls at each site is dependent on the facilities (California State Water Resources Control Board, 2019). There are ten regulated industrial activities defined by the EPA; the ones that are most relevant to the scope of our project include coal and oil mining, landfills, hazardous waste treatment, metal scrapyards and car junkyards, and construction sites (US EPA, 2019). Though adequate in theory, many industrial sites are not held accountable for polluting stormwater because they do not register themselves as industries.

In order to regulate point sources that enter bodies of water from an operating and permitted facility, the EPA sets limitations for toxic pollutants. The NPDES program requires the implementation of Best Management Practices (BMP) to ensure technology-based or water quality-based effluent limits are met. Typically, BMPs should involve the most effective or practical system of practices for conservation and pollution prevention (Fletcher et al., 2015). When applied in the context of stormwater, BMPs refer to the most practical methods for managing land and human activities to reduce pollution of water sources. (US EPA, 2018b). BMPs include infrastructural changes that aim to address the criteria necessary to manage stormwater: reduce or delay the volume of stormwater that enters sewer system, reduce maximum flow rate into combined sewer systems by decreasing the stormwater volume and increasing the duration of the discharge, and improve water quality through volume reduction, filtering, and biological and chemical processes (US EPA, 2018b). BMPs include Low Impact Development (LID) and Green Infrastructure (GI) which allow for less invasive and more effective methods to reduce and mitigate pollutants in stormwater.

Sources of Zinc

Zinc is a naturally occurring element commonly found in air, water, and soil (Lenntech, 2018). The amount of zinc that occurs naturally in a given environment without any addition from human activities is referred to as the background level, which can range from 10-200 µg/L in rivers (IZA, 2013). However, there are substantial inputs of zinc into urban environments from anthropogenic sources which can result in elevated levels or even toxic conditions in urban waterways. The largest contributors of zinc in urban stormwater runoff have been reported as galvanized surfaces and vehicle tire wear debris (CASQA, 2015).

Zinc is commonly used in a process called galvanizing, where it is coated over steel or iron surfaces in order to increase the lifespan of these metals (Weston Solutions, 2011). The most common galvanized surfaces include roofs, fencing, guard rails, and light poles (CASQA, 2015), as well as building sidings (Bookter, 2017; Kennedy & Sutherland, 2008; Kszos, Morris, & Konetsky, 2004; Weston Solutions, 2011). Numerous studies have cited galvanized roofs as the top contributor of zinc to stormwater runoff (Bookter, 2017; Brown and Peake, 2006; Charters et al., 2016; Golding, 2006; Hwang, Fiala, Park & Wade, 2016; Kennedy & Sutherland, 2008; Minton, 2010; Yu et al., 2014). Other surfaces, such as building siding, also contribute to zinc concentrations in stormwater runoff. A 2001 study conducted by Davis, for example, found high zinc concentrations of approximately 1000 µg/L in water samples from building sidings (Davis, 2001). Larger zinc concentrations were attributed to runoff from commercial buildings in contrast to residential buildings (2001). Zinc was found to be at one or two orders of magnitude higher in concentrations than other chemicals on all types of siding including: brick, concrete, painted wood, metal, vinyl, unpainted wood (2001). However, galvanized metal roofs still contributed the highest zinc concentrations out of the materials (2001).

One of the other largest inputs of zinc into stormwater is tire wear (see, e.g., Brix, 2010; Brown and Peake, 2006; CASQA, 2015;). Voss and Janssen (2008) rank traffic and transport the third-largest contributor of zinc in Dutch surface waters, behind agriculture (contributing 39%) and sewer systems and wastewater treatment (contributing 30%). A study conducted by Eriksson found that 1.5% of tires are composed of zinc, which can then be released onto road surfaces when the tires are worn out (Eriksson, 2018). Unfortunately for source control purposes, as a 2015 report by the California Stormwater Quality Association (CASQA) pointed out, tire manufacturers do not have incentive to produce low-zinc or zinc-free products because of the increased costs and effort it would entail.

Locally specific sources of zinc can also contribute significantly to runoff contamination (CASQA, 2015). For example, one study found that, moss control products serve as the largest source of zinc in a commercial and industrial area in Washington state, accounting for 42.8% of zinc in runoff in a 7.2 square-mile study area (Bookter, 2017). The 2015 CASQA report also identifies zinc-containing paint as a potential major contributor of zinc in California. Although buildings generally have not been painted with zinc-based paint since the 1950s, older buildings that have not been repainted can serve as large contributors of zinc when rainfall sweeps across the exterior (CASQA, 2015). Further, antifouling paint, which prevents organisms from attaching to the hulls of ships, is an additional source of zinc in waters that affects deposit feeders in estuarine environments by making the sediment they live in inhabitable (Jones and Turner 2010). As a result, while galvanized surfaces and tire wear may be the largest overall contributors of zinc to stormwater, the CASQA report suggests that watershed-specific conditions may exist that may require assessment. Figure 4 shows various sources of zinc that the CASQA report identifies that could be present in any given area (2015).

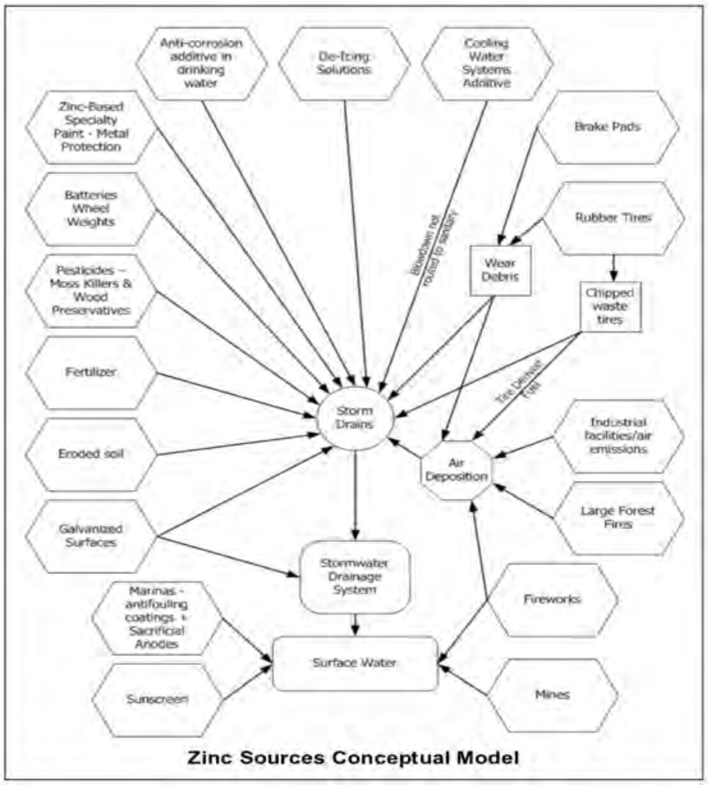


Figure 4: Conceptual Model of Sources of Zinc

Other sources of zinc may be more indirect. Atmospheric deposition of particles is also widely accepted as a source that contributes moderate amounts of zinc to stormwater runoff (Golding, 2006; Charters, Cochrane, & O'Sullivan, 2016). In a study by Liu et al. conducted in Queensland, Australia, four main modes of transportation of heavy metals as a source into stormwater were examined, one of which was atmospheric deposition (2018). In urban environments, heavy metals and other pollutants derived from anthropogenic activities can accumulate in the air and can linger on impervious surfaces before being picked up by stormwater. The sites examined in this study were all in the City of Gold Coast, which has experienced high population growth, leading to increased traffic volume; these sites included road surfaces and areas in close proximity to anthropogenic activities (2018). Within the study, zinc was the heavy metal with the highest concentration in all four pathways (Liu et al. 2018). A similar study conducted in the same location by Gunawardena (2013) found that large amounts of zinc were being deposited into stormwater through atmospheric deposition; higher amounts were associated with dry deposition, which occurs when particulate matter is suspended in the atmosphere, and bulk deposition, which occurs when heavy metal particles are transferred into stormwater through rainfall events in combination with dry deposition.

Liu also found that for the road surface build-up pathway, traffic volume was the most important indicator of where heavy metal build-up would be located (Liu, 2018). With the washoff pathway, the researchers found that industrial and commercial areas tended to produce larger loads of metals in stormwater compared to residential areas (2018). This finding can be attributed to the diversity of traffic characteristics such as volume of vehicles, type of vehicles, and speed of vehicles on industrial and commercial sites.

There are challenges in understanding the transport of heavy metals, specifically zinc. It is difficult to understand all the factors involved in transporting particulate pollutants because of the spatial and temporal variability, such as wind, rainfall intensity, and duration, and other physical processes. The interaction between heavy metals and processes between water and air are complex and need to be researched further. In addition, there is a lack of knowledge on how accumulation processes influence the behavior of contaminants when they have undergone one of the four main pathways listed by Liu (2018).

Field research and analysis has covered a broad array of urban spaces: highways, roads, airports, ports, residential and industrial areas. Many have analyzed catchment areas, which are areas where pollutants are delivered into a receiving body of water via rainfall. The specific materials from buildings and automobiles that generate zinc have also been identified and are fairly well understood. However, more research and knowledge on the mechanisms of transport would be helpful in further understanding the interaction between pollutants and their environments.

Identification of Major Zinc Sources

There is not universal agreement on how to identify major sources of zinc within a given urban area. Most studies utilized different modeling calculations to identify what sources contribute the most zinc to stormwater runoff. However, the ion composition changes as runoff travels from the source to receiving water bodies, as Brix (2009) points out, making it difficult to decide where runoff samples should be collected. Another study points out that different surface materials necessitate the use of different modeling calculations in order to quantify pollutant loading, especially as materials age or break down over time, meaning that sources-specific models are needed (Charters et al., 2016).

Fate and Transport of Zinc

Generation

Although zinc is often identified as the most common metal pollutant in stormwater runoff, Copper (Cu), Cadmium (Cd), Chromium (Cr), Nickel (Ni), and Lead (Pb) from anthropogenic sources are all also commonly identified in runoff in urban areas. Traffic is a major contributor to the large amounts of metals in stormwater, with increased pollutant input and zinc concentrations being correlated with higher volumes of traffic (Gunawardena, 2013; Huang 2016). This correlation is supported by other findings that link zinc concentrations in stormwater to the components of automobile parts. In a study specifically looking at the components of tires that contribute to zinc generation, Hwang found that tire treads contain zinc in order to add strength to rubber compounds; this improves their resistance to heat and abrasion (Hwang 2016). Hwang also found that tire tread material is broken down during tire usage and then deposited onto roads. Additional sources of zinc include brake pad wear and urban road dust (2016). The amount of zinc derived from urban road dust was found to be up to 100 times higher than background levels (Huang 2016). Zinc is also used in engine oil as an additive, and as 20% of engine oil is made of lubrication additives, this zinc can be released when the oil leaks onto urban pavements (Hwang, 2018).

There is widespread agreement that vehicles have a large input on the amount of zinc found in stormwater runoff, but even cleanliness can further impact the amounts of zinc. A study using pollutant yield rating curves showed that clean urban roadways do not always generate loads of pollutants in stormwater (Davis, 2010). Instead, it acknowledges that vehicles are responsible for depositing pollutants onto urban roadways, in turn polluting large volumes of stormwater. It shows that the maintenance and cleanliness of roadways can reduce the concentration of pollutants within stormwater runoff, highlighting the importance of street maintenance.

Mobilization

Mobilization of pollutants, especially heavy metals, can lead to "significantly greater loading to the environment of common toxicants" in stormwater (Brix et al. 2010). One study found that zinc was correlated with the mobilization of other heavy metals such as iron (Fe) or manganese (Mn) oxides in soils, which in the presence of water, led to the release of arsenic (As) and zinc (Zn) that were bound to them (Mukwaturi and Lin 2015). These iron and manganese oxides in soils were "frequently nanometer-sized materials, which have a large surface area to volume ratio and thus are capable of binding metals" (2015). By attaching to other metals, zinc can move further along in runoff and release upon mixing with water (2015). In another article, Stephan et al. state that "free zinc (Zn^{2+}) is one of the most soluble and mobile of [...] metal cations" with the positive charge on zinc indicating its availability to bind to other materials (Stephan et al. 2008). Once released, this free zinc can hydrolyze and become an insoluble form of zinc (zinc hydroxide), lasting indefinitely in stormwater runoff and leading to its mobilization towards other water bodies (Mukwaturi and Lin 2015).

Another study used simulated rainfall to measure the relationship between heavy metals and dissolved organic carbon (DOC) and total suspended solids (TSS) (Herngren et al. 2005). Researchers used the simulated rainfall to measure how heavy metals would normally react with water as well as DOC and TSS and found that in urban stormwater runoff, most heavy metals were introduced into the water through their attachment to suspended solids (2005). Zinc had the highest concentrations out of all the other metals that were tested (Cu, Pb, Al, Fe, Cd, Cr, and Mn) and at all three sites, was correlated with DOC, which enhances the release of heavy metals from suspended solids (2005).

Based on the various articles and case studies that are available, it is generally accepted that metal pollutant transport is linked with sediment and total suspended solids. They attach to other particles in water, whether it be sediments or other metals, stay longer within stormwater, and move further away from their source, leading to pollution of other water bodies and soils.

Identifying Stormwater Pollutant Sources with Remote Sensing

GIS is a powerful tool to spatially analyze data. Coupled with remote sensing, it may be a potential means of identifying sources of zinc pollution in a watershed. Researchers have used GIS and remote sensing techniques, often with in situ field sampling data for the analysis of zinc pollution in several environmental applications. These include analysis of soil, stream sediments, groundwater, and stormwater models for zinc pollution. Industrial processes are often a source of zinc, so identification of land use and land cover is meaningful in the exercise of determining pollution sources (Xian, Crane, & Su, 2007). By using remote sensing to identify sources of zinc pollution and visualizing this information within GIS, further analysis about zinc pollution in our waterways can be possible. While the majority of existing literature on this topic focus on pollution loads in environmental systems rather than the detection of pollutant sources, a few methods confirm the feasibility of using remote sensing hyperspectral imagery to identify galvanized metal rooftops in a watershed. Integrated with stormwater models, the detection of this potentially significant pollutant source could inform the implementation of best management practices to mitigate pollution and protect both aquatic life and human health.

With the knowledge that, in urban areas, galvanized metal surfaces are a significant contributor to zinc pollution in stormwater (TDC Environmental LLC, California Stormwater Quality Association, 2015), it is relevant to detect galvanized metal zinc sources such as roofs in a watershed to assess their contributions to zinc loads in water bodies. While detection of rooftop footprints with remote sensing is a relatively straightforward process, identification of roofing material is a much more complex process executed much less often in the literature. Two methods for classifying galvanized metal and zinc roofing materials from satellite imagery are described below.

Heiden et al. (2012) of the German Aerospace Center developed spectral indicators for the identification of urban structure types, including roofing materials. Their multi-stage processing system uses hyperspectral images and height information to identify 38 spectrally distinct surface materials including "roofing zinc." The urban planning standard for urban structure type mapping is cost- and time -intensive field surveying or manual interpretation of aerial photography, however with the emerging availability of high- resolution multispectral remote sensing data, this process has the feasibility to increase in efficiency. The study used three airborne hyperspectral HyMap scenes for the automated surface material mapping. This sensor records image data in 128 spectral bands in the visible, near infrared, and short wave infrared wavelength ranges. The methodology consisted of preprocessing, hyperspectral surface material mapping, indicator calculation, and multi-level validation. They found that the mean absolute error for surface material identification was less than 8% and that for indicator calculation, mean error ranged from 3 to 11% (Heiden et al., 2012).

Lemp and Weidner of the University of Karlsruhe also used hyperspectral data with high spectral resolution for their classification of urban surface materials. Their research focused specifically on the characterization of roof surfaces by combining hyperspectral and laser scanning data using a segment -based approach. This method used eCognition, a software that allows a hierarchical classification of surfaces. Their methodology used a Digital Surface Model acquired from the TopoSys system with 1 meter resolution raster datasets, with hyperspectral imagery from the same HyMap imagery used by Heiden and colleagues. The classification results were then compared to a 3D model with surface materials as reference data generated from aerial images, completed by field checks (Lemp & Weidner, 2005b).

Upon identification of zinc rooftops, a stormwater model may be applied to estimate the contribution of the roofs toward zinc levels in stormwater as well as dry weather flow in the watershed (Fraga, Charters, O’Sullivan, & Cochrane, 2016). With the integration of remote sensing, GIS, statistical models, and field sampling, there is great potential for the application of existing methods and technology for the assessment of zinc sources in urban environments, especially through land use classification and galvanized roof identification.

Health and Environmental Impacts of Stormwater

Stormwater pollution has detrimental effects on both the environment and public health. Components of stormwater pollution can include oil, pathogenic bacteria and viruses, nutrients, sediments, and heavy metals; each pollutant can contribute a variety and range of adverse effects on humans and the environment (Ma, Egodawatta, McGree, Liu, & Goonetilleke, 2016). The impacts of heavy metals found in stormwater, in particular, include toxifying waterways and adversely affecting fish development, altering the human digestive and endocrine system, and increasing the likelihood of cancer (Young, Kochenkov, McIntyre, Stark, & Coffin, 2018). The effective concentrations, the concentration required to produce a biological response for a toxicant, for a 96 hour exposure time for different heavy metals on a variety of fish range from 0.4 to 5,329 µg/L for cadmium, 47 to 3,323 µg/L for lead, and 21 to 3,704 µg/L for zinc (Mebane, Dillon, & Hennessy, 2012). In fish, even low concentrations can cause a biological response such as decreased immunity state, digestive enzyme activity, growth rate, and a change in behavior (Golovanova, 2008). Aquatic invertebrates exposed to copper, zinc, mercury, and cadmium can experience a change in growth rate, swimming speed, intensity of breathing, productivity, and survival (Golovanova, 2008). Heavy metals in stormwater runoff also increase their bioavailability in other locations, and they do not readily degrade in the environment, making it difficult to prevent or catch these pollutants (Herngren 2005). The existence of these heavy metals is important because of their toxicity within other systems, as they also cannot be chemically transformed or destroyed (Davis et al. 2001).

Other metals typically found in stormwater include chromium, iron, manganese, nickel, copper, and selenium (McKenzie, Money, Green & Young, 2009). A common feature among all of these heavy metals is their ability to bioaccumulate and biomagnify. Organisms are not able to decompose and metabolize these elements, causing the metals to remain within their bodies without any removal process (Damodharan, 2013). This disrupts both the environment and potentially human health as organisms higher up on the food chain consume prey contaminated with these metals, which then accumulates in them without removal. Another metal often found in stormwater that is harmful to both animals and humans is mercury; it is a neurotoxin and its various forms can have a variety of detrimental effects, including lack of movement coordination, muscle weakness, neuromuscular changes, changes in nerve response, skin rashes and dermatitis, and impacts on cognitive thinking, such as memory and attention (OA US EPA, 2015).

Zinc in stormwater is particularly problematic. In soil, detritivores are negatively affected by higher zinc concentrations, as additional zinc prevents them from breaking down organic matter in soil (Wuana and Okieiman 2011). Zinc in estuarine environments affects mobilization of metals as deposit feeders need to dig further into the sediment to find suitable habitat, which then increases the availability of newly exposed solids for zinc to attach to (Jones and Turner 2010). Excess concentrations of zinc in waters can then bioaccumulate up the food chain in aquatic environments, starting with phytoplankton and moving up to fish and other species (Jartun et al. 2008). Heavy metals such as zinc can also affect photosynthetic fixation of carbon by phytoplankton, preventing one of the most important biological processes in the ocean from occurring (Noulas et al. 2018). This has strong implications for sustaining food webs that phytoplankton are the basis for (Brix et al. 2010). The effects of zinc on fish, even in low levels include “altered behavior, blood and serum chemistry, impaired reproduction and reduced growth" (Admin, n.d.-b). This impairment of fish reproduction can include disruption of and decrease in sperm motility. (Giardina, Larson, Wisner, Wheeler, & Chao, 2009). For larger fish such as trout, higher levels of exposure to zinc resulted in gill damage, which corresponds to respiratory dysfunction (2010). Other fish species can store zinc in their tissues, further exacerbating the issue of zinc biomagnification up the food chain (Wuana and Okieiman 2011). Zinc can also increase the acidity of waters, and because many aquatic and marine species are attuned to specific pH levels, changes in acidity can affect longevity (Wuana and Okieimen 2011).

When mammals are exposed to excess amounts of zinc through ingestion or contact, it also negatively affects healthy reproduction, even causing infertility and underweight offspring (Admin, n.d.-b). Zinc, at concentrations of about 150 mg, can cause stomach problems, skin irritation, nausea, vomiting, and anemia ("Zinc (Zn) Chemical properties, Health and Environmental effects," n.d.). At even higher concentrations, zinc can damage the pancreas and disrupt protein metabolism ("Zinc (Zn) Chemical properties, Health and Environmental effects," n.d.). For humans, ingestion of zinc is most commonly attributed to drinking water contaminated by stormwater("Zinc (Zn) and water," n.d.).

In addition to metal pollutants, stormwater frequently also contains biological contaminants such as pathogenic and fecal indicator bacteria. Those at the highest risk of infection due to these pollutants are children, the elderly, pregnant women, and those who are immunocompromised. These at-risk populations account for 20% of the total population (Gaffield et al., 2003). Surfers were studied during wet and dry conditions and researchers found that they were affected by a variety of illnesses because of their exposure to contaminated ocean water (Arnold et al., 2017). Wet weather conditions were shown to increase frequency of illnesses as the more stormwater brings more pollutants into the ocean. Surfers who suffered from gastrointestinal illnesses experienced symptoms such as diarrhea, vomiting, nausea, stomach cramps, and even death (2017). Those who suffered from respiratory illnesses had symptoms including sore throat, runny nose, coughing, and fever (2017). Hepatitis and the flu are also found to affect those who swam in these contaminated ocean waters ("State Water Resources Control Board," n.d.).

Other pollutants in stormwater include sediments, trash, and oils. Sediments in waters reduce water clarity, impede aquatic plant growth, and destroy aquatic habitats ("Stormwater Issues & Impacts | Environmental & Natural Resource Issues," n.d.). Heavy metals are also suspended and transported by sedimentation into water bodies (Huang, Ge, & Wang, 2012). In addition, sediments can contain excess nutrients, which cause algal blooms; these algal blooms are toxic to both humans and wildlife, reducing biodiversity by accelerating the growth of invasive species and reducing oxygen levels in the water, ultimately killing fish and other organisms (Bay, n.d.). Trash may suffocate wildlife and is visually unappealing ("Stormwater Issues & Impacts | Environmental & Natural Resource Issues," n.d.). Oils carried by stormwater can cause health problems to the liver and kidneys, and these oils and other hydrocarbons can negatively affect the ability for aquatic organisms to reproduce (Admin, n.d.).

Stormwater Treatment and Mitigation

In many urban areas, there has been an increase in hardscape and impervious surfaces. This creates a major issue when it rains as the water volume can cause flooding. To mitigate flooding issues, major infrastructure often just directs stormwater runoff away from development with little treatment, which leads to another problem: pollution. Although there are grey infrastructure, or engineered solutions, and other approaches to dealing with stormwater, as described above, low impact development (LID) is one of the most effective methods to reduce and mitigate pollutants in stormwater. These practices are designed to mimic natural hydrologic processes that infiltrate, retain, and filter stormwater, and they effectively remove a variety of pollutants, including heavy metals. While space is often a limiting factor when considering methods of stormwater treatment in urban areas, LID can be adapted for sites ranging from small spaces to regional parks, which makes it important and relevant in urban areas (US EPA, 2018).

LID is generally defined as practices and systems that mimic natural hydrologic processes, and use infiltration, retention, or evapotranspiration to manage stormwater sustainably, protecting water quality and associated aquatic habitats (US EPA, 2015). Green infrastructure (GI) usually refers to the coordinated efforts within a broader scale, such as a community. Therefore, LID can also be considered a subset of the practice known as green infrastructure. In addition, the term best management practices (BMP) generally describes a larger set of practices that can include the use of both gray and green infrastructure. Typically, BMPs should involve the most effective or practical system of practices for conservation and pollution prevention (Fletcher et al., 2015). When applied in the context of stormwater, BMPs refer to the most practical methods for managing land and human activities to reduce pollution of water sources. These methods are broad and may not always include LID. Despite similarities in their definitions, the terms above still define separate practices. There still is not industry consensus on the specific definitions of these terms, but within the context of our project, the terms are defined as above.

LID is an effective stormwater treatment and management strategy, with multiple types of techniques to remove heavy metals. Infiltration-based LIDs, such as permeable pavement, infiltration trenches, and bioretention areas are commonly used to remove heavy metals from stormwater. Retention-based LIDs include wetlands, greenroofs, and rainwater capture. Studies on both types of LIDs have come to widely varying results on their effectiveness at removing heavy metals. Since low impact developments are site-specific, the best design and materials are often unique to that location (Eckart, McPhee, & Bolisetti, 2017). One type of design may perform better in one environment, where a certain type of metal pollutant is more commonplace, while a different design would perform better in a different environment.

III. Project Objectives/Research Questions

1. What are the distribution patterns of potential sources of zinc in the Los Cerritos Channel Watershed?
2. Can we develop a methodology to identify these specified types of sources using remote sensing/mapping approaches and publicly available data?
3. How can this methodology be applied to other watersheds?

Our initial goal for this project was to develop a methodology for identifying sources of zinc, particularly galvanized surfaces such as roofing, using remote sensing techniques and to then conduct a spatial analysis of the distribution of these and other known sources, such as industrial facilities, to assist in developing mitigation at the source. In our initial work, we thought we had identified a methodology for locating several of these major potential types of sources using publicly available data. However, using remote sensing techniques to locate these types of features within the watershed proved challenging, as will be discussed further below. Because of this, the focus of our objective shifted to more accurately analyzing the distribution of known sources within the watershed. Lastly, our remaining goal was for our methodology to be replicable to other watersheds within California or potentially beyond.

IV. Methodology

This methodology serves to outline the steps we took in analyzing publicly available data that we felt would most likely allow for accurate location and analysis of the distribution of the sources of zinc within the Los Cerritos Channel Watershed; we then manipulated that data to best answer our research questions. We interpreted the available data using a variety of remote sensing and GIS techniques in the hopes that the images would align with ground truthing and previously identified sources within the watershed.

Modeling

We originally used the Watershed Management Modeling System (WMMS), which was developed by Tetra Tech, to identify potential areas of concern. The average maximum zinc concentrations between 1/1/2010 and 4/30/2012 for each subbasin were mapped to identify the subbasin with the highest zinc concentrations. These concentrations were derived from pollutant loading data calibrated to the Los Cerritos Channel Watershed within the WMMS system and sampled from monitoring sites during 2000-2010. However, this data was averaging concentrations over large subsections of the subbasins, with not enough records of current monitoring data related to zinc.

In terms of how modeling was approached, the model was spun up from January 2010 to October 2010 to be oriented to water year configuration. Weather data for 2010 to 2012 was loaded in and the model provided averages of pollutants of all 47 subwatershed zones developed for the model. From there, the average maximum zinc concentrations for all subwatershed zones in a subbasin were extracted and had summary statistics provided. The results and limitations of this modeling approach are discussed in section VIII, below.

Remote Sensing

In order to identify the distribution of zinc sources within the watershed without the resource-intensive process of identifying each source on the ground, in person, we used a remote sensing approach. Satellite and aerial imagery allow for a visual inspection of the land use and land cover throughout our watershed. This can help with finding unexpected sources or sites of interests that may not have been known from other data sources or modes of inquiry. The primary focus of our project was to detect metal surfaces in the watershed that would have a galvanized coating, which could be a source of zinc pollution. As discussed earlier, a hyperspectral satellite with over 200 bands of spectral library information is an ideal source for this type of survey. This comprehensive library of spectral information allows us to center on the ideal absorption wavelength for zinc. However, the only publicly available hyperspectral mission is AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) from the National Aeronautics and Space Administration (NASA). While we initially focused on using data from the AVIRIS program, the diagonal paths its images were taken in makes it difficult to stitch the scenes together into a cohesive image of the watershed. Also, the large file size with its multiple spectral bands added to the challenge of manipulating data since we had a limited time frame and inadequate computing power to properly complete an analysis before the end of our project. In addition, AVIRIS data’s 20-meter resolution is too coarse for delineating metal roofs and other desired features in the watershed.

As a result, our remote sensing approach shifted to using a multispectral – rather than hyperspectral – sensor with a better spatial resolution of 10 meters (a multispectral satellite has less than 10 bands whereas a hyperspectral satellite has over a hundred, thus implying a larger file size). These absorption bands aligned well with the general land covers the survey was concerned with (vegetation, zinc, and metal) including B2, B3, and B4; these bands were in the visible and near infrared portion of the electromagnetic spectrum. The satellite meeting these parameters with the best possible open-source data was the European Space Agency's Sentinel 2A (S2A). Sentinel 2A is a collection or "fleet" of satellites deployed from the European Space Agency (ESA) which has a high-resolution multispectral imager with 13 bands (ESA, n.d.a). Only four of the bands (B2, B3, B4, and B8) provided 10-meter spatial resolution in the visible and near infrared spectrum and the remaining bands covered other wavelengths at a coarser resolution.

The steps taken for our Sentinel 2A Survey start with downloading imagery from the USGS Explorer for February 8th, 2019. The Explorer is a database that contains all freely available, open-source scenes from NASA, USGS, and ESA missions. This date was selected as it was the most recent image acquired when we began our analysis. Next, we cropped the image for 100 km^2 to accommodate the entirety of the Los Cerritos Channel Watershed. We then identified regions of interest by creating sample polygons for metal surfaces, dirt/sand, vegetation, and concrete pavement representative of land cover found in the watershed. For this, we selected samples from known surface materials such as metal roofs identified through a Google Earth lookup, dirt or soil from baseball fields, trees and grass in parks, and concrete or asphalt pavement from streets. We used the Total Color image, or a composite RGB image using bands 2, 3, and 4 with each band having a different wavelength and bandwidth correlated to it; we used these bands to establish as a baseline the spectral composition of each land use type. We then used a supervised classification with the minimum distance algorithm across all regions of interest. As a last step, we generated a final classification map at 10m x 10m spatial resolution, given the specifications of the bands used (See Figure 5, below).

This final image did not provide viable enough spatial resolution to delineate air conditioning (AC) units, smaller roofs, and in some cases, tank farm tanks with galvanized coating, which are known sources of zinc pollutant loading. Thus, we decided to search for a higher spatial resolution image with only an additional infrared band attached to it as Sentinel 2A proved to be the only multispectral satellite with 10 meter or smaller resolution data that was freely available.

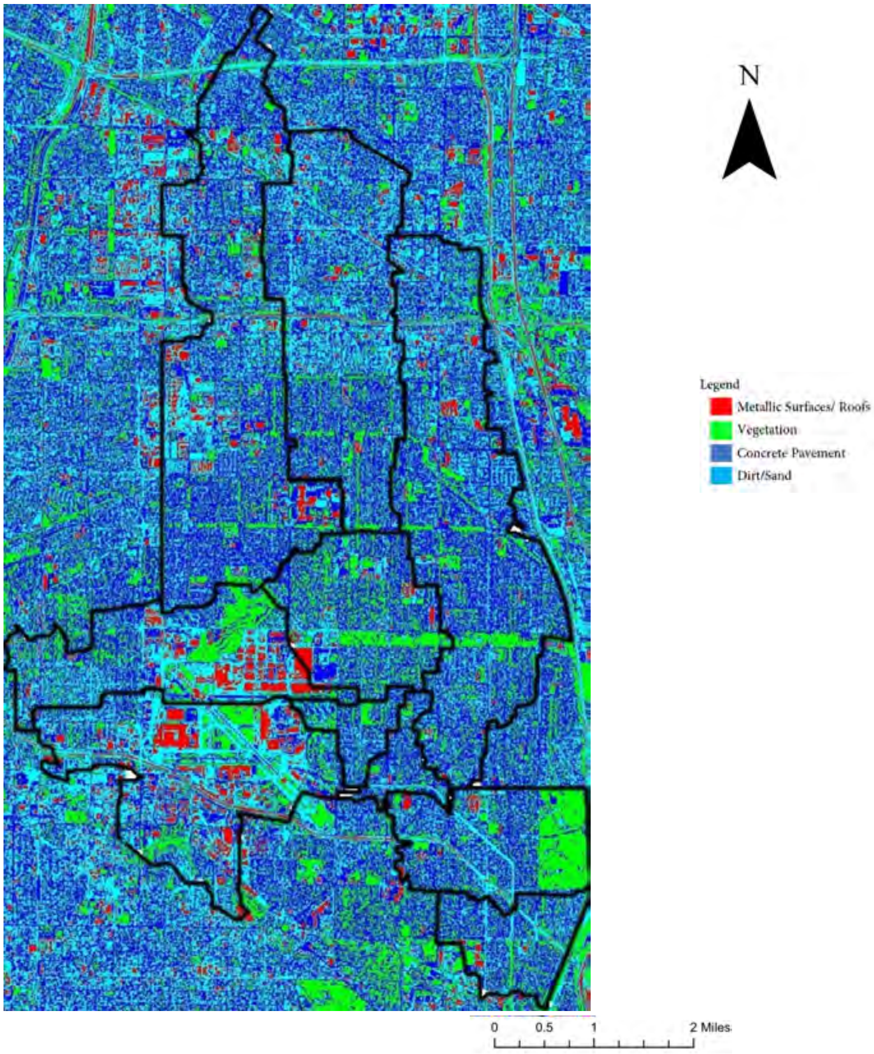


Figure 5: Los Cerritos Channel Watershed Minimum Distance Classification Map - Sentinel 2A Imagery

The National Agriculture Imagery Program (NAIP), administered by the United States Department of Agriculture (USDA), has aerial photographic imagery of the United States (“NAIP Imagery”). It is used to track agricultural growing seasons and provides updated imagery every three years following 2009, although the program started in 2003 (“NAIP Imagery”). It has a natural color spatial resolution – meaning it contains three bands: Red, Green, and Blue (RGB) – though some years contain a fourth band, near infrared, as well (“NAIP Imagery”). The steps taken for analysis of NAIP imagery started with downloading nine individual images containing pieces of the Los Cerritos Channel Watershed from the June/July 2016 NAIP survey of California, and merging the images together using ArcGIS with all four bands (RGB Composite and Near IR). Similar to the Sentinel 2A process, we then clipped this mosaic image to contain just the Los Cerritos Channel Watershed region and identified regions of interest by creating sample polygons for metal surfaces, sand, vegetation, water, and concrete pavement. We used a near infrared band to establish as a baseline the spectral composition of each land cover type. We then used the supervised classification with the minimum distance algorithm across all regions of interest in the Environment for Visualizing Images (ENVI) module. As a last step, we generated a final classification image at 60cm x 60cm map spatial resolution (See Figure 6, below). Overall, the main issue that persisted in this remote sensing survey of the watershed was reconciling between high spatial resolution and multispectral bands for accurate land cover classification. This will be discussed further in the results section below.

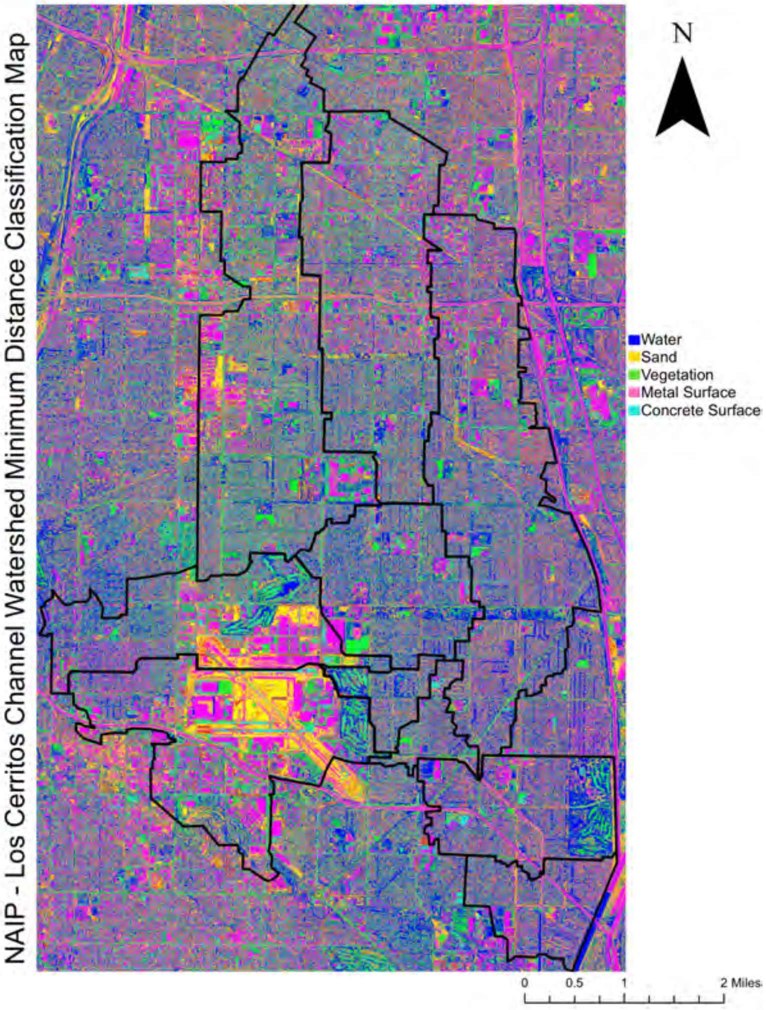


Figure 6: Los Cerritos Channel Watershed Minimum Distance Classification - NAIP Imagery

GIS Methods

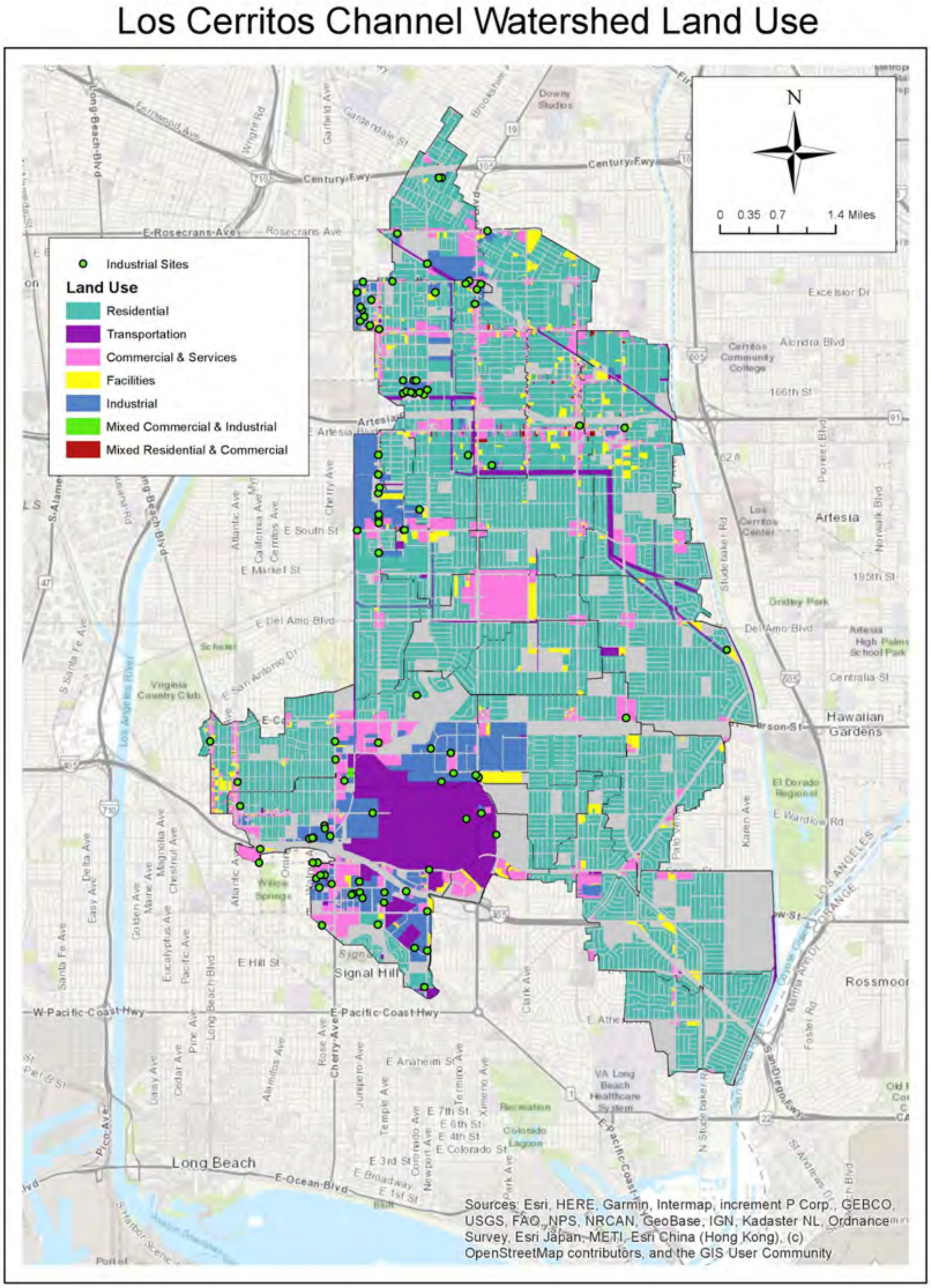
The Southern California Association of Governments (SCAG) is a Joint Powers Authority under California state law, organized as an association of local governments and agencies that work to address issues for the southern California region. SCAG maintains a database of information relevant for southern California; from SCAG, we downloaded shapefiles that categorize and display various land use types including industrial, residential, and transportation. We decided to use land use coverage to help us locate areas that could serve as potentially high sources of zinc. Some land use types, such as industrial and transportation, are expected to have higher levels of zinc from the activities that occur in these areas. Examples of activities that contribute to higher zinc concentrations in particular include transportation, which deposits zinc from tires as the tires wear down, and industrial activity, which deposits zinc when certain materials are produced and used. By identifying areas that have these types of activities, we could potentially identify areas in the watershed that contribute high levels of zinc. We clipped the land use data to exclusively show land use within the Los Cerritos Channel Watershed. Using land codes from a corresponding SCAG report, we grouped similar land uses into more broad categories. For example, land uses classified as single family residential, multi-family residential, and mixed-use residential, were combined into a singular residential land use category. Using the grouped data, we were able to identify and map areas of potential concern for zinc; we expected areas with high industrialization to have higher zinc concentrations relative to residential areas, so those areas were our initial focus for identification (See Figure 7, below).

As the project progressed, we changed the land use map so that all relevant types of land use including industrial, commercial, and transportation were re-separated into detailed categories. For example, Industrial land use (which had codes in the 1300s) was re-split into Manufacturing and Petroleum Refining and Processing, which were land use codes 1321 and 1322, respectively. We then removed land use types that were less likely to contribute significant concentrations of zinc in stormwater runoff (See Figure 8, below). Examples of these land use types are Open Space and Recreation (land use codes 1800s) and Agriculture (land use codes 2000s). This allowed us to easily distinguish where each specific land use of interest – including industrial, commercial, and transportation land use types – was located.

In addition to the land use data, industrial site data from the Stormwater Multiple Application and Report Tracking System (SMARTS), California's database for permits operated by the State Water Resources Control Board, was overlaid onto the map. We projected and clipped industrial site data from SMARTS to include industrial site data within the Los Cerritos Channel Watershed (See figures 7 and 9). Using the permitting data, we identified clusters of industrial sites that could be major contributors to high zinc concentrations. Furthermore, we overlaid areas with clusters of auto and tire shops – commercial activities which are not required to obtain permits through the Clean Water Act's NPDES program and are therefore not registered under SMARTS – onto a portion of the land use map to locate them within the watershed and identify potential hot spots for pollutant generation. Since tires have zinc in the rubber material, we assumed that shops that work with car tires could be potential contributors of zinc. A variety of auto parts are additionally plated with zinc, such as the engine, fuel systems, power steering systems, and chassis hardware, all of which need to be serviced at various points ("Zinc Plays A Prominent Role In Today's Automotive Manufacturing Processes," 2014). We focused on the shops in Subbasins 8 and 9, as those subbasins were known to be problematic due to other factors. Using Google My Maps, we searched for auto shops using relevant terms, such as "auto", "auto shop", or "tire" and downloaded the resulting GPS coordinates as a .kmz file. We then imported and projected these coordinates onto the GIS map (See Figure 9, below).

We also obtained data from the Los Angeles Regional Water Quality Control Board on stormwater monitoring sites within the watershed, projected them into GIS using GPS coordinates, and labeled each site with its identification number. We sorted and analyzed corresponding monitoring data for each site, taken from the Los Cerritos Channel 2017-18 Semi Annual California Environmental Data Exchange Network (CEDEN) Chemistry water quality data for each sampling location. Sampling locations had a wide variety in the number of samples taken, with inconsistent sampling across the locations. We then looked at the average, maximum, minimum, and standard deviation for total zinc concentrations and dissolved zinc concentrations at each monitoring location. This was to identify high concentration areas and determine if there were any patterns in exceedances. We then overlaid the flow regime of the watershed on the map to identify whether we could identify any correlation between sampling points with high zinc values and identified land uses of concern (See Figure 11, below).

Overall, we used GIS to help us identify two important features. We originally mapped water quality monitoring sites to find areas with historically high levels of zinc, as well as land use and industrial sites to find where we would expect to find high levels of zinc. However, as the project continued, we added additional components, including industrial sites and auto shops to our maps and used these sites as well as industrial sites to cross-reference locations of high priority.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 7: Los Cerritos Channel Watershed Land Use overlaid with Industrial Sites - Preliminary Map

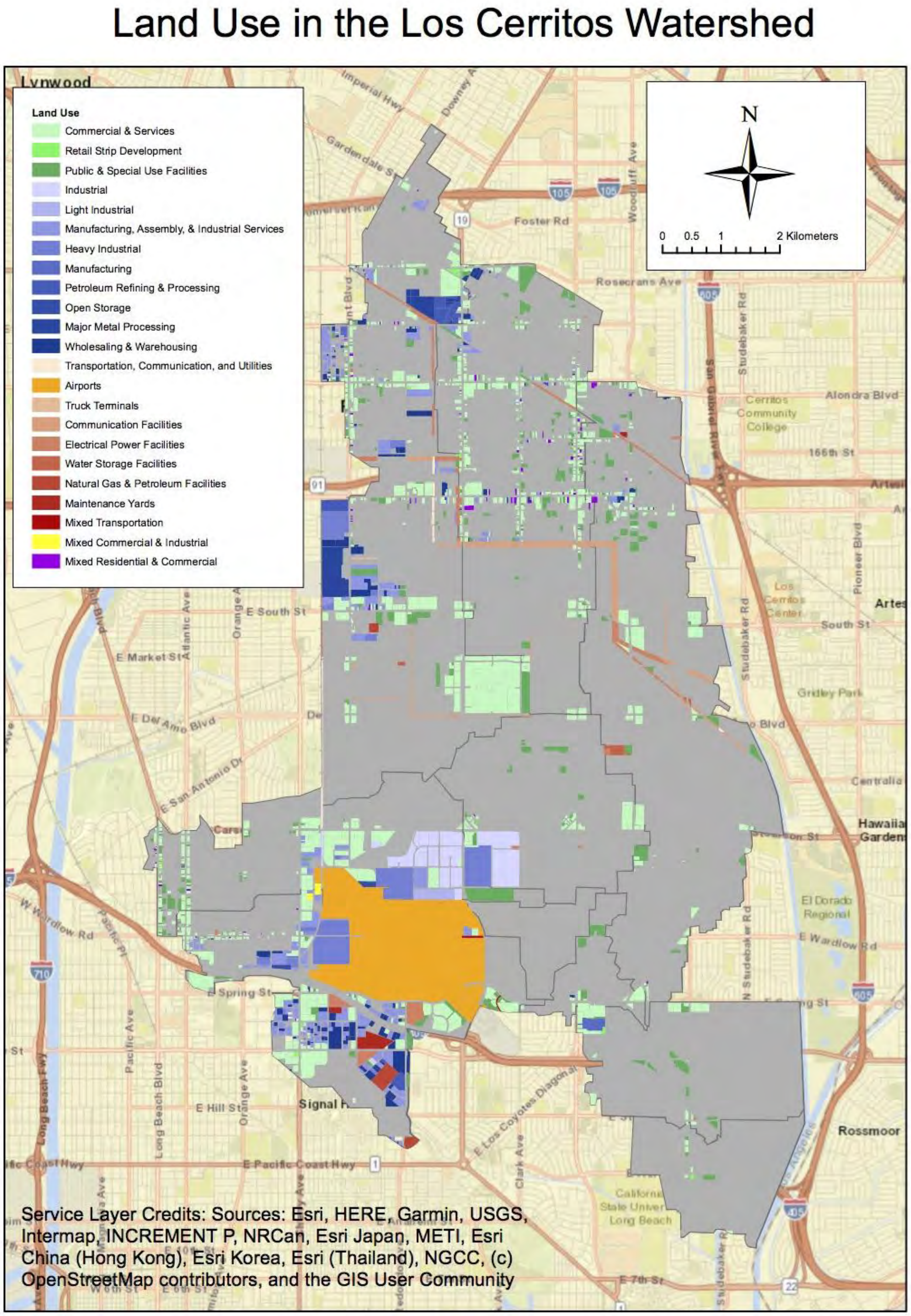
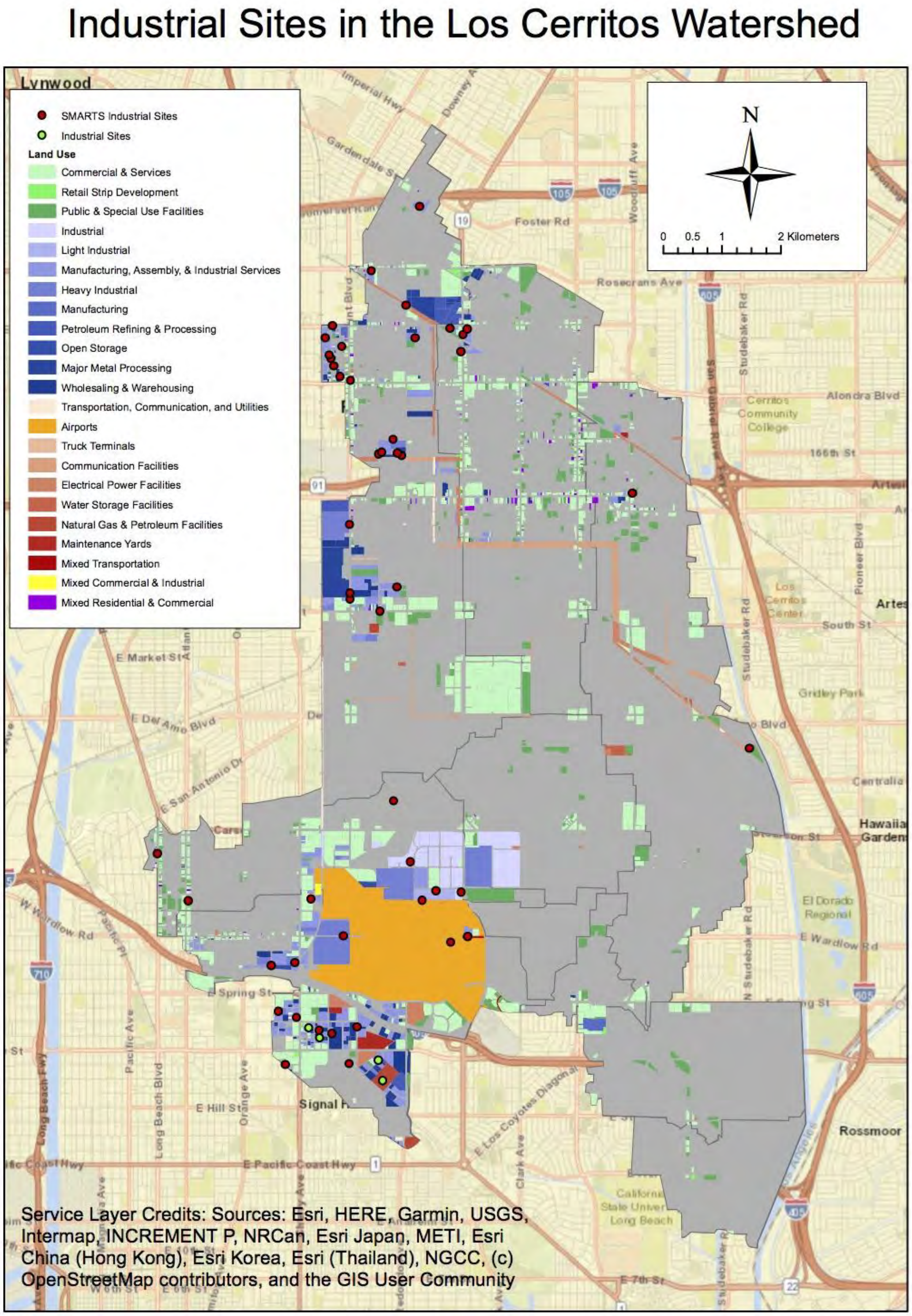
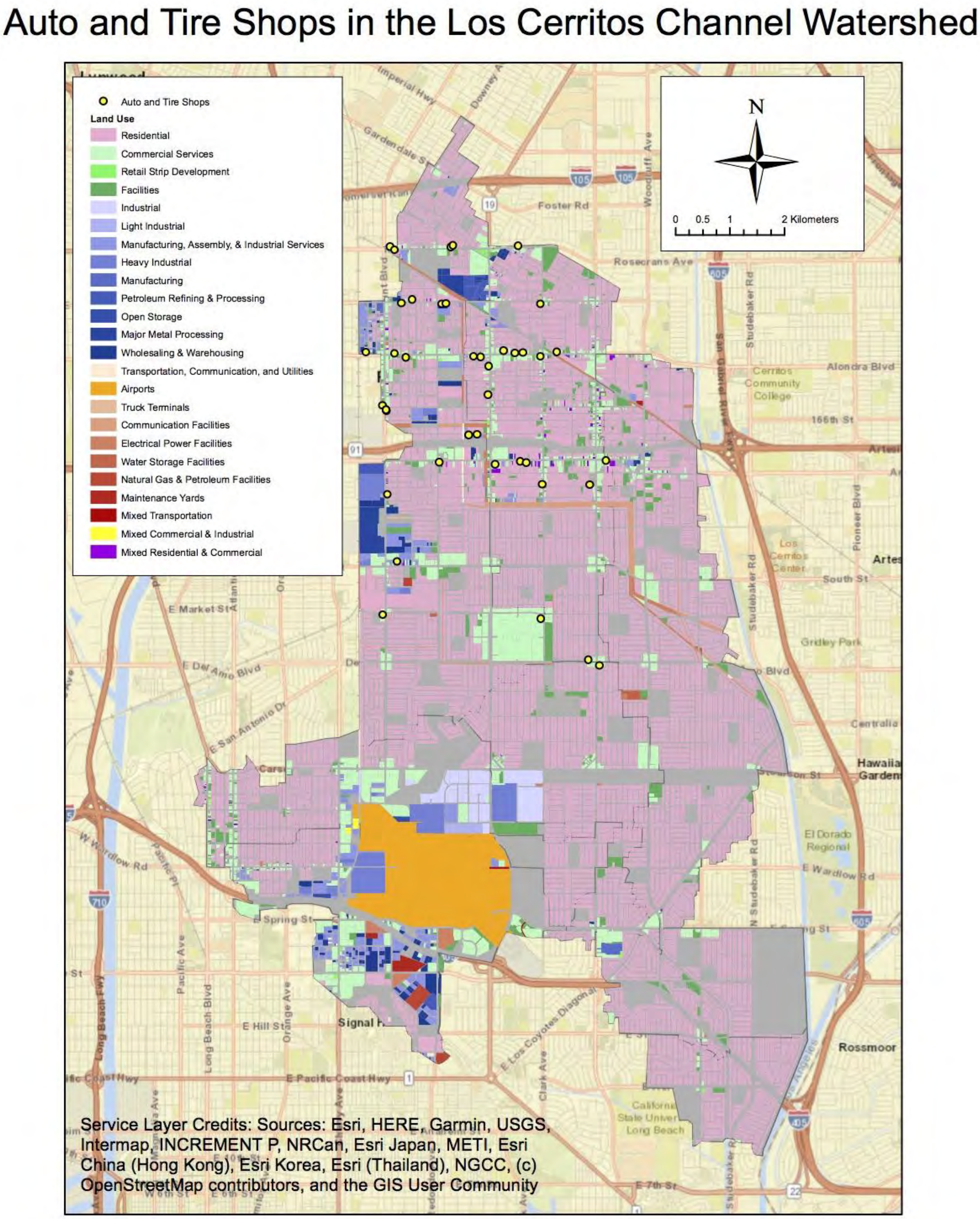


Figure 8: Land Use in the Los Cerritos Watershed - Updated Map (residential and other land uses not of concern are grayed out)



Service Layer Credits: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 9: Los Cerritos Channel Watershed Industrial Sites overlaid with Land Use - Updated Map. This site includes the actual number of active industrial sites and additional added sites that were seen from the project ground truthing trip (residential and other land uses not of concern are grayed out).


Auto and Tire Shops in the Los Cerritos Channel Watershed

Service Layer Credits: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 10: Auto and Tire Shops in the Los Cerritos Channel Watershed

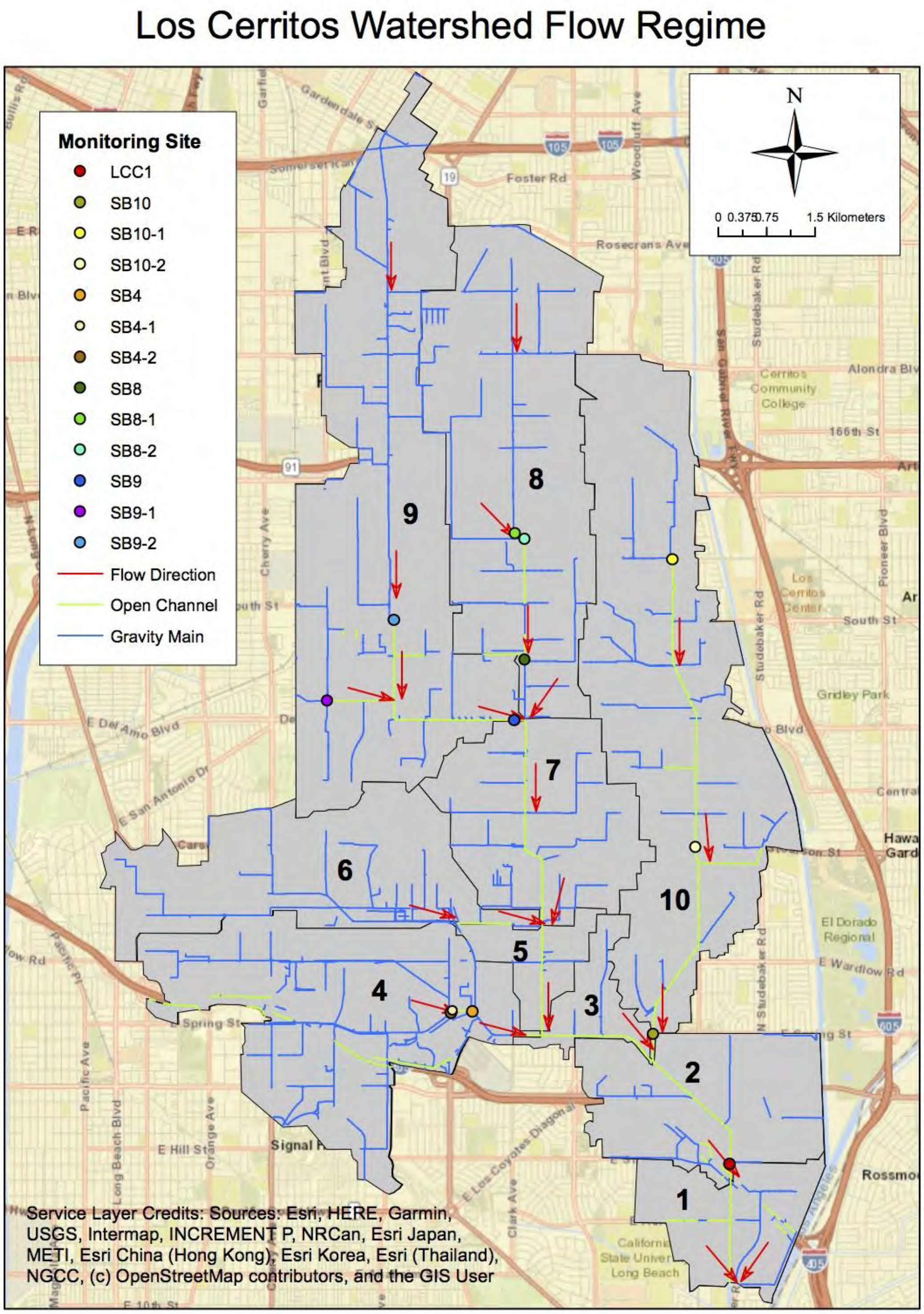


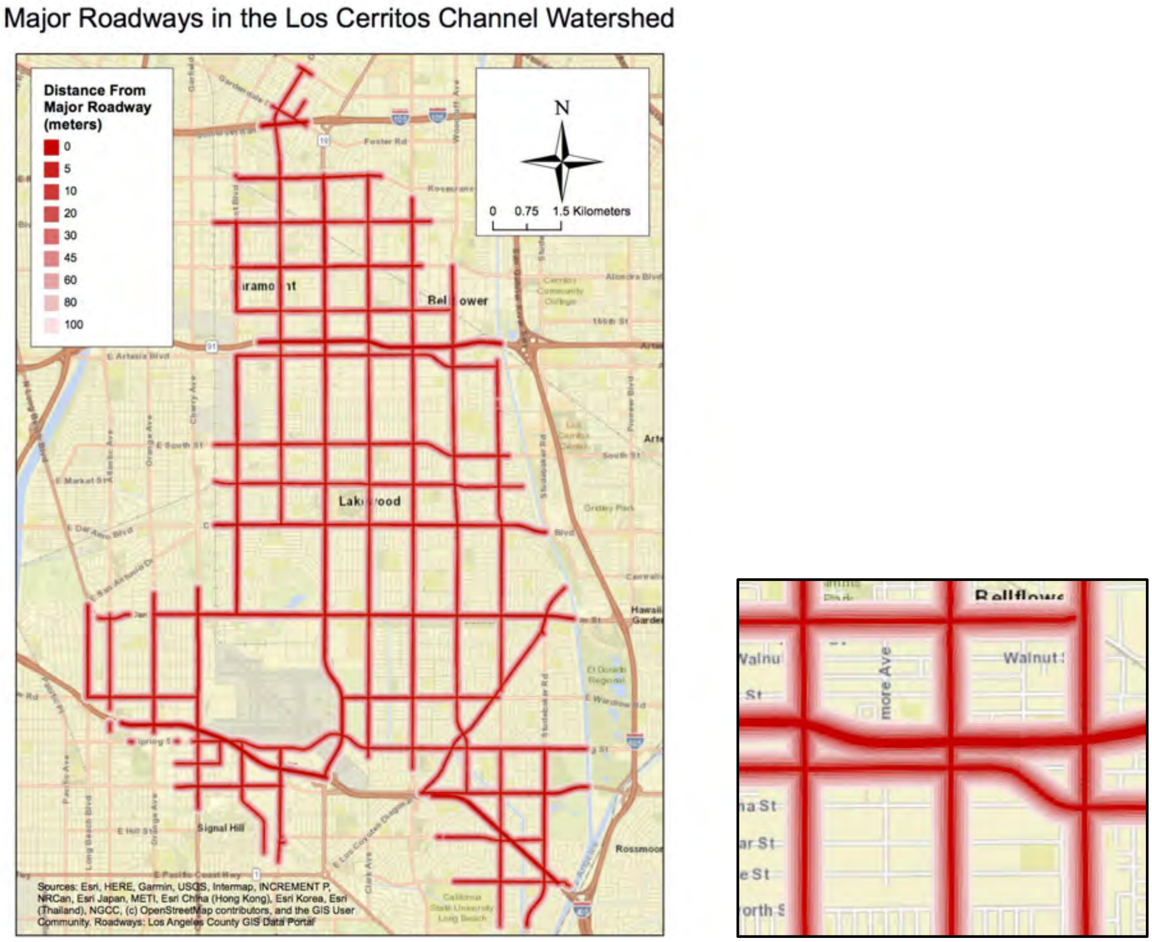
Figure 11: Los Cerritos Channel Watershed Monitoring Sites and Flow Regime. Tracks the flow of stormwater in the watershed and how it reaches the monitoring sites through the channel.

Roadway GIS Methods

Using data from the Los Angeles County GIS Data Portal, LA County Roadway shapefiles were downloaded and manipulated in ArcGIS. “Major roads,” consisting of State Highways, Non-State Highways, and highways identified in the Department of Public Works’ Master Plan, were of interest. Tires have zinc embedded in its rubber material and are a significant source of zinc as it wears down and deposits on roadways; major roadways are therefore of interest because there is more activity and traffic compared with minor or local roads. Only “major” roads were studied because “minor” roads (non-highways, generally smaller than four lanes each way) are ubiquitous throughout the watershed based on a general aerial-view assessment of the area. “Major” roads (highways and arterials, generally larger than four lanes each way) are not as uniformly distributed throughout the watershed and have the potential to disproportionately affect certain areas of the watershed due to increased levels of tire debris pollution. The location of these roadways were confirmed with data from Topographically Integrated Geographic Encoding and Referencing (TIGER).

Our methodology estimates the contribution of a given major roadway to tire debris, and as a result, zinc in the watershed by assuming pollution generation to be proportional to the number of lanes in a given roadway. National Highway System State Highways were observed to be 10 lanes across on average, non-state highways and state highway arterials were observed to be six lanes across on average, and Department of Public Works Highways were four lanes on average. After clipping the roadway shapefiles to the boundaries of the watershed, removing redundant data between the three datasets used, and merging the three shapefiles together, each type of roadway was converted into a polygon of appropriate width (for highway size) based on the assumption that state highways were 50 meters wide, non-state highways and state highway arterials were 34 meters wide, and other DPW Highways were 26 meters wide (road width was in turn based on several measurements of aerial imagery completed using Google Earth). With the footprints of these major roads mapped out, buffer regions were created around the roadways to simulate the regions of potential tire debris deposition from the roadways. Based on the research of Yan et al. (2013) regarding the relationship between distance from roadways and heavy metal concentrations in roadside topsoil, a maximum distance of 100m from the roadway was designated as the farthest distance before zinc levels returned to baseline levels. It is important to note that although Yan et al.’s research provides the 100m value for the maximum distance from the roadway that elevated zinc levels were detected, their study location and conditions have several differences from the conditions of the Los Cerritos Channel Watershed. For example, the study area in Qinghai-Tibet Plateau, which was selected based on its lack of industrial activities and low population density differs from densely-populated and developed Los Angeles. Therefore, this number should be taken as a widely generalized value representing one possible set of conditions to contribute to the heatmap.

With the observation in Yan et al.’s paper that zinc concentration decreased exponentially with distance from the roadway, a “gradient” was created from the edge of the roadway, with boundaries at 5m, 10m, 20m, 30m, 45m, 60m, 80m, and 100m distances from the roadway. For the 0-10 scale of zinc polluting potential for the heatmap, values of 10, 9, 8, 7, 6, 5, 3, and 1 were assigned to their respective gradient zones, with severity decreasing farther away from the road. This gradient can be seen in the zoomed map of major roadways in the watershed, with dark red areas on and around the roadways associated with higher likelihood of elevated zinc levels and pale red associated with lower likelihood of elevated zinc levels.


Major Roadways in the Los Cerritos Channel Watershed

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Roadways: Los Angeles County GIS Data Portal

Figure 12: Major Roads in the Los Cerritos Channel Watershed

Heatmap Methods

We created a Zinc Source Heatmap by using data on land use, location of permitted industrial sites, and distribution of major roadways to identify areas of likely zinc pollution (See Figure 12, above). The heatmap is intended to highlight potential zinc pollution sources in the watershed based on available information, acknowledging that certain potential pollution sources, such as galvanized roofs and integration of stormwater monitoring data, were not included because they could not be comprehensively identified or did not encompass a substantial enough data set. The three land use layers were converted into raster files and weighted in GIS by an original severity index (See Appendix 3). The severity index is an original index with values from 0 to 10, with 10 assigned to sources most likely to contribute to zinc pollution, and 0 assigned to sources not likely to contribute to zinc pollution. The scale is assumed to be linear, so values between 0 and 10 were assigned according to presumed severity based on the team's background research and assumptions about each source. It is important to note that these values were not based on specific measurements, but rather a holistic assessment of perceived problem areas in the watershed. The scores given to different land uses can be seen in Appendices 3 and 4.

To compliment the findings of our heatmap, we also calculated a problematic land use map by subbasin (See Figure 13, below) with “heatmap scores” extrapolated from the findings of the Zinc Source Heatmap. This was to identify which individual subbasins are of primary concern based on the proportion of problematic land uses in a subbasin compared to total subbasin area. Problematic land uses here are defined to consist of major roads and the areas immediately surrounding them, industrial sites, and sites with industrial land use classification. A breakdown of industrial land use classifications and their associated assumed severities can be seen in Appendix item 4. Using the three datasets that informed the original heatmap (land use, industrial sites, and major roadways), land areas of likely zinc pollution sourcing were identified and weighted by the same severity index created for the original heatmap. These weighted land area values were then added together by subbasin and compared to the total area of each subbasin (as a percentage) to create a heatmap score (See Appendix 2), which gauges the proportion of potentially zinc-polluted land in each subbasin. A map showing the heatmap score by subbasin is presented as Figure 14.

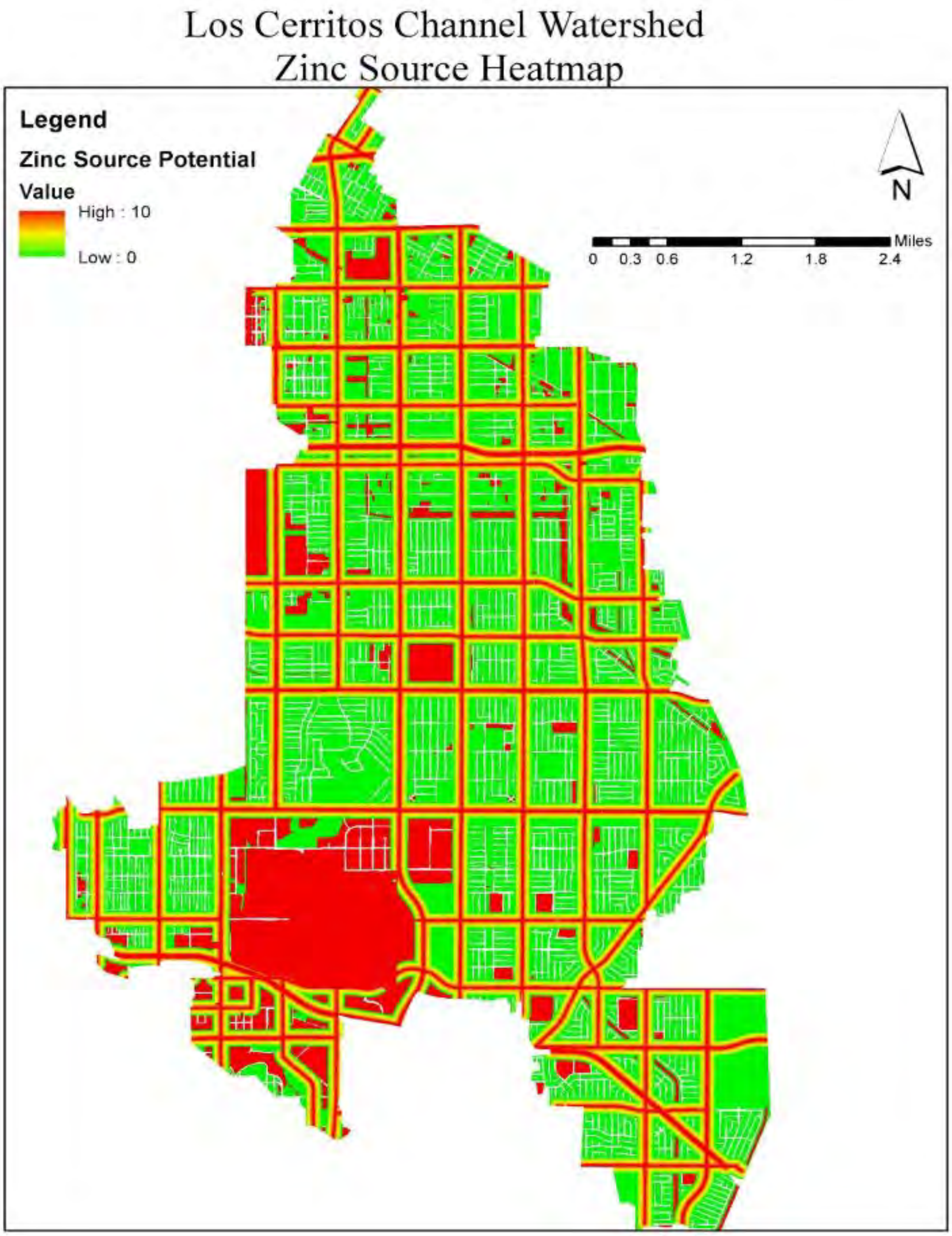
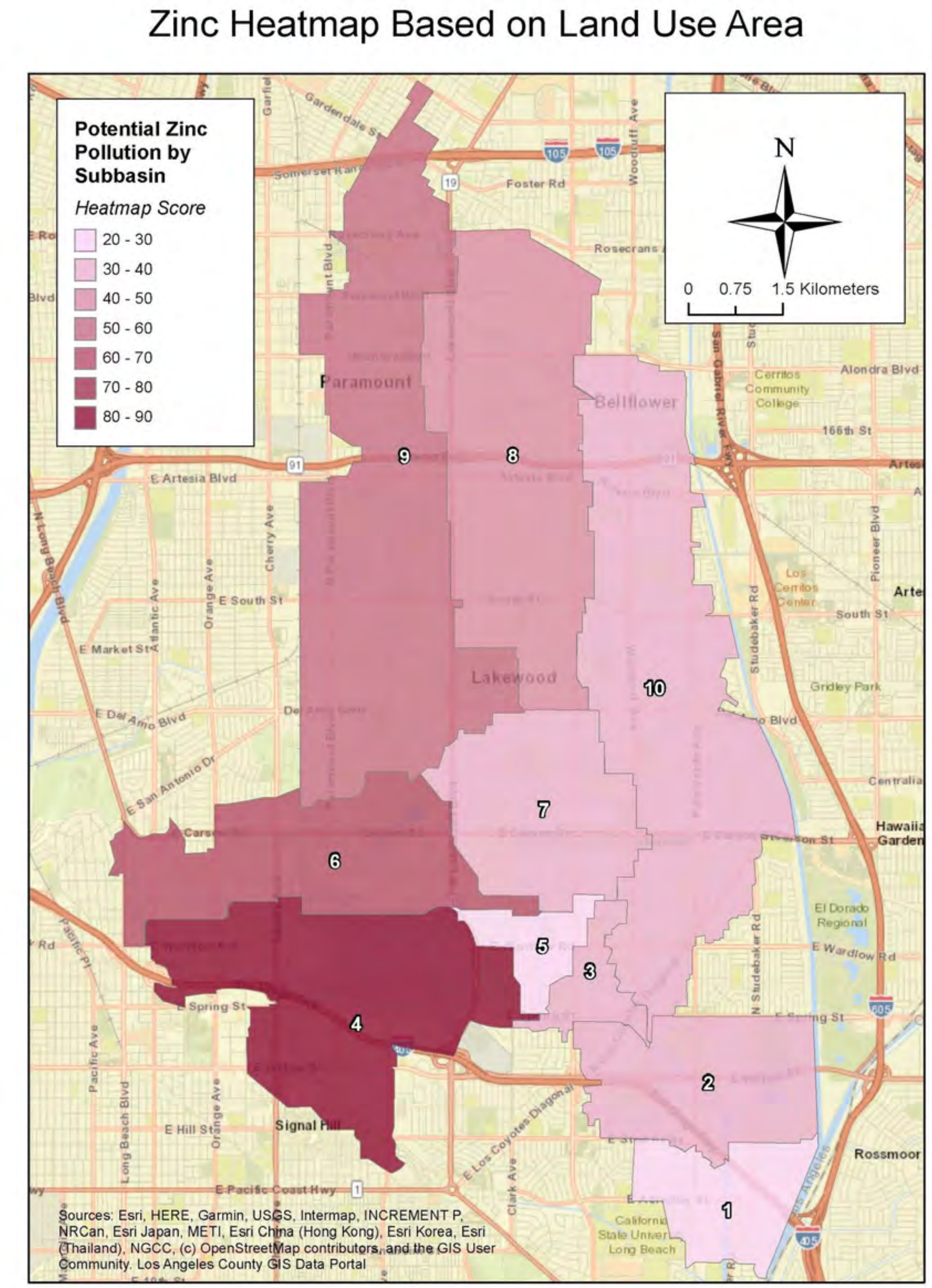


Figure 13: Los Cerritos Channel Watershed Zinc Source Heatmap


Zinc Heatmap Based on Land Use Area

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Los Angeles County GIS Data Portal

Figure 14: Zinc Heatmap Based on Land Use Area by Subbasin. Shading of each subbasin was based on Problematic Land Use by Subbasin Calculation.

V. Results and Discussion

The technical aspect of our project was divided into different sub-projects, all of which shared a common theme of running into either limited or incomplete data. The sub-projects, discussed below, were stormwater runoff modeling, remote sensing, stormwater sampling data analysis, and GIS work.

Modeling

Only a limited set of data was available for modeling of stormwater runoff through the State's SMARTS database, which appeared outdated, with apparently no data relevant to modeling being uploaded into the system since 2012. While the initial modeling effort we undertook using WMMS using this data provided a potentially good snapshot of past conditions, it was limited by only containing data for the period 2010 to 2012, and therefore does not provide an accurate, updated prediction about current zinc concentrations and distributions in the watershed. In addition, simply averaging and mapping the maximum zinc concentrations between the years 2010 and 2012 does not provide any additional data about the time of year these samples were taken at, ignoring potential differences in zinc concentrations that occur seasonally. Furthermore, the WMMS modeling program itself is being updated, with a newer version set to be released in the near future - WMMS version 2.0 is currently in development, and once released may allow for more current modeling of runoff conditions in the Los Cerritos Channel watershed. Overall, while modeling is possible to perform with the data and tools currently available, it is also likely to provide an incomplete if not actually misleading picture of zinc pollution in the watershed, and to be rendered irrelevant by a newer modeling program in the near-term, vastly limiting its utility.

Remote Sensing

Remote sensing analysis of zinc sources in the Los Cerritos Channel also faced challenges with data. We had to identify relevant imagery and choose the best datasets based on spatial resolution, spectral resolution, cost, and scale. One of the options, multispectral imagery (S2A) has the most potential to identify galvanized metal but demonstrates the tradeoffs between its high spectral resolution and low spatial resolution data. As a result, for Sentinel 2A the classified image provided a general idea of where metal roofs and surfaces were located throughout the channel. However, there was a slight overrepresentation of metal surfaces because some of the highways and densely packed surface streets were incorrectly placed under the same classification. Additionally, the 10m resolution was too coarse to identify metal surfaces at scale and did not precisely delineate suspected metal surfaces on roofs. Because of the large pixel size, the scenes were not properly demarcated along the edges of assets within the watershed. This occurred in assessment of other surfaces as well, for example, even the line between concrete pavement and buildings was frequently unclear, with one bleeding into another in most cases. In short, this option also has many layers of spectral bands, which should help with identifying different land cover, but still has issues distinguishing between different surfaces because of limitations with S2A and the algorithm's inability to accurately assess land use classifications based on heterogeneous regions of interest assigned. Other remote sensing options may have higher spatial resolution data, but may be limited in other aspects.

From a public use perspective, near infrared imagery (NAIP) has more accessible data in very high spatial resolution (60cm by 60cm), but only has four bands (R,G,B, and infrared), which is itself limiting and can result in the inappropriate classification of a variety of materials or land cover surfaces as galvanized metal even though they are clearly not visually discriminable. For example, the classified image from composite NAIP imagery grossly overestimated the amount of metal roofs present within the watershed. Most buildings and even a substantial percentage of concrete paved surfaces in the area were designated as metal surfaces, even when aerial imagery or ground reconnaissance demonstrated this was clearly not the case. This can be attributed to the imprecision of the infrared sensor – as opposed to multispectral sensors – in terms of distinguishing between different manmade materials, such as concrete and metal (there was no spectral band decomposition to make the RGB composite and thus the Total Color Image was not used). It was further difficult to distinguish galvanized surfaces using aerial imagery. Some of these surfaces are painted, deposited debris, or are significantly rusted which shows the heterogeneity of these types of roofs (See Figure 15, below). The algorithm does not respond well to these different types of polygons for the same region of interest. Overall, although the spatial resolution of 60cm for the NAIP imagery was ideal, the lack of multispectral bands in this survey put the classification at a disadvantage. Effectively, there is a potential to use infrared imagery to detect impervious surfaces at low, medium and high albedo counts. However, this still does not translate to detecting metal surfaces, concrete, or clay.

After the creation of our remote sensing maps, we went to the cities of Signal Hill and Paramount for the first time to ground truth Subbasins 4 and 9 for galvanized metal roofing. During this trip, we discovered that both the Sentinel 2A and NAIP imagery greatly overestimated the amount of galvanized surfaces within the watershed. Areas that were indicated as metal through remote sensing turned out to be entirely different materials on the ground, and included asphalt, water, and other metal surfaces, such as cars, as galvanized. What we suspected as exposed metal rooftops found in a region of interest assessment through Google Maps and Google Earth also did not necessarily contain metal. Within an area of Subbasins 8 and 9 surveyed by car that included hundreds of properties, less than 10 confirmed galvanized roofs were identified on the ground. Additionally, there were major discrepancies from what was found in the aerial photography provided by the Quickbird satellite that Google uses and what was found in an in-person street view. This led the team to suspect that although galvanized metal roofs are present in the watershed, they may not be as large of a contributor to zinc sourcing in the watershed as initially suspected.

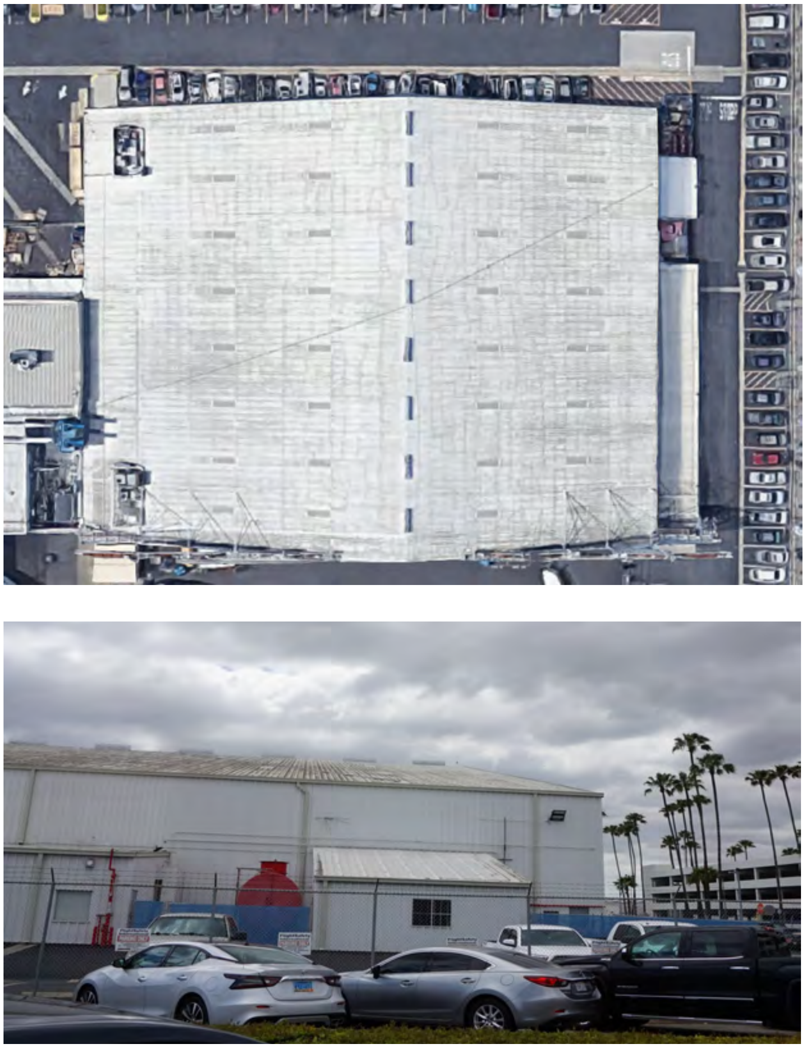


Figure 15: Mismatch with Warehouse Bird's Eye View and Street View. Some surfaces assessed as being galvanized using aerial imagery were complicated by rusting, debris, or different color paint cover on the ground, which is hard to detect.

GIS Analysis of Industrial Stormwater Sources

During our ground truthing trip at Signal Hill and in Subbasins 4, 8, and 9 we also found that there were what appeared to be industrial sites operating that were not included on the SMARTS database. A number of these sites may be operating without a stormwater permit, and as a result, we believe the list on SMARTS may be incomplete. Certain industrial sites may have their own, individual permits that are not registered under the Industrial General Permit (IGP), and thus may also be missing from the list of permitted industrial sites. Through contact with the Regional Board, we did identify four industrial sites with individual permits that were not otherwise listed in the SMARTS database, however, a challenge that we faced with further GIS analysis was that representatives from both the State Water Resources Control Board and Los Angeles Regional Water Quality Control Board repeatedly referred us back to the SMARTS database for identification of industrial sites. Ultimately, we were unable to find much additional data outside of SMARTS.

Previous UCLA Environmental Science Practicum projects have identified similar issues with SMARTS, such as a project investigating stormwater discharges in the Dominguez Channel in south Los Angeles County. This Practicum team conducted ground surveys in portions of the cities of Carson, Gardena, Wilmington, Torrance, and Compton and found "86 sites that appeared to represent industrial facilities operating without a permit" after cross referencing these sites with the list of permitted industrial sites provided from SMARTS (UCLA IoES). Our team experienced a similar underrepresentation of industrial operations identified in the SMARTS database during this project after initial ground truthing. One explanation the Dominguez Channel group offered for the incomplete list within SMARTS is that "certain types of industries are not required to obtain a permit for their industrial activities" (UCLA IoES), raising the possibility that industrial operations that may be a source of zinc pollution are simply not accounted for by the State Water Boards under the Clean Water Act. Further, certain facilities that may serve as sources of zinc to stormwater runoff, such as auto maintenance or repair and tire shops, are considered commercial rather than industrial for permitting purposes, and therefore are not required to be registered under the IGP. We conducted a google map survey of these types of facilities for Subbasins 8 and 9, and separately contacted the city of Paramount and received a list of businesses that operate under these terms in order to at least informally assess the extent to which these types of businesses may currently operate in the Los Cerritos Channel watershed. However, this is an avenue that can be pursued further in order to assess additional potential zinc contributors within the watershed.

Stormwater Monitoring Data

Monitoring data for analysis of zinc runoff sources in the Los Cerritos Channel was limited. Monitoring data taken from Los Cerritos Channel Semi Annual California Environmental Data Exchange Network (CEDEN) Chemistry water quality data sets provided by the Los Angeles Regional Water Quality Control Board for 2016 to 2018 provided limited basis to draw conclusions regarding zinc concentrations within stormwater. One notable drawback is that these datasets did not include sampling for all of the subbasins within the Los Cerritos Channel Watershed; there are 10 subbasins in the watershed, but water quality data for zinc was only available from five (1, 4, 8, 9, 10). For the monitoring data that was available, not all of the sites report data on the same dates, rendering it potentially difficult to compare conditions. While SMARTS could provide more insight to monitoring data from permitted sites, historically, the database does not go far back enough to provide a reliable picture of zinc source distribution and data is not well integrated into the system. Further, since not all permitted sites actually monitor for zinc, using the available data could skew or bias results to suggest pollution is occurring only in areas where monitoring is occurring; this is problematic because sites that are not being monitored may imply that zinc exceedances are not occurring, when instead there simply is not data to show potential exceedances.

A summary table on the zinc monitoring data from channel and TMDL monitoring programs supported our belief that the available data was not robust enough to draw firm conclusions from (See Table 3 & Table 4, below). Average concentrations for both total and dissolved zinc were relatively within range of each other, however, the standard deviation of data for each monitoring site varied significantly, and maximum and minimum reported levels of zinc varied even within single locations. Therefore, there was inadequate data to support a determination as to which subbasins, let alone more localized areas, were more prone to high levels of zinc pollution.

Total Zinc Concentrations	LCC1	SB4	SB4-1	SB4-2	SB4-M	SB4-Total	SB8	SB9	SB10
Number of Samples	23	7	3	2	9	21	7	12	11
Average Zinc Concentration (µg/L)	260.78	264.37	187.33	269	293.2	266.16	171.86	242.78	154.45
Std Dev (µg/L)	222.72	105.73	62.36	29.7	155.89	121.53	72.17	171.89	65.68
Max Zinc Concentration (µg/L)	738	477.44	258	290	623	623	298	646	317
Min Zinc Concentration (µg/L)	10.7	151.16	140	248	147	140	106	136	82.3

Table 3: Total Zinc Concentration Summary Statistics from monitoring sites in Los Cerritos Channel Water Quality Data, January 2016 to December 2018

Dissolved Zinc Concentrations	LCC1	SB4	SB4-1	SB4-2	SB4-M	SB4-Total	SB8	SB9	SB10
Number of Samples	36	7	3	2	7	19	5	10	14
Average Zinc Concentration (µg/L)	54.75	72.09	100.43	61.9	53.89	68.78	57.72	70.91	75.4
Standard Deviation (µg/L)	43.36	42.53	22.71	43.92	31.46	35.78	19.49	37.64	50.16
Max Zinc Concentration (µg/L)	147.16	107.88	124	72.8	107	124	82.8	124.04	171.15
Min Zinc Concentration (µg/L)	8.4	3.45	78.7	8.4	21.3	3.45	29.2	19.22	25.11

Table 4: Dissolved Zinc Concentration summary statistics from monitoring sites in Los Cerritos Channel Water Quality Data, January 2016 to December 2018

Our heatmap and problematic land use assessment mostly aligned with the EPA assessment of the Los Cerritos Channel Watershed's harmful TMDL subbasins in the 2010 Los Cerritos Channel Total Maximum Daily Loads for Metals, March 2010 (Final Report) (US EPA, 2010). We used roadway gradients, industrial sites, and land use maps whereas the EPA also included monitoring data to inform their TMDL subbasin map. Based on our analysis, Subbasins 4, 6, and 9 are problematic because of a concentration of industrial facilities, freeways, transportation regions, and industrial shops. One area where our analysis differs from that of the EPA is for Subbasin 8, which our analysis did not identify as highly problematic, but which the EPA assessment found also of concern (US EPA, 2010).

VI. Recommendations/Conclusions

Because of the consistent theme of incomplete or inadequate data, we are unable to draw definitive conclusions about the sources and distribution of zinc in stormwater runoff in the Los Cerritos Channel, but have several recommendations for further investigation. More data, both in terms of stormwater runoff monitoring and specific land cover or use is needed in order to advance efforts to map out locations likely to contribute the highest levels of zinc to the watershed using remote sensing and GIS.

Unfortunately, neither S2A satellite nor NAIP program provided imagery sufficient to create a holistic image of the galvanized metal surfaces in the watershed. Again, S2A had a comprehensive suite of spectral bands but poor spatial resolution, and NAIP had good spatial resolution but limited spectral bands. As a result, we did not find publicly available images that met our specifications for identification of galvanized surfaces in the Los Cerritos Channel watershed.

We recommend that the Los Cerritos Channel Watershed seeks the Worldview 2 satellite images provided by the Satellite Imaging Corporation based in Houston, Texas. There is a 0.6m resolution panchromatic band and a 2.0m resolution multispectral band suite provided with relatively recent scenes, only 90 days older than the current date, that have surveyed the watershed. This balance with spectral band information calibrated to the appropriate absorption wavelengths and high spatial resolution may provide a strong potential for accurate classification of galvanized surfaces in the watershed.

In fact, use of the Worldview 2 image could extend beyond the purposes of land use classification. With multispectral imaging in near infrared wavelengths, the watershed can use this data to understand areas that can be classified as urban heat islands and introduce more vegetation and green infrastructure to cool it down, which could be coupled with efforts to implement green infrastructure to mitigate stormwater pollution. Although remote sensing using publicly available sources of data did not meet our goals for identifying metal and galvanized surfaces as part of our analysis, remote sensing has tremendous implications for future studies of the watershed.

To create a more informed heatmap of zinc pollution sources, more monitoring data in the channel and at major storm outfall points, as well as better localized or individual site monitoring, is needed. On-the-spot sample collection and subsequent in-lab monitoring of the collection allows for a more comprehensive cycle of zinc loading modeling throughout the watershed per annum. In addition, a heatmap would be more robust if all permitted and unpermitted auto shops, refineries, industrial sites, and other facilities are represented, which would go well beyond the current slate of sites identified in the SMARTS database. With advanced remote sensing supervised classification methods, potentially using the Worldview 2 image, the set of existing galvanized roofs, though likely fewer than initially anticipated, can also populate the heatmap to point to more direct leaching sources in a storm event.

Overall, we recommend increased monitoring data at both the site specific and mass emissions level, and more comprehensive and accessible permitting data throughout the entire watershed, but especially in Subbasins 4, 6, and 9. Since the Long Beach Airport in Subbasin 4 is a known potential major source of zinc pollutant loading, it remains a major area of concern, despite inconclusive or missing subbasin data. Airports commonly have galvanized hangar roofing, which wears down during storm events and washes zinc into larger bodies of water (Long & Zou 2019), and which could be identified at the site scale with more advanced remote sensing analysis. In general, robust and consistent monitoring is essential in making more holistic recommendations about pollutant sources, not only for the Los Cerritos Channel Watershed, but for other watersheds as well.

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VIII. Appendices

Appendix 1: GIS Shapefiles and their Sources

File Name	Source
LCC Water Quality Monitoring Program Station IDs/Locations	Los Angeles Regional Water Quality Control Board
Southern California Existing Land Use	Southern California Associations of Governments
TMDL SubBasins	Los Angeles Department of Public Works
Open Channel	Los Angeles Department of Public Works
Gravity Main	Los Angeles Department of Public Works
Industrial Application Specific Data	Stormwater Multiple Application and Tracking System
Industrial Sites	Self Report
LA County DWP Watershed Flow Direction	Los Angeles County Open Data
State Highways	Los Angeles County Data Portal
Non-State Highways	Los Angeles County Data Portal
Department of Public Works' Master Plan	Los Angeles County Data Portal

Appendix 2: Statistical Heatmap Scoring

Subbasin	Problematic Land Use Area	Industrial Site Area	Tire Debris Pollution Zone Area (weighted) (m^2)	Sum	Area (m^2)	Percent of Subbasin (Heatmap Score)
1	35625.68	0	735041.462	770667.142	2915035.794	26.438
2	308925.1747	0	1439031.612	1747956.787	5023031.697	34.799
3	117622.5011	0	343036.116	460658.6167	1234952.874	37.302
4	5644359.101	40081	2610960.212	8295400.313	9186666.69	90.298
5	4573.885108	124.914113	342792.404	347491.2031	1342059.875	25.892
6	2450111.49	400744.0967	1274898.484	4125754.071	6733685.191	61.270
7	646270.0685	0	1206641.322	1852911.391	5503533.229	33.668
8	1515954.226	14010.077	3253513.917	4783478.22	10974965.07	43.585
9	3682928.374	62031.3711	4102972.684	7847932.429	15051248.87	52.141
10	1229092.719	4683.971	3420098.164	4653874.854	13774470.27	33.786

Appendix 3: Roadway Severity Index - used to make the Zinc Source Heatmaps
Distance from road

0 (on road) [10]
5 [10]
10 [9]
20 [8]
30 [7]
45 [6]
60 [5]
80 [3]
100 (farthest from road - edge) [1]

Appendix 4: Land Use Codes Severity Index - used to make Zinc Source Heatmaps

Land Use Code	Severity
1200, 1210, 1211, 1212, 1220, 1221, 1222, 1223, 1230, 1231, 1233, 1240, 1241, 1242, 1243, 1244, 1245, 1246, 1247, 1250, 1252, 1253	10
1300, 1310, 1311, 1320, 1322, 1340	10
1400, 1410, 1411, 1416, 1420, 1431, 1434, 1435, 1440, 1450,	10
1500	4
1600	2
All Other Land Use Codes	0