Comprehensive Literature Review: Storm Water Runoff Impacts of Copper and Zinc Building Materials

Final Literature Review & Inventory

Prepared For:

City of San Diego
Transportation & Storm Water Department
Storm Water Division
9370 Chesapeake Drive, Suite 100, MS 1900
San Diego, CA 92123

May 2011

WESTON SOLUTIONS

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EXECUTIVE SUMMARY

The principles of public outreach and pollutant source abatement may offer the most direct and immediate means for reducing storm water pollutants. When compared to other storm water best management practices (BMPs) such as treatment and prevention controls, pollutant source abatement offers a cost-effective solution that generally has no long-term management costs and is easy to measure and inventory. These source abatement efforts may be affected through product substitution, statutory directive or prohibition, and social buying patterns and uses.

Regulatory Driver
Adopted metals total maximum daily loads (TMDLs) and anticipated toxicity TMDLs require the City of San Diego (City) to meet water quality objectives (WQOs) and pollutant load management goals specifically for copper and zinc. Each of these metals is used in many industrial and building material applications as well as in fertilizers, pesticides, motor vehicles (i.e., brake pads, tires, fan belts, etc.) and many recycled materials. Efforts to reduce copper and zinc require an understanding of the complete source inventory, relative application, application rate, and spatial distribution. For example, zinc is more widely applied as a building material than copper.

Copper Use
Because of its high cost, copper and copper patina is limited in its use as a building material and is typically chosen for architectural accents, rain gutters, and downspouts. Reference studies show that relative copper application rates are extremely low and limited to high-end residences and commercial buildings. Despite claims by manufacturers that patina chemically binds copper and reduces environmental impacts, direct monitoring of runoff from buildings with copper building material reveals high levels of total and dissolved copper in storm water runoff, even on old buildings that have patina oxidation.

Zinc Use
Because of its low cost, high strength, and reusability, zinc building materials are the primary choice for metal storm drains, corrosion-resistant roofing and siding, rain gutters, downspouts, and fencing. In addition, recycling efforts have created uses for used tires (synthetic lawns and recreation fields), which have been documented to contribute zinc to runoff. Studies have shown than in urbanized areas, zinc materials are much more common than copper, especially in commercial and industrial sectors, high-moisture areas such as ports and harbors, and public-use facilities, such as, parks, schools, and stadiums. Despite claims by manufacturers that zinc oxidation chemically binds the zinc and reduces environmental impacts, direct monitoring of runoff from buildings with galvanized roofs and rain gutters show high levels of total and dissolved zinc.

Prohibitions and Directives
Several municipalities have initiated zinc and copper source control for storm water compliance purposes through administrative control and modification of municipal ordinances or building codes. The City of Palo Alto, CA, specifically issued an ordinance in response to TMDL requirements to control copper. The City of Boston, MA, is experiencing a conflict reducing copper discharges under its TMDL because many of the city's historical buildings are being

preserved with their copper roofs, shingles, rain gutters, and adornments. Overall, there have been few documented administrative controls for copper or zinc. Most emerging information has been identified through professional networks and professionals corresponding on social networking sites.

These two focused efforts highlighted above, demonstrate the diverse sources of copper and zinc and that source control for these metals may include municipal ordinances as well as management of land use decisions, building code modifications, industry standards, maintenance of assets (street sweeping), and even code enforcement.

Direct Effects and Challenges

There are numerous industries and businesses in San Diego County and throughout the United States that specialize in the production of sheet metal goods for the manufacture of building materials that include corrugated roofing, rain gutters, downspouts, and fencing. These businesses may be adversely impacted by ordinances that prohibit the sale, application, or use of products they manufacture.

Building permits are not required for fencing; rain gutter installation, repair, or maintenance; and roof repairs. Thus, it would be difficult to administer and measure application and reduction rates should administrative controls be implemented.

Considerations

The lack of studies that document the application and management of zinc- and copper-based building materials limits the scientific foundation and understanding of the economic, social, environmental, and political implications of restricting the use of these materials. Ultimately, the formula for implementation of controls will have to balance the effort required to address the implications with the relative pollutant reduction and ongoing management costs to track and administer. The City may consider the following:

- Develop a comprehensive inventory of sources of both metals that includes a list of potential sub-categories of building material sources. This is a critical step in understanding their application and application rates.
- Work with California Stormwater Quality Association (CASQA) and universities to conduct pilot studies within the City of San Diego to determine the application rates and potential reductions that could be affected through administrative controls such as redevelopment regulations, ordinances, and other code modifications.
- Conduct modeling to determine how redevelopment regulations, administrative controls, outreach, and/or incentives may reduce copper and zinc loads from building materials. The City may use this model to determine whether abatement of all or part of these sources would affect reductions necessary for TMDL compliance. Scientific literature indicates that the abatement of copper applications would produce negligible loading reduction while the abatement of zinc applications would likely create measurable and significant loading reductions relative to TMDL requirements.
- Implement the most efficient and effective administrative and treatment alternatives for controlling these (Table ES-1). This may also include true source control coordination activities similar to the Brake Pad Partnership.

Table ES-1 summarizes several potential administrative management options to reduce discharges of copper and zinc from building materials. Each management option is assigned a relative priority ranking based upon three evaluation criteria. Relative Potential Effectiveness represents the potential improvement to water quality of each management option. Implementation Feasibility represents potential challenges associated with industry partnership, resistance to change, economic factors, building codes, and presence/absence of product alternatives. Ongoing Management represents the relative effort and cost required to implement the management option (i.e., program administration, system maintenance, and ongoing inspections). The management options may be refined in subsequent years as additional information, scientific studies, and scientific literature support modification of the factors and rankings. As presented in Table ES-1, an outright ban of architectural copper may have limited effectiveness relative to vehicle brake pad replacement and other sources deposited by aerial deposition, but strong restrictions on the use of copper materials for redevelopment projects is more feasible than new construction and other applications. Moreover, treatment strategies for dissolved metals are only partially effective, are generally expensive to implement, and require ongoing maintenance and administrative tracking. Copper and zinc development regulations (i.e., ordinances) and less restrictive administrative controls (i.e., bulletins with product recommendations) appear to be the most effective and feasible options. Treatment options may be effective, particularly for temporary use at strategic point sources, but will require additional monitoring, maintenance, and tracking.

Table ES-1. Summary of 2011 Potential Administrative Management Options to Reduce Discharges of Copper and Zinc from Building Materials

Potential Management Option		Relative Potential Effectiveness	Implementation Feasibility	Ongoing Management	Relative Management Option Ranking
Cu	Ordinance Restricting Use of Architectural Copper for All Buildings	Medium / Low	Medium	$	**MEDIUM**
	Copper Sacrificial Temporary Coatings	Medium	Medium	$$	**MEDIUM**
	Ordinance Requiring Pre-Patination of Copper	Low	Medium	$	**LOW**
	Copper Infiltration Option	Medium	Medium	$$	**MEDIUM**
	Copper Treatment Option	Low	Low	$$$	**LOW**
Zn	Ordinance Restricting Use of Architectural Zinc for All Buildings	Medium	Medium / Low	$	**MEDIUM**
	Zinc Sacrificial Temporary Coatings	Medium	Medium	$$	**MEDIUM**
	Ordinance Requiring Pre-Patination of Zinc	Low	Medium	$	**LOW**
	Zinc Infiltration Option	Medium	Medium	$$	**MEDIUM**
	Zinc Treatment Option	Low	Low	$$$	**LOW**
	Artificial Turf Crumb Rubber Product Substitution	High	Medium	$	**HIGH PRIORITY**

1.0 COPPER

This section discusses known uses of copper, mechanisms of copper introduction to the environment, and studies conducted to determine runoff water quality from building materials containing copper.

1.1 Copper Use

When moisture (i.e., rain, wash water, air conditioning condensate, fog, etc.) comes in contact with copper surfaces, moisture picks up small quantities of copper salts (Copper Development Association, 2011). When these salts become mobile they have the potential to enter the municipal separate storm sewer system (MS4). Evidence of mobile salts can be visually recognized by the green stains present on porous surfaces that have adsorbed copper salt (Figure 1). Copper has been used as an outdoor structural feature or architectural accent for multiple building materials, including the following:

- Roofs
- Gutters and downspouts
- Copper-containing algae-resistant shingles
- Wood preservatives made of chromated copper arsenate (CCA) or alkaline copper quaternary (ACQ)
- Other (spires, cupolas, doors, light fixtures, signs, railings, weathervanes, mailboxes, and other exterior ornamental features)

Figure 1. Copper salt staining from a copper-clad building, Brandeis University, Boston, Massachusetts (Quigley, 2011)

Although most refined copper used in the United States is found in products that have limited potential to release copper to surface waters (e.g., copper wire and rod used for electrical applications) (TDC Environmental, 2004), structural and aesthetic building components containing copper may consist of up to 8% of the 4.7-million-pound refined copper market (Figure 2). Within the first 6 to 12 months of exposure to the atmosphere, refined copper exposed to the atmosphere usually weathers to a uniform russet brown. This natural corrosion process, which ultimately results in a highly durable, corrosion-resistant surface and copper's characteristic blue-gray color (patination), generally forms within 5 to 7 years of installation in seacoast atmospheres. Exposed horizontal surfaces patinate more rapidly than sloping surfaces which, in turn, patinate more rapidly than vertical surfaces (Copper Development Association, 2011).

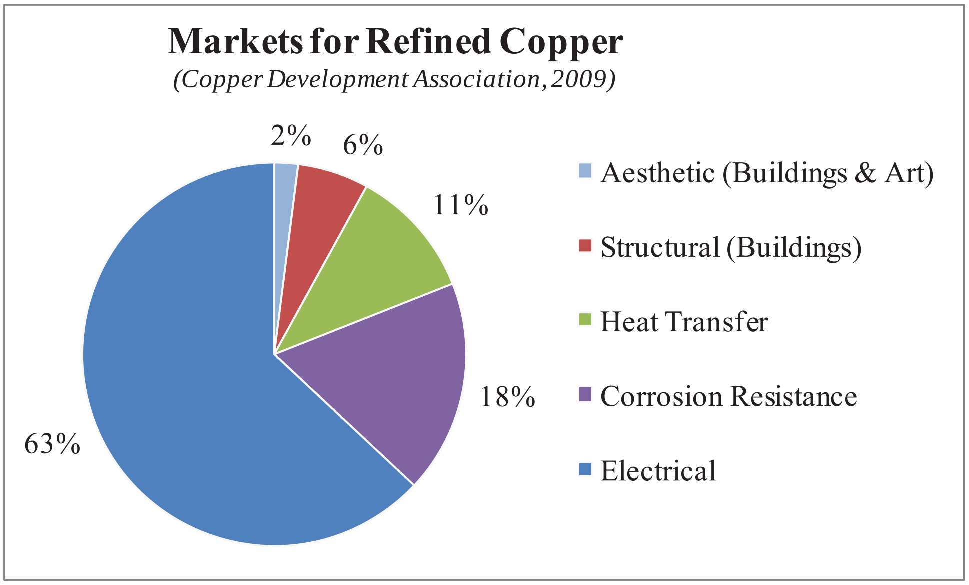


Figure 2. Markets for refined Copper

Copper is also found in pesticides (e.g., algaecide, fungicide, and bactericide) applied to landscaping, swimming pools, ornamental ponds, and wood preservatives applied on/around buildings. Copper sulfate and copper hydroxide represent two of the top 25 active ingredients found in these products (USEPA, 2001). As shown in Figure 3, copper is generally not a common active ingredient in residential products, but is often found in agricultural and industrial products. Of the 1.2 billion pounds of pesticides used in the United States in 2001, copper represented 14 million pounds, approximately 1.2%, of the total active ingredients (USEPA, 2001).

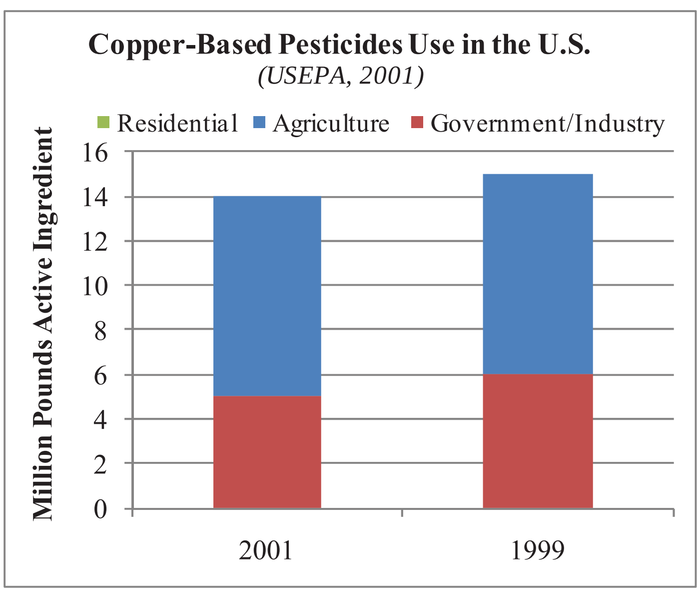


Figure 3. Copper as an Active Ingredient in Pesticides and Other Products

1.2 Copper Building Materials and Potential Water Quality Impacts

1.2.1 Literature Review of Copper Loads from Building Materials

Copper concentrations in runoff from copper roofs and building materials have been evaluated in studies conducted worldwide. Table 1 summarizes the potential loads for copper roofs, copper roof shingles, and copper gutters/downspouts that may potentially be applied to buildings within the City's jurisdiction. Studies have found the following:

- Copper roofing may represent approximately 0.05% of the net roof area in the San Francisco Bay area (Barron, 2001).
- Algae-resistant (copper containing) composition shingles are estimated by a manufacturer to be used on 0.03% of the net roof area. In contrast, regular (non-copper) composition shingles are estimated to be 60% of residential and 10% of commercial and industrial roofs in the San Francisco Bay area (Barron, 2001).

Table 1. Annual Copper Loading from Various Roof Building Materials

Building Material		Annual Load *(lb per 1,000-ft² roof)*	Study Notes	Reference Source
Copper Roof	New copper	1.1 – 1.2	Singapore. Annual load of 5.5 – 5.7 g/m².	(Wallinder et al., 2002)
		0.23 – 0.33	Stockholm, Sweden. Annual load of 1.1 - 1.6 g/m². Rainfall of 0.53 m/yr.	
	Naturally aged copper (patination)	0.20 – 0.31	Stockholm, Sweden. Annual load of 1 - 1.5 g/m²; total Cu concentration of 0.9 – 9.7 mg/L; 60% – 100% of Cu in form $Cu(H_2O)_6^{(2+)}$, the most bioavailable species.	(Karlen et al., 2002)
		1.7 – 1.8	Singapore. Annual load of 8.4 – 8.8 g/m². Natural patination over 130 years.	(Wallinder et al., 2002)
		0.33 – 0.47	Stockholm, Sweden. Annual load of 1.6 – 2.3 g/m². Rainfall of 0.53 m/yr. Natural patination over 130 years.	
		0.41	Connecticut, USA. Annual load of 2.0 g/m². Rainfall of 1.19 m/yr. Natural patination over 130 years.	(Boulanger & Nikolaidis, 2000)
	Range	**0.20 - 1.8**	-	-
Copper Roof, Gutters, and Downspouts		**0.22**	Model for: 2,500-ft² Cu roof with Cu gutter/downspout.	(Barron, 2001)
Copper Gutters and Downspouts only		**0.01**	Model for: 2,500-ft² slate roof with Cu gutter/downspout.	
Algae-Resistant Shingles		**0.03**	Model for: 2,500-ft² roof with steel gutters/downspouts. Algae-resistant composition shingles contain 25 mg/kg of Cu.	
Copper-Based Wood Preservatives		**0.13**	Assumed 0.5 gal. of CCA or ACQ preservative needed for 2,500-ft² wood roof (contains 0.33 lb Cu).	

1.2.2 City of San Diego Studies Related to Copper Building Materials

The City has also completed special studies that support these results, indicating runoff from copper building materials may have an impact on storm water quality and the receiving waters.

The 2009 Phase III Aerial Deposition study evaluated roof runoff at six commercial buildings in the Chollas Creek Watershed, which has a copper TMDL. None of the buildings were explicitly made of copper materials and runoff concentrations of copper were relatively low but still higher than the California Toxics Rule (CTR) benchmark (i.e., total copper concentrations at six sites ranged from 47 µg/L to 192 µg/L). The study suggested that aerial deposition of copper could account for up to 100% of the copper loading resulting in concentrations in storm water and receiving waters above the water quality benchmark (Weston, 2009); mobile emissions sources and localized parcel-based sources play a role in metals deposition contributing to this load.

The 2010 Rain Barrel Downspout Disconnect Program evaluated metals concentrations discharged from eight buildings constructed at different times and of different building materials across San Diego, which included libraries, recreation centers, and maintenance yards and shops. The study found measurable concentrations of copper discharged from all building roof surfaces, supporting the 2009 study results that aerial deposition is a contributing source of copper loading (Weston, 2009). At Mira Mesa Library, a facility with a partially patinated (brown) copper downspout, small copper roof area, and potential for aerial deposition, total copper concentrations ranged from 741 µg/L to 12,450 µg/L (Figure 4) (Weston, 2010). The City's study shows that copper building materials can increase copper concentrations in roof runoff.

Figure 4. Brown Copper Downspout at Mira Mesa Library with Rain Barrel Downspout Disconnect System and Adjacent Infiltration Area

Similar to the Barron (2001) results, a load analysis suggests that the copper system at the Mira Mesa Library could contribute 0.002 to 0.03 lb of copper each year.[1] Additional information about roof and downspout connectivity to the MS4 is needed to evaluate the potential load contribution of copper building materials to the MS4 and ultimately to the receiving waters.

[1] Approximately 15% (50 ft^2) of the 375-ft^2 roof study area for the Mira Mesa Library was copper (WESTON, 2010). For comparison with other studies presented in this document, runoff concentration results were normalized to a 1,000-ft^2 roof surface area and a full wet weather season. The calculation assumes an average of 10 storms per year in the San Diego area, design storm event rainfall, and approximately 125 ft^2 of copper roof surface.

2.0 ZINC

This section discusses known uses of zinc, mechanisms of zinc introduction to the environment, and studies conducted to determine runoff water quality from building materials containing zinc.

2.1 Zinc Use

Unlike copper, zinc is often used to increase the service life of metals. Nearly 50% of all the zinc produced annually is used to galvanize steel products to prevent corrosion[2] or mixed with other metals to create unique compounds like brass (Figure 5). Zinc roof products have an 80- to 100-year lifetime without maintenance. These qualities make zinc a desirable building material. Once a product reaches its lifetime almost the entire volume of material can be recycled and it can be recycled indefinitely without loss of physical or chemical properties. Nearly 70% of the zinc from end-of-life products becomes recycled (Zinc for Life, 2011).

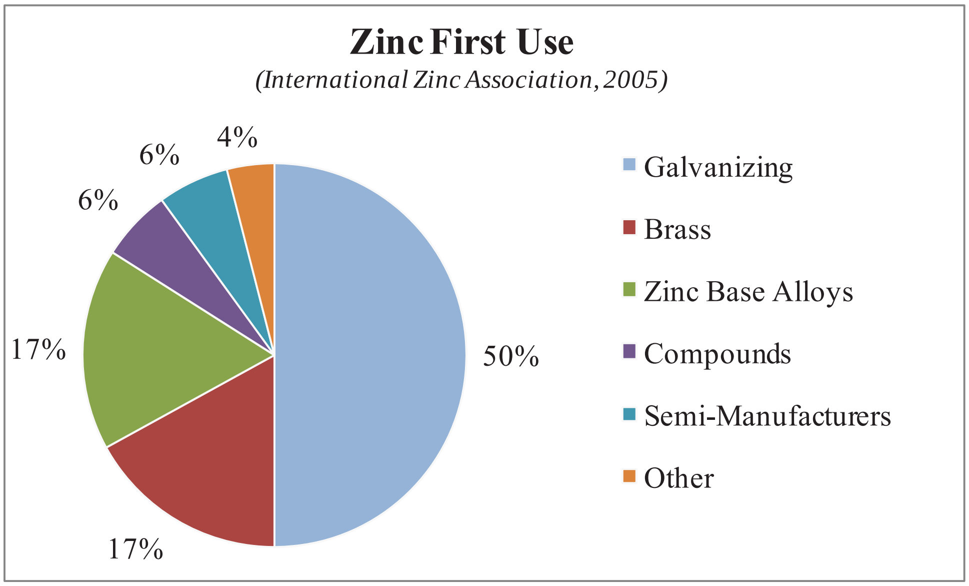


Figure 5. Uses and Applications of Zinc

Common sources of zinc in building materials include the following:

- Roofs, gutters/downspouts, building siding
- Nails and solder
- Wood preservatives (zinc naphthalene)
- Fungi biocides and coatings (zinc sulfate, zinc chloride)
- Rubberized paving (recycled tires)
- Synthetic turf underlayment (recycled tires)
- Corrugated metal storm drain pipes
- Propane and natural gas lines
- Cathodic protection
- Chain link fencing

[2] When in an oxygen environment and in contact with the water, zinc materials patinate to zinc carbonate which is 'insoluble' in rainwater and protect the zinc from further corrosion. The greatest formation of zinc carbonate is within the approximately 5 years of installation (Zinc for Life, 2011).

Because of its broader application, zinc is more likely to enter the MS4 from multiple types of zinc-based building materials than copper. Table 2 presents zinc concentrations measured in roof runoff from five common building materials. Table 3 presents zinc concentrations associated with leaching from various zinc-based building materials other than roofs. No information was found characterizing runoff from galvanized fencing, outdoor furniture, railing, and other architectural features. Based on the concentration data, potential priority sources may consist of roofing (i.e., galvanized steel and/or wood shingle roofs treated with zinc-based paint) and crumb rubber used for asphalt, turf, and other building applications. A complete inventory of the type of materials used is needed to prioritize sources and evaluate the actual impact on water quality.[3]

Table 2. Zinc Concentrations in Roof Runoff

Type of Zinc Building Material		Concentration in Runoff	Notes	Reference Source
Roofs	Zinc	3.6 – 7.1 mg/L	Paris. Annual average concentration.	(Robert-Sainte et al., 2009)
Roofs	Galvanized steel	0.33 mg/L	Bench test. 1 sample @ 30% concentration.	(Kszos et al., 2004)
Roofs	Galvanized steel	0.12 – 212 mg/L	Texas. 31 samples. Mean: 11.8 mg/L. Median: 8.2 mg/L	(Chang et al., 2004)
Roofs	Galvanized steel	0.03 – 0.04 mg/L	Paris. Annual average concentration.	(Robert-Sainte et al., 2009)
Roofs	Aluminum	0.5 – 16.6 mg/L	Texas. 31 samples. Mean: 3.2 mg/L. Median: 2.3 mg/L	(Chang et al., 2004)
Roofs	Wood shingle	0.04 – 110 mg/L	Texas. 31 samples. Mean: 16.3 mg/L. Median: 9.7 mg/L	
Roofs	Composite shingle	0.04 – 13.6 mg/L	Texas. 31 samples. Mean: 1.4 mg/L. Median: 0.9 mg/L	

3 Approximately 1% of the parcels in the Chollas Creek Watershed were identified as having metal roofs (WESTON, 2009). One tire equals approximately 10 to 12 lb of crumb rubber. On average, a single soccer field may consist of 20,000 to 40,000 tires (i.e., approximately 100 to 400 tons of crumb rubber per field) (City of Portland, 2008). The number of fields in the City of San Diego is unknown. More information is necessary to compare and accurately prioritize these two possible sources of zinc loading to the MS4.

Table 3. Zinc Concentration in Unit of Building Material

Type of Zinc Building Material		Concentration / Unit Building Material	Notes	Reference Source
Paint	Zinc primer	0.30 – 0.36 mg/L	Bench test. 1 sample @ 30% concentration.	(Kszos et al., 2004)
	Zinc primer + coating	0.06 – 0.09 mg/L	Bench test. 1 sample @ 30% concentration.	
	Galvanized steel + coating	<0.05 mg/L	Bench test. 1 sample @ 30% concentration.	
Siding / Walls	Brick	0.63 mg/m^2	Bench test. Geometric mean of 30 samples.	(Davis et al., 2001)
	Wood (painted)	1.4 mg/m^2	Bench test. Geometric mean of 13 samples.	
	Concrete	0.90 mg/m^2	Bench test. Geometric mean of 7 samples.	
	Wood (unpainted)	0.20 mg/m^2	Bench test. Geometric mean of 3 samples.	
	Vinyl	0.05 mg/m^2	Bench test. Geometric mean of 3 samples.	
Alternative Landscape	Synthetic turf (made from recycled tires)	1.0 – 2,320 µg/ g tire	Literature Review of leachate studies.	(OEHHA, 2007)
		21.0 – 55.0 µg/ g tire	Bench test. USEPA SW-846 Method 1312.	(EHHI, 2007)

2.2 Zinc Building Materials and Potential Water Quality Impacts

2.2.1 Literature Review of Zinc Loads from Building Materials

Zinc from crumb rubber and roofing materials are the most studied and likely to be the most common type of zinc building material to be found above ground within the City's jurisdiction; therefore, this section focuses on potential annual loading from these sources. However, corrugated metal pipes and galvanized fencing may contribute significant quantities though no studies could be identified.

The zinc load modeling assessment conducted by Verschoor (2007) suggests that synthetic turf made from crumb rubber may translate to an average load of 800 mg/m^2/year (600–1,000 mg/m^2/year). Zinc loads from crumb rubber were 12–20 times greater than loads from agricultural sources. It was estimated that a single synthetic turf field with a life expectancy of 10 years would exceed regulatory water quality standards within 3 years of installation (Vershoor, 2007). While groundwater impacts were generally discussed, fields in low-lying areas may require underdrains, which could be connected to the MS4.

Table 4 presents typical annual loads from galvanized metal or zinc-plated roof surfaces. Van Metre and Mahler (2003) estimated that metal roofs contributed 20% of the zinc load to a small study watershed in Texas.[4]

Table 4. Annual Zinc Loading from Various Roof Building Materials

Building Material		Annual Load *(lb per 1,000-ft² roof)*	Notes	Reference Source
Roof	New zinc	0.68 - 0.79	Paris. Load: 3,868 mg/m^2-yr to 3,299 mg/m^2-yr.	(Robert-Sainte et al. 2009)
		0.68	Stockholm. Load: 3.3 g/m^2-yr.	(Wallinder et al. 2002 in Robert-Sainte et al. 2009)
	Naturally aged zinc (patination)	0.85 - 0.93	Paris. Load (40-year old Zn roof): 4,517 mg/m^2-yr to 4,145 mg/m^2-yr.	(Robert-Sainte et al. 2009)
		1.0	Stockholm. Load (40-year old Zn roof): 4.9 g/m^2-yr.	(Wallinder et al. 2002 in Robert-Sainte et al. 2009)
	Range	**0.68 – 1.0**	-	-
	Galvanized steel	0.38 - 0.40	Paris. Roof with 70-100µm Zn surface. Load: 1,966 mg/m^2-yr to 1,867 mg/m^2-yr.	(Robert-Sainte et al. 2009)
		0.78	Stockholm. Roofs with 70-100µm Zn surface. Load: 3.8 g/m^2-yr.	(Wallinder et al. 2002 in Robert-Sainte et al. 2009)
	Range	**0.38 – 0.78**	-	-
	Painted galvanized steel	0.002 – 0.005	Paris. Roof with 20µm Zn surface and painted surface coat(s). Load: 24.6 mg/m^2-yr to 7.4 mg/m^2-yr.	(Robert-Sainte et al. 2009)
		0.02	Stockholm. Roof with 20µm Zn surface and painted surface coat(s). Load: 0.1 g/m^2-yr.	(Wallinder et al. 2002 in Robert-Sainte et al. 2009)
		0.003	Texas. Load: 1,385 µg/m^2/storm. Assumed 10 to 12 events per year.	(Van Metre and Mahler, 2003)
	Range	**0.002 – 0.02**	-	-

[4] This same study quantified approximately 40% of the zinc load was "aerial deposition." Aerial deposition represents the route for zinc to reach the MS4 but does not identify the specific source(s), which may include industrial admissions, brake wear, and corrosion from zinc-based building materials.

2.2.2 City of San Diego Studies Related to Zinc Building Materials

The City has also completed special studies that support these results, indicating runoff from zinc and galvanized building materials contribute to increased zinc concentrations in runoff and may have an impact on the receiving waters.

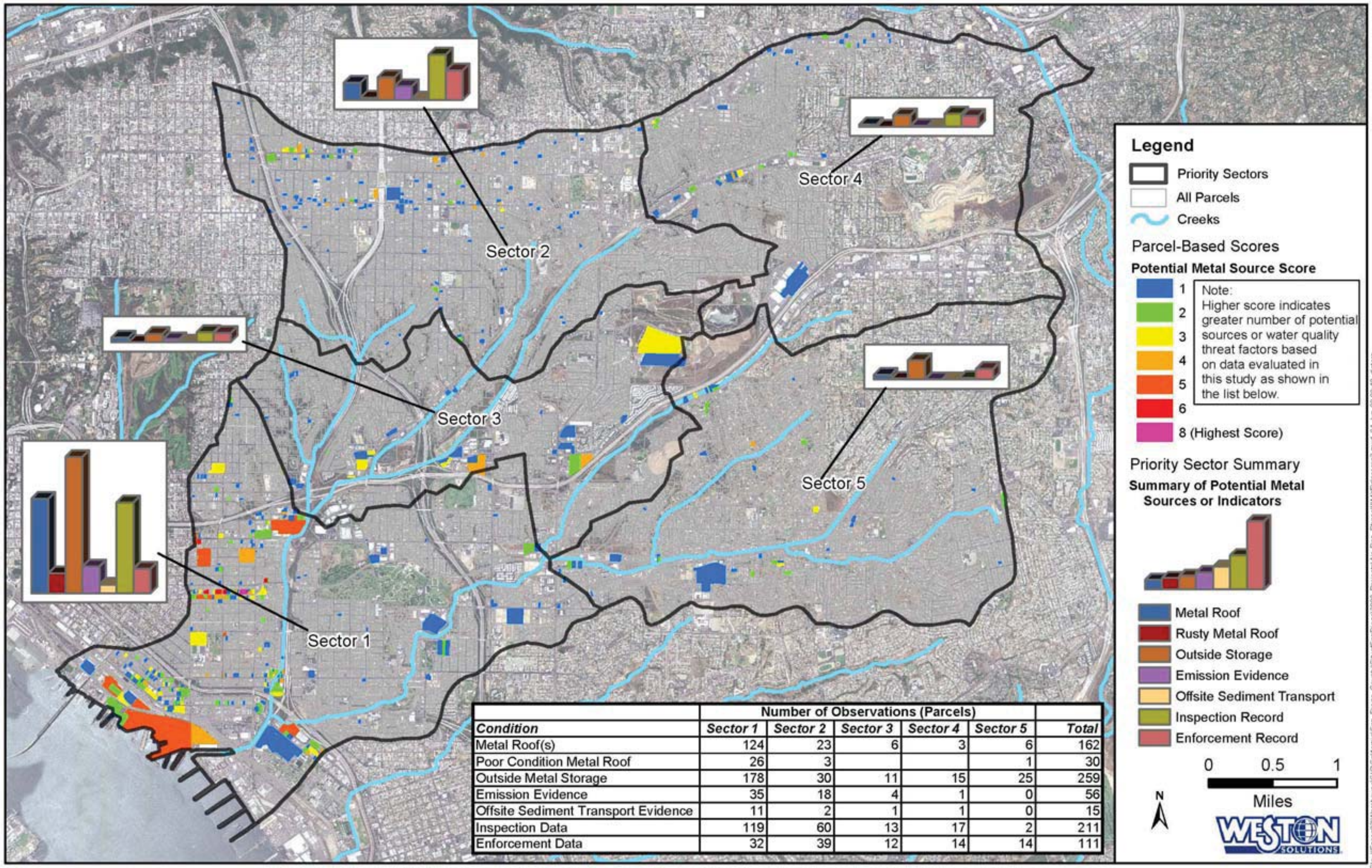
The 2009 Phase III Aerial Deposition study used aerial photography to complete a geographic information system (GIS) desktop review of 16,412 parcels within the Chollas Creek Watershed (Weston, 2009). Metal roofing was identified for 162 parcels, or approximately 1% of the properties in the watershed (Figure 6). Subsequent study and monitoring of zinc concentrations in runoff from metal roofs averaged 12,600 µg/L and reached concentrations of 29,000 µg/L. Despite high concentrations measured from relatively few metal roofs, the study suggested that aerial deposition of zinc could account for up to 74% of the loading, resulting in concentrations in storm water and receiving waters above the water-quality benchmark. The study also determined that zinc deposition rates are higher in areas close to major transportation corridors.

The 2010 Rain Barrel Downspout Disconnect Program (Weston, 2010) monitored runoff from several buildings with various zinc building materials (Table 5). Zinc concentrations from roofs in this study were less than those identified from aerial deposition, however, the roof runoff concentrations were identified from a known point source of zinc. Concentrations of zinc in direct rooftop runoff exceeded water quality benchmarks by several orders of magnitude. However, the benchmarks are hardness-based and the low hardness in rainwater produces a relatively low water quality benchmark compared to those in receiving waters.

Table 5. Zinc Concentrations and Estimated Annual Loads for the Rain Barrel and Downspout Disconnect Study (Weston, 2010)

Municipal Building	Zinc Material	Mean Concentration (µg/L)	Water Quality Benchmark[1] (µg/L)	Annual Load (lb/1,000 ft^2/yr)
Rancho Bernardo Recreation Center	Downspouts	1,436	33	0.006 – 0.083
South Bay Wastewater Treatment Plant	Downspouts	945.0	50	0.011 – 0.081
Scripps Institution of Oceanography	Roof	5,693	52	0.008 – 0.009
San Ysidro Library	Downspouts	291.4	14	0.004 – 0.019
Southcrest Park Recreation Center	Downspouts	802.1	33	0.002 – 0.071

[1]Water quality benchmark based on hardness and represents Criterion Maximum Concentration (CMC) WQO.



Condition	Number of Observations (Parcels)					
	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Total
Metal Roof(s)	124	23	6	3	6	162
Poor Condition Metal Roof	26	3			1	30
Outside Metal Storage	178	30	11	15	25	259
Emission Evidence	35	18	4	1	0	56
Offsite Sediment Transport Evidence	11	2	1	1	0	15
Inspection Data	119	60	13	17	2	211
Enforcement Data	32	39	12	14	14	111

Figure 6. Roofs in the Chollas Creek Watershed Scored as Priority Metals Sources where 8=High Priority and 1=Low Priority (Weston, 2009)

3.0 REGULATORY CASE STUDIES

There are multiple regulatory options that may be considered for managing metal building materials. This section provides examples of regulatory options and administrative controls that have been used to manage copper and zinc products by other municipalities.

3.1 Case Study: Municipal Ordinance

On January 1, 2003, the City of Palo Alto adopted Municipal Code Section 16.09.160(b), an ordinance prohibiting the use of copper roofing materials (e.g., copper metal roofing, copper granule containing asphalt shingles and copper gutters) on new development and redeveloped residential, commercial, and industrial buildings. The Copper TMDL identified copper allocations from wastewater and storm water discharges. The City of Palo Alto conducted outreach to industry partners (plumbing organizations) to affect possible reductions in the wasteload allocation through copper piping management. The storm water ordinance was implemented to address the storm water allocations as a result of a water quality study investigating the relative importance of copper used in roofing materials in the San Francisco Bay area. The policy and treatment options presented in Table 6 represent building-specific treatment solutions that would require ongoing maintenance and enforcement and were not guaranteed to prevent copper discharges. As stated in the ordinance, "there are no practical or effective ways to prevent copper from washing off of copper roofs or to remove copper from roof runoff" (City of Palo Alto, 2003). After reviewing the feasibility, effectiveness, and cost of all recommended options, true source control through a municipal restriction on copper roofing on new development and redevelopment was selected as the final management action. The ordinance is enforced at the City of Palo Alto Development Center[5] where engineering drawings are evaluated for copper features as part of the building permit review process.

Table 6. Options to Reduce Copper Discharges from Buildings Located in the San Francisco Bay Area

Option *	Potential Effectiveness	Assessment *
Alternative roofing material	**High -** *Recommended Option in Study*	Use of painted stainless steel would resemble aged copper and reduce the copper load 100%. Added benefits included reduced construction and materials costs (a savings of $15,000 for a 10,000-ft^2 building) and comparable roof product service life.
Pre-patinated copper	**Medium**	Patina is fragile and includes a higher cost ($12,000 for a 10,000-ft^2 building). The study indicated that this option could reduce loading 50%.
Apply clear-coating to copper surfaces	**Medium**	This was flagged as an unproven technique, but was assumed to reduce loading by 75% or more.
Metals treatment train	**Medium / Low**	A combination metallic and ion exchange unit (similar to units at photo shops and dental offices) could be installed downstream of the building(s) discharging copper. Unit costs were moderate ($10,500 for a 10,000-ft^2 building), but inefficient regionally because systems would be required

[5] The Development Center consists of the Fire, Public Works, Building, Planning, and Utilities departments.

Table 6. Options to Reduce Copper Discharges from Buildings Located in the San Francisco Bay Area

Option *	Potential Effectiveness	Assessment *
		downstream of each building. Treatment was assumed to treat the first hour of rainfall or the full storm event.
Infiltration	**Medium / Low**	"The ability of planted areas to permanently capture copper from runoff over time is not known" (Barron, 2001).
Filtration	**Low**	Copper is typically in the dissolved form and unable to be removed through filtration.
Electrically active cathodic protection	**Low**	An open air application on rooftops is unable to force the current needed to stop metal ions (ineffective design).
Applying a sacrificial coat on top of copper material	**Low**	Sacrificial lead and/or zinc coatings do not resemble bare copper. This option, as written, is a poor option for the City of San Diego because lead and zinc are also priority constituents.

* Options and descriptive information in the assessment from Barron, 2001.

When the final municipal ordinance was being drafted, three key exceptions to the copper restriction were identified in order to make it palatable to the public (Table 7). These exceptions were adopted into the ordinance because they presented no additional water quality risk and would encourage stakeholder cooperation.

Table 7. Exceptions to the City of Palo Alto Municipal Ordinance Restricting Use of Copper Roofing Materials

Exceptions to the Ordinance	Assessment
Copper flashing for use under tiles or slates	Flashing is a waterproof material and important to building design in the rainy San Francisco Bay area. Copper is a popular material for flashing because of its durability and chemical compatibility with newer wood-preservatives (Gibson, 2011). There is also limited to no environmental water quality impact when the material is covered by other materials such as tile or slate.
Replacement roofing and gutters on historic structures	Municipal ordinances usually provide special provision for the preservation of historic structures (also see Appendix A). By requiring historic copper roofing and gutters to be replaced with materials pre-patinated at the factory, the City of Palo Alto was able to ensure that existing copper roof loads would not increase. The definition of "historic" is limited to structures designated as Category 1 or Category 2 buildings in the most recent edition of the Palo Alto Historical and Architectural Resources Report and Inventory (City of Palo Alto, 2003).
Small copper ornaments	The special study demonstrated that an incremental load increase was associated with 1,000-ft^2 of copper roofing (Barron, 2011). Small copper ornaments would not significantly contribute to the overall load.

The City of Palo Alto also encountered strong industry opposition to the ordinance. In 2002, the Copper Development Association (CDA), an industry-sponsored organization that promotes copper products and industries, published a scientific study evaluating copper corrosion, storm water runoff, and environmental impacts. This study evaluated copper concentrations from a new copper roof, aged copper roof, parking lot, and grassy area on the University of Iowa campus and compared results to the receiving water exiting the campus. According to the study, copper corrosion and its presence in storm water "does not necessarily lead to environmental harm" because street-level concentrations of copper measured were insufficient to cause toxicity to the water flea, *Daphnia pulex*. The study also showed that the grassy area contributed the greatest copper flux, followed by the new copper roof and parking lot (Michels et al., 2002), which implies that copper-based pesticides, algaecides, and vehicular brake wear are a greater source of copper than roofing materials. The study is currently available on the CDA Web site and this view is strongly supported by building industry professionals (Songer, 2011). It is estimated that copper roofs are installed on 0.05% of residences, 0.3% of industrial commercial buildings, and 1.5% of other structures within the Palo Alto's jurisdiction (Barron, 2001). Because of the relatively small impact to the building industry, it is likely that the energy behind the opposition decreased with time. The City of Palo Alto has also integrated the CDA into the pollution prevention process by partnering with the organization on other copper-related pollution prevention activities[6] (City of Palo Alto, 2011).

3.2 Case Study: Zoning Ordinance

In 2010, Scott County, Minnesota updated the zoning ordinances to reduce the amount of metal materials permitted for the exterior of commercial, industrial, and institutional buildings. The objective of these amendments was to enhance regional architectural aesthetics. While this control was mainly for aesthetic purposes, the ordinance would reduce pollutant runoff. A key point of contention between the community and Scott County was that metal materials could only be used for 25% of the total building, compared to 50% of the building under pre-existing ordinances. Cost was the driving factor for many of the residents against the ordinance (Scott County Planning Advisory Commission, 2009). Excerpts from the ordinance include the following:

> **Section 4-3-5(1)(a)** "Except in association with farming activities, no galvanized or unfinished steel or unfinished aluminum buildings (walls or roofs), except those specifically intended to have a corrosive designed finish such as CORTEN steel shall be permitted in any zoning district."
>
> **Section 4-3-5(3)(b)** "The following are permitted accent materials that may be used for up to 25% of any exterior wall area:
> 1. Wood, natural or composite, provided the surfaces are finished for exterior use or wood of proven exterior durability is used, such as cedar, redwood or cypress.
> 2. Metal.
> 3. Vinyl, steel, or aluminum siding.
> 4. Field painted materials (i.e., decorative band on precast concrete)."

[6] These activities include educating pipefitter unions and engineering associations about plumbing guidelines to reduce copper corrosion.

Section 4-3-5(3)(d) "Principal building roofs that are exposed or an integral part of the building architecture shall be constructed only of commercial grade asphalt shingles, wood shingles, standing seam metal, slate, tile, or materials similar in appearance and performance. Flat roofs (1/12 slope or less) and accessory building roofs are not subject to these material limitations."

Exemptions: Whenever an existing industrial or commercial building has been damaged or destroyed to the extent of 50% or more of its fair market value, and a building permit has been applied for within 180 days of when the property was damaged, the re-built structure shall be exempt from the exterior building standards of this Section.

3.3 Case Study: State and Federal Regulations

Generally, municipal ordinances build upon regulations and restrictions/bans implemented at the state or federal level. The following two case studies indicate how the City of San Diego may work with public agencies to effectively implement true source control of copper and zinc discharges from building materials.

3.3.1 Federal Regulation of Chromated Copper Arsenate

CCA is a chemical wood preservative used in pressure-treated wood to protect it from rot caused by insects and microbial agents. This wood preservative has been used since the 1940s. As of the 1970s, it was the most common product used for residential outdoor wood applications such as decks, fencing, and play-sets. Approximately 60 billion board feet of CCA-treated wood has been installed nationwide (Thompson et al., 2008).

In 2004, the USEPA classified CCA as a restricted product for use only by certified pesticide applicators (USEPA, 2008). At the same time, the pesticide industry voluntarily phased out CCA for residential use. While these restrictions were primarily put into effect to minimize human health risk of exposure to leached arsenic, the studies also found significant concentrations of copper in unprotected wood. Future application of CCA and similar wood preservatives, including acid copper chromate (ACC), ammoniacal copper arsenate (ACA), ammoniacal copper zinc arsenate (ACZA), and chromated zinc chloride (CZC), are controlled under the federal regulations. A 2-year study suggested that applying penetrating stains and coatings to CCA-treated structures at least once a year reduced potential pollutant leaching from CCA-treated wood (USEPA, 2008). Coating treated wood was the interim source control measure until recommended disposal techniques could be implemented. Under R9-2003-0306, the Regional Board adopted these disposal techniques to regulate potential discharges from uncoated, improperly managed wood.[7] The Integrated Pest Management brochure for termites on the County of San Diego Web site refers residents to these techniques to the local Household Hazardous Waste Collections program (University of California, 2001). General information related to household hazardous waste management is available on the City of San Diego Web site.

[7] For example, common residential disposal practices prohibited under R9-2003-0306 include burning, chopping wood into wood chips and mulch, and discarding wood into the municipal trash.

3.3.2 California Senate Bill 346 - The Brake Pad Partnership

The Brake Pad Partnership in California has brought together regulatory, administration, and industry to determine possible ways to reduce the heavy metals, specifically copper, in the manufacture of vehicle brake pads. In 2010 the Brake Pad Partnership successfully had Senate Bill (SB) 346 (Kehoe) signed into law. SB346 requires brake manufacturers to reduce the use of copper in brake pads sold in California to no more than 5% by 2021 and no more than 0.5% by 2025. This legislation and ongoing support will help change the industry standard to reduce heavy metals deposition, specifically to meet Clean Water Act (CWA) and TMDL requirements.

The Brake Pad Partnership and resulting copper source control abatement strategy illustrates how and why integrated sustainable planning and industry partnerships are important for TMDL implementation. The City of San Diego helped sponsor the Brake Pad Partnership and actively gathered aerial deposition and water quality data vital to development of SB346. Based on recommendations from this sound science, brake manufacturers now have 14 years to develop and introduce copper-free materials, and municipalities subject to copper TMDLs will have time to demonstrate receiving water reductions (e.g., three seasons of wet-weather monitoring in the Chollas Creek Watershed prior to the 2028 Dissolved Metals TMDL compliance date). The City of San Diego and the Brake Pad Partnership were also able to incorporate provisions that will help ensure that copper is not replaced with materials containing other harmful substances.[8]

3.4 Case Study: 3rd Party Certification Program

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is an internationally recognized, third-party green building certification program developed by the United States Green Building Council (USGBC). The LEED certification is designed to incentivize and verify sustainable design and development. The lowest LEED certification is achieved when a building earns 40 credits (out of a possible 100 credits).

"Cool metal roofs" are marketed by the building industry and the LEED Green Building Rating System as sustainable, energy-efficient roofing products with high solar reflectance and high thermal emittance. This case study provides context for the possible limitations of a City ordinance change for allowed building materials, identifies potential project partners for implementing broad true source control measures for building materials, and highlights the importance of an integrated solution.

Cool metal roofs comprise unpainted metal (e.g., copper, coated copper, zinc-coated, tin-coated, stainless, and stainless-coated), prepainted metal, and granular-coated metal. Galvanized steel and Galvalume steel,[9] with and without a Kynar 500 coating layer, are popular materials selected for their relative low cost, light weight, and solar reflectance (Cool Metal Roofing Coalition, 2006a). The LEED Green Building Rating System gives buildings 1 credit for installation of a cool metal roof (United States Green Building Council, 2011) and up to 12 additional credits for "Energy Optimization" and "Material Recycling" (McElroy Metal, 2011). Based on the 2011

[8] Provisions include: de minimis use of existing pollutants of concern (i.e., cadmium, hexavalent chromium, lead, mercury, and asbestiform fibers) and product review through California's Green Chemistry Initiative (Sustainable Conservation, 2011).
[9] Galvalume sheeting is made of a 55% aluminum-45% zinc alloy (Cool Metal Roofing Coalition, 2006a).

scoring system builders may be incentivized to install a cool metal roof to obtain 32.5% of the minimum LEED score needed for certification. Individual homeowners may also be incentivized to install cool metal roofs through the federal tax credit available under the USEPA Energy Star program (Cool Metal Roofing Coalition, 2006b). While prescriptive criteria set in the 2008 California Title 24 Energy Code have effectively prohibited use of unpainted metal as a cool metal roofing material in this state (California Energy Commission, 2010), and water quality data are not available for Galvalume steel or Kynar 500 coatings, the galvanized steel and general coating data presented in Subsection 2.2.1 suggest that (cool) metal roofs may potentially be a source of zinc and copper load to the MS4. This case study also demonstrates how different groups (i.e., City Storm Water Division, San Diego Gas & Electric, federal agencies, state agencies, 3^{rd} party/industry stakeholders) potentially have similar yet possibly conflicting goals regarding sustainable development (i.e., energy efficiency with a potentially unaccounted-for water quality impact).

3.5 Existing Policy at the City of San Diego

This section discusses existing policy at the City of San Diego related to copper and zinc building materials. If the City of San Diego chooses to pursue an ordinance restricting the use of metal building materials ordinance, these policies may need to be reviewed and modified to ensure no internal conflicts exist.

3.5.1 Metal Roofing Requirements – Copper and Zinc

The City of San Diego allows copper and galvanized steel to be installed as roofing, provided the exposed metals is corrosion-resistant and installed in accordance with the requirements established by the California Building Code (CBC) and manufacturer recommendations (City of San Diego, 2003). The standard specifications and guidelines for metal coatings (City of San Diego, 1999) include the following:

- Coatings are required to last 20 years without "significant peel, blister, flake, chip, crack or check in finish, and without chalking in excess of 8, ASTM D4214, and without fading…"
- "Sheet steel shall be minimum 20-gauge hot-dip zinc-coated, ASTM A 653, Grade A, Designation G90, for maximum coating performance."
- Kynar 500 is the recommended corrosion-resistant polyvinylidene fluoride (PVDF) resin coating. According to the manufacturer's Web site, there is no environmental/ecological information available for this product (Arkema, 2005).

3.5.2 Metal Fencing Requirements – Zinc

The municipal code (Chapter 14, Article 2, Division 3) regulates the types of fencing permitted within the City of San Diego, as follows:

- Types of metal fences permitted include metal chain link fences (**§142.0310**), metal solid fences (**§142.0370**), and metal open or screen fences (**§142.0370**).
- Sharp metal fences are permitted for agricultural uses in agricultural zones (**§142.0360**).

- Metal fences in required front and street side yards shall be covered with a colored finish other than galvanized metal. Exception: zones IH, IS, IL, AG and AR (**§142.0370**).

3.5.3 Synthetic Turf - Zinc

On January 20, 2011, the City of San Diego Park and Recreation Department released guidelines for the design, construction, maintenance, and replacement of synthetic turf. The memorandum identifies multiple new and planned synthetic turf fields, including a 1.25-acre synthetic turf field that was installed in the Chollas Creek Watershed on September 2007 at Edison Elementary School.

Based on publicly available water quality data, the memorandum concluded that there is little to no health or environmental risks associated with synthetic turf. Several of the studies (discussed above) indicated elevated levels of zinc in drainage water from crumb rubber synthetic turf, but in concentrations not considered a risk to human health. This potential environmental risk was incorporated into the City's guidelines as follows:

> "Synthetic turf fields will not be installed in highly flood prone areas due to potential damage to the turf and possible dissemination of synthetic turf materials, such as the infill material, into storm drains or natural drainage courses" (City of San Diego, 2011).

The memorandum highlights that most water quality issues are related to crumb rubber. Alternative infill materials such as coconut fiber, cork, and resin-coated silica sand were discussed and allowed as standard design as follows:

> "The synthetic turf system shall be a crumb rubber, crumb rubber and silica sand, synthetic or organic infill type with a subterranean drainage system sufficient to allow the playing surface to drain quickly" (City of San Diego, 2011).

4.0 POTENTIAL MANAGEMENT OPTIONS

The following table presents multiple management options to reduce copper and zinc concentrations in storm water runoff (Table 8). Each management option is assigned a relative priority ranking based upon three evaluation criteria. Relative Potential Effectiveness represents the potential improvement to water quality of each management option. Implementation Feasibility represents potential challenges associated with industry partnership, resistance to change, economic factors, building codes, and presence/absence of product alternatives. Ongoing Management represents the relative effort and cost required to implement the management option (i.e., program administration, system maintenance, and ongoing inspections). The management options may be refined in subsequent years as additional information, scientific studies, and scientific literature support modification of the factors and rankings. Based upon additional information, a systematic ranking system would be an appropriate next step to further refine the prioritization of the management options.

Table 8. Potential Management Options to Reduce Copper and Zinc Concentrations in Storm Water Runoff

Potential Management Option		Relative Potential Effectiveness	Implementation Feasibility	Ongoing Management	Relative Management Option Ranking	Assessment
1) Ordinance Restricting Use of Architectural Metals for All Buildings	CU	**Medium / Low**	**Medium**	**$**	**MEDIUM**	100% effective true source control option provided viable alternative materials. More known alternatives for copper than zinc. Potential alternative roofing products include: • Aluminum – low cost, high corrosion. • Corrugated bamboo sheets – higher (shipping?) cost, unknown maintenance. • Slate – highest cost, zero corrosion. There are fewer copper applications. The overall impact of copper restrictions will likely be limited. But due to wider building application, stronger push-back anticipated from zinc industry than copper industry which will inhibit program implementation.
	ZN	**Medium**	**Medium / Low**	**$**		
2) Ordinance Requiring Use of Sacrificial Temporary Coatings		**Medium**	**Medium**	**$$**	**MEDIUM**	Opportunity to build upon the City's existing building criteria and construction specifications. A discussion of different types of coatings is provided in Section 4.1.
3) Ordinance Requiring Pre-Patination of Metal Building Materials		**Low**	**Medium**	**$**	**LOW**	Patina is fragile, associated with higher building cost, and unlikely to significantly reduce load.
4) Infiltration BMPs		**Medium**	**Medium**	**$$**	**MEDIUM**	Infiltration BMPs that capture and fully remove runoff from the system (i.e., disconnected from the MS4) are relatively effective and lower cost than treatment BMPs. Effective long-term provided BMPs are considered a "mass storage" rather than "treatment" and have appropriate maintenance programs for plants and soils (Hathhorn and Yonge, 1995).
5) Treatment BMPs		**Low**	**Low**	**$$$**	**LOW**	Unit system costs are moderate (Barron, 2001), but include significant administrative costs with wide-scale implementation. Likely high risk of failure when implemented regionally.
6) Require alternative material to crumb rubber for artificial turf		**High**	**Medium**	**$**	**HIGH PRIORITY**	A full ban of artificial turf is at odds with water conservation goals. True source control by targeting the predominant zinc source in turf design. Expand upon existing City policy to minimize industry push-back.

4.1 Coatings that Prevent Zinc and Copper Runoff

Temporary sacrificial transparent surface coatings are commonly used by the copper industry to preserve the natural yellow-golden copper color by providing a protective barrier that excludes moisture (Copper Development Association, 2011). Prior to implementing the ordinance restricting use of copper building materials, the City of Palo Alto considered sacrificial coatings as an alternative means to prevent copper discharge to the MS4 (Barron, 2001). Studies of surface coatings (e.g., Robert-Sainte et al. (2009)) have shown 99% lower emissions from prepainted galvanized steel compared to standard galvanized steel, and Kszos et al. (2004) found that top coating zinc with epoxy or acrylic material reduced runoff concentrations by half). The City may consider requiring all copper or zinc surfaces to be coated by select products (Table 9). In addition, the runoff from considered or approved coated materials should be studied to prevent toxic or otherwise adverse effects. To ensure long-term maintenance of these coatings, this potential policy measure would also require a long-term coating maintenance plan for coating re-applications. Though the scientific and product literature provide coating recommendations to prevent runoff and extend product life, none of the recommended temporary coatings eliminate runoff of copper and zinc and prevent further degradation of runoff because the coatings contain potentially toxic substances.

Table 9. Temporary Coatings that Could be Applied to Metal Surfaces

Building Material	Coating Type	Metal	Notes
General	Chemical Patination[3]	Copper and Zinc	Chemical patination using acid chloride or acid sulfate solutions may be purchased at local supply depots and applied in the field. Chemically induced patinas may lack adhesion (i.e., exhibit flakiness and fragility) and are costly. Chemical patination solutions are toxic, and unless applied carefully, pose a potential hazard to groundwater and soil. Typically, chemical patination is limited to small areas.
	"Sacrificial" Coating[3]		In theory, a sacrificial coating would be applied to corrode in place of copper. Popular sacrificial coatings are lead- or zinc-based paints, which are also constituents of concern. Reapply at least once every 3 years.
Roofing, Flashing, Gutters[1], Downspouts[1]	Paraffin Oil[2]	Copper	Readily available. Easy to apply. Contains wax, which may result in streaking. Reapply at least once every 3 years.
	Linseed Oil[2]	Copper	Widely accepted use. Boiled linseed contains varnish and peels as it degrades, which can result in unevenly protected surfaces. Excess raw linseed oil reacts with copper to produce insoluble organic copper salts, which are characteristically dark green in color. Reapply at least once every 3 years.
	Crude Oil[2]	Copper	Collects dirt. Possible constituent of concern. Reapply at least once every 3 years.
Architectural components	Wax[2]	Copper	Readily available. Easy to apply. May result in streaking. If applied heavily may also capture dirt and particulates in aerial deposition. Reapply at least once every 3 years.

1: Generally, coatings are not applied to gutters and downspouts, especially inner surfaces of these structures.
2: Source: Barron, 2001.
3: Source: Copper Development Association, 2011.

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