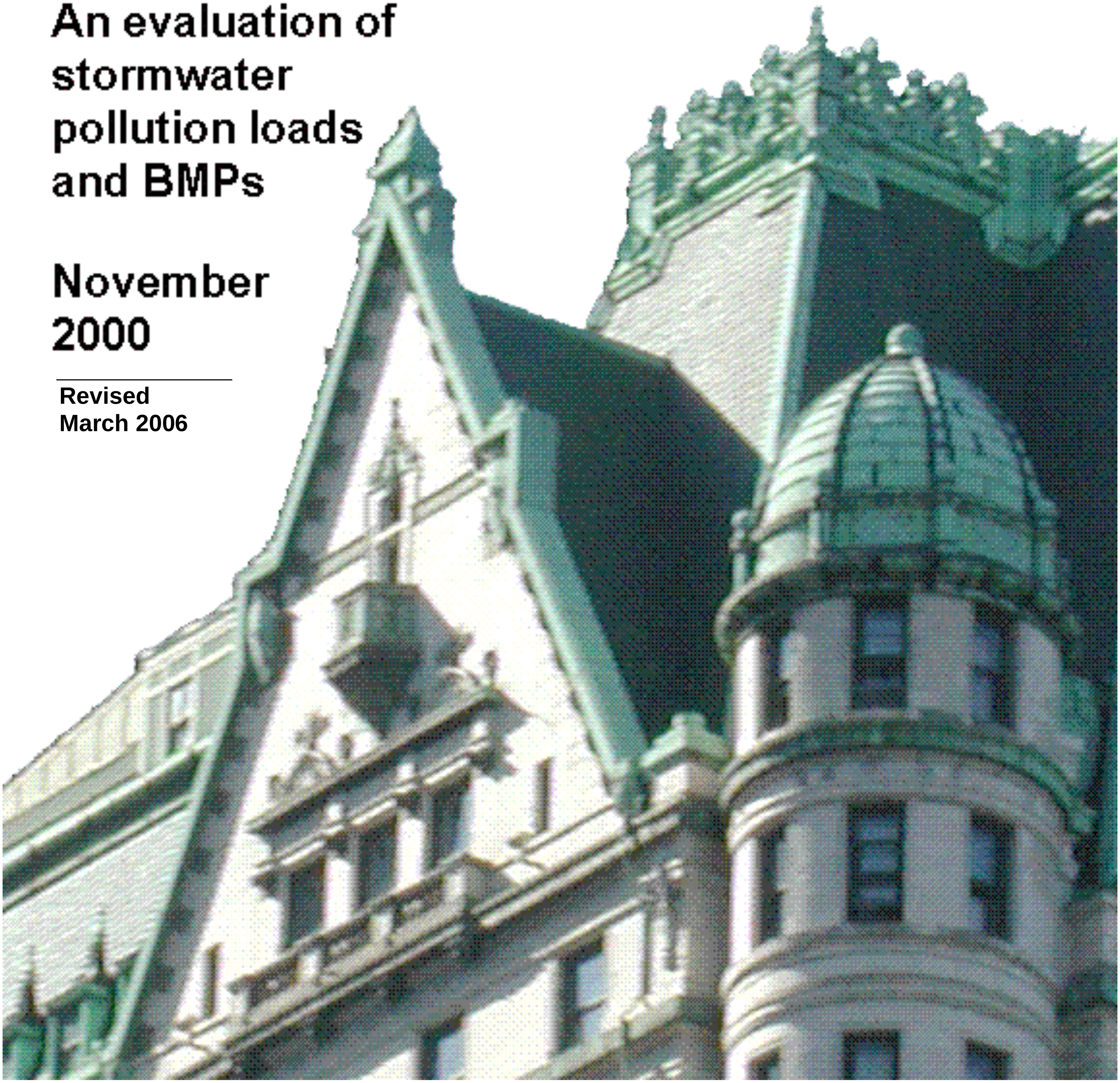
Architectural Uses Of Copper

An evaluation of stormwater pollution loads and BMPs

November 2000

Revised
March 2006



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Palo Alto Regional Water Quality Control Plant

November 2000
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PREFACE

This report presents an "order-of-magnitude" estimate of the amount of copper released from roofs and other architectural features in the Palo Alto RWQCP service area, and compares that release with the amount of copper measured in local streams. Corrosion rates and other key assumptions for this estimate are based upon technical studies performed in other states and in Europe. Only a limited amount of local testing work was done, and that was focused upon measuring runoff from copper-containing composition shingles. Further, the numbers of local buildings with copper roofs, and the overall areas of these roofs, are not known with certainty. These parameters were developed through interviews with local suppliers, contractors, and building inspectors.

This project involved a number of individuals and organizations. The author wishes to acknowledge the efforts of the participating suppliers, contracting firms, and the staff of the Palo Alto Regional Water Quality Control Plant. In addition, thanks are given to the individuals who offered comments and suggestions for improving the final report. [41]

Revision 1 • Misc. clarifications based upon reviewer comments.
Revision 2 • Clarifications based upon Planning Commission comments.
Revision 3 • Administrative edit (no technical changes)

Prepared for the
Palo Alto Regional Water Quality Control Plant

By

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ABSTRACT

This report describes common uses of copper materials in buildings, and explains how exposure to the elements corrodes that copper.

Interviews with suppliers, contractors, and inspectors lead to rough estimates of the area of local copper roofs.

Corrosion release rates by other researchers suggest how much of this copper might enter into the local environment via rainfall runoff.

This release of copper from buildings is next compared to the total amount of copper observed in local creeks.

Finally, best management practices are presented for decreasing these copper releases.

Architectural Copper

- **A copper roof on a new 230 sqm (2,500 sqft) home initially corrodes at a rate of perhaps 1.2 kg (2.5 lbs) per year.**
- **About 20% of this amount dissolves and washes off the roof when it rains. The rest stays on the roof.**
- **Copper releases from all roofs in the Palo Alto RWQCP service area is believed to be something on the order of 136 kg (300 lbs) per year.**
- **This dissolved copper release is about 20% of the total copper load measured in local creeks.**
- **Use of coated steel roofs or rainwater treatment units would reduce these copper releases.**

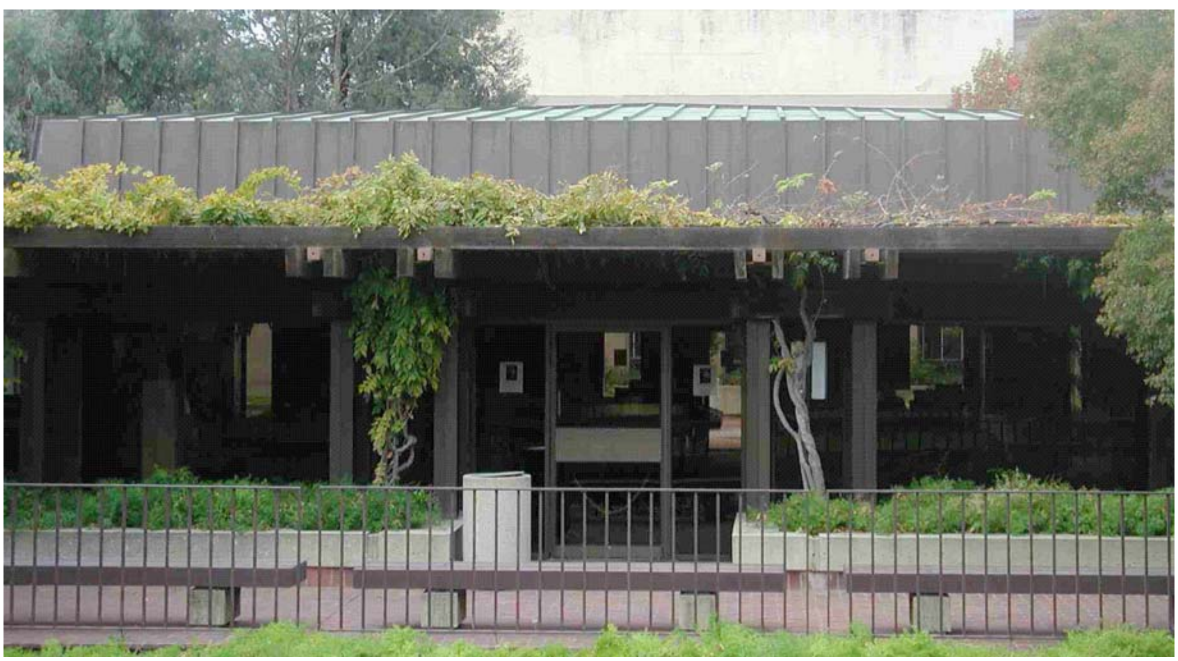


Photo: Copper Roof (Hoover Center, Stanford University)

1. How Is Copper Used In Buildings?

Roofing sheets, roofing tiles, flashing strips, gutters, downspouts, cupolas, vents, handrails, light fixtures and signs are available in copper. Owners and architects choose this metal for its appearance, constructability, fire resistance, and longevity. The initial cost of copper is significantly more than other materials with shorter lifespans. However, the overall life cycle cost of copper can be less than wood shakes and other roofing materials that must be replaced more frequently.

2. How Quickly Does A Copper Roof Corrode?

Corrosion tests by other researchers suggest that a copper roof on a new 230 sqm (2,500 sqft) home converts perhaps 1.1 kg (2.5 lbs) of metal per year into copper oxide, sulfides, and other byproducts. Corrosion of copper gutters and downspouts adds about 0.1 kg (0.2 lbs). This initial mass loss is less than 1% of the total roof weight. Furthermore, after 30+ years a light green patina builds up and the corrosion rate drops significantly. The overall life of a copper roof is several hundred years.

3. How Much Copper Is Released Via Rainfall Runoff?

Palo Alto receives 0.35 m (14 in) of slightly acidic rain a year, which typically falls in about 1,000 hours each winter. Rainfall runoff from a 230 sqm (2,500 sqft) home will:

- be about 81,400 liters (21,500 gal), and
- contain about 0.25 kg (0.5 lbs) of copper while the roof is new.

Tests in Oregon, Connecticut, and Sweden suggest that copper washed off the structure is 20% of the corrosion that occurs on the new roof. As decades pass, the release rate increases until it equals the corrosion rate.

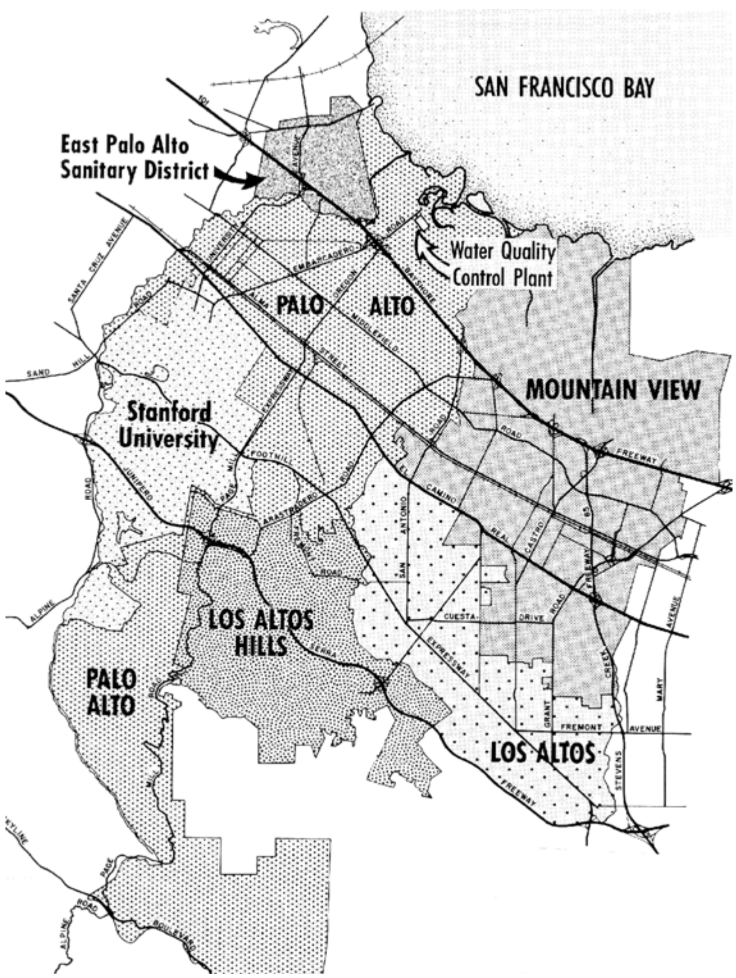
4. Where Does The Copper Go?

Althought not yet confirmed by tests, it is believed that rainfall runoff that passes through planted areas and infiltrates into soil may initially leave behind much of the copper it contains. Runoff that passes directly to the street or into a storm sewer will contain its original full amount of dissolved copper.

5. What Is The Total Copper Released In The Service Area?

A complete inventory of copper roofs and other architectural features installed in the Palo Alto RWQCP service area is not available. However, conversations with roofing associations, suppliers, contractors, and building department officials suggest that approximately:

- 70 local homes and a hundred larger structures have copper roofs;
- 220 structures of all kinds are believed to have copper gutters and downspouts, and
- 40 homes have roofs made of copper-containing algae-resistant shingles.



Palo Alto RWQCP Service Area - Approx. 15,000 ha (37,800 acrea)

These architectural features release a very approximate total of 136 kg (298 lbs) of copper per year throughout the RWQCP service area.

Annual Copper Load From Buildings

Type of Feature	Estimated Copper Release Kg/yr	Estimated Copper Release lbs/yr
Copper Metal Roofs		
- Homes	16	35
- Retail / Commercial	16	35
- Institutions	92	202
Algae Resistant Comp. Shingle Roofs	2	4
Copper Gutters & Downspouts	10	22
Total	**136**	**298**

A fraction of this copper release may be captured from the runoff by plants and soil, while the rest is carried into the stormwater system. The actual amount of such capture is unknown.

6. Is The Released Copper Significant?

An estimated 136 kg/yr (298 lbs/yr) of dissolved architectural copper, less whatever is captured by soil and plants, is released via rainfall runoff. About 5 times this amount, or a total of 700 kg per year (1,540 lbs per year) of total copper mass (i.e., dissolved + particulate copper), has been observed in creeks flowing through the RWQCP service area.

7. How Can These Copper Releases Be Reduced?

- Use another roofing material of similar appearance, such as coated steel or factory-supplied pre-patinated copper.
- Route runoff to planted areas.
- Cover the copper feature with a clear coating.
- Avoid use of chemicals that are applied at the construction site to accelerate copper patina development.
- Treat runoff with metallic exchange / ion exchange. This technique is commonly used for photo processing wastes, but is yet to be proven for rain water treatment.

Contents

EXHIBITS

Architectural Uses Of Copper

An evaluation of stormwater pollution loads and alternative best management practices

1. Introduction

This report describes common architectural uses of copper, and then estimates how much of this copper corrodes and is released into the Palo Alto RWQCP service area as rainfall runoff. Best management practices are presented for reducing the amounts of these copper releases.

2. Copper Architectural Features

Builders use copper because of its appearance, ease of construction, weather-tightness, flexibility, fire resistance, and longevity. Although more expensive to purchase, copper is seen as a wise choice for buildings with a long design life.

For example, one local builder recently selected copper flashings and gutters to install with a slate roof that is expected to last 100+ years.

Another local contractor used copper gutters and downspouts in a remodel project because the owners wanted to achieve the architectural appearance of European buildings dating to the late 1800s.

Both of these Palo Alto residential projects had budgets exceeding $1 million, highlighting the kind of building in this area where the use of copper features is most likely. Schools, offices, and retail buildings also employ copper materials.

2.1 Copper Roofs & Appurtenances

Copper roofs and flashing are fabricated into standard or custom shapes by a number of manufacturers. Roof panels (see photo at left) are commonly from 0.4 to 1.0 m (16 to 36 in) wide, and up to 3.1 m (10 ft) long, with other sizes available via special order.

Historically, copper roof panels have been soldered, overlapped, or physically seamed together. Panels today usually have formed edges that add strength and provide a simple, water-tight way of joining adjacent pieces. [1]

Copper shingles and unseamed copper panels are also used for roofing. These items are installed in an overlapping pattern, from the eaves up to the crown of the roof, in much the same way as wood or composition shingles.

Exhibit 1 shows that copper roofs have a warranted life that is 2-1/2 times that of steel roofs, and that copper costs 2 to 6 times more than steel. Actual service life for both materials can significantly exceed these warranties and will probably be longer than that of the structure itself if care and skill are used to install the roof, and if local environmental conditions are favorable. [1, 2, 11]

Exhibit 1
Comparison of Metal Roofing Materials

Type	Warranted Life	Format	Cost
Copper	50 Yrs	Panels Shingles	$27 / sqm ($2.50 / sqft) $50 / sqm ($4.60 / sqft)
Patina Copper (Factory-Applied)	50 Yrs	Panels Shingles	$38 / sqm ($3.50 / sqft) $70 / sqm ($6.40 / sqft)
Coated Steel [8] (Copper Color)	20 - 30 Yrs	Panels, Shingles	$11 / sqm ($1.00 / sqft)
Coated Steel (Patina Color)	20 - 30 Yrs	Panels, Shingles	$13 / sqm ($1.20 / sqft)

Notes: Costs are per unit area for an order of 930 sqm (10,000 sqft). Shipping and installation add 25% to 50% more. Panels are attached to roof using clips and screws made of same material as roof. Shingles are attached with nails or screws of same material as roof. Maintenance/replacement of steel roof panels may occur more frequently than copper (thus costing more), and may involve chemicals to strip and re-apply the coating. [43]

Copper roof and flashing pieces come with either a bare metal finish, or with a factory-applied weathered appearance (i.e., a "patina"). Copper pieces of either type are special order items that are not stocked in local building supply stores.

For example, one specialty contractor in San José does keep a small stock of copper pieces in its shops for repair work, but typically orders new materials needed by each project. Job orders of this type are particularly important for pre-patinated panels so that colors can be matched. [3]

Chemicals are available to accelerate the aging of bare copper so that a light-green patina finish develops more quickly than the 7 to 10 years required for normal weathering. Suppliers indicate that these field-applied solutions require great skill to handle correctly, cost about $5.00 per sqm ($0.50 per sqft), and are most often used for small copper features rather than entire roofs. Use of such chemicals has a relatively high risk of soil or groundwater contamination during construction. [3, 4]

Anecdotes told by contractors, building inspectors, and local suppliers suggest that less than 2% of the roofs (equivalent to 0.05% of the net roof area) in the San Francisco Bay region are made of copper sheets or have copper flashing. The project team contacted roofing associations, trade publications, suppliers, insurers, building departments, and property tax agencies in an effort to learn how many roofs are constructed of copper or with copper flashing. Unfortunately, these entities only have limited records of roofing types (e.g., identifying a roof only as built-up asphalt, composition shingle, metal, or wood). None of the sources are able to say with certainty how many copper roofs exist in the United States, much less in the Palo Alto RWQCP service area.

2.2 Coated Steel Roofs

Coated steel roofing sheets, shingles (photo), and tiles are available in colors that closely match the red gold of bare copper or the light green of a copper patina. Companion features, such as gutters, downspouts, and appurtenances, are available in matching colors and textures. With proper installation, the expected life of these features should be over 100 years. [30]

2.3 Composition Shingles

Composition shingles are constructed in layers that include surface granules, impervious asphalt, and a backing sheet. Limited tests done by the RWQCP indicate that ordinary composition shingles contain about 10 mg/kg of copper, although only a limited amount appears to be released via rainfall. [31]

Some composition shingles contain special granules that release copper to limit the growth of roof-top algae or fungus. More commonly used in wet climates such as the southern states and Pacific Northwest, these shingles are visually the same as ordinary ones, and are installed by the same methods. [10] The amount of copper in these shingles is about 25 mg/kg, much of which is positioned as granules on the surface where it is released via rainfall for at least ten years, i.e., half the warranted life of the shingles. [31]

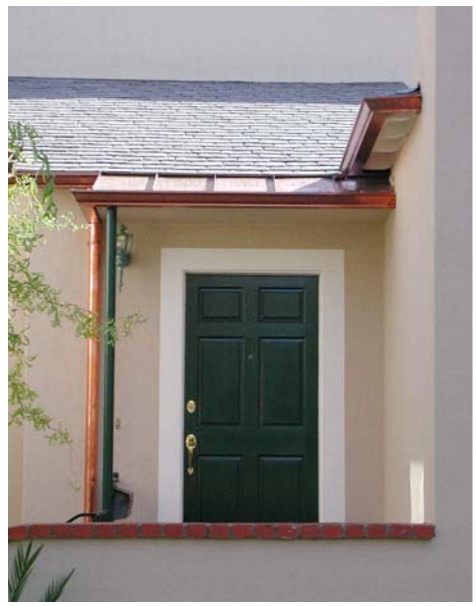
As shown by Exhibit 2, roofing manufacturers consider algae resistant shingles as a special order item, and price them accordingly. To date there are few algae-resistant shingle roofs in the Bay Area, probably totaling somewhat less than 1% of all buildings (i.e., 0.03% of the net roof area). Marketing efforts are predicted to increase the use of this specialty product. [5]

Exhibit 2
Composition Shingle Roofs

Type	Copper Content [31]	Warranty Period	Cost
Regular	10 mg/kg	20 years	$6.00 / sqm ($0.55/sqft)
Algae Resistant	25 mg/kg	20 years (algae resist: 10 years)	$6.35 / sqm ($0.59/sqft)

Notes: Costs are per unit area for an order of 230 sqm (2,500 sqft). Installation adds 100% or more. Shingles are attached to the roof with galvanized roofing nails. Copper nails are seldom used.

2.4 Gutters and Downspouts



Although specific data are not available, copper drainage features (photo) are known to be used with a variety of different roofing types, and are therefore believed to be somewhat more common in the Bay Area than are complete roofs made of bare copper metal or copper-containing shingles.

Exhibit 3 compares the attributes of gutters and downspouts made of four alternative materials, with copper being the most expensive of these choices.

Exhibit 3
Gutters and Downspouts

Type	Warranted Life	Format	Cost
Copper	50 Yrs	3.1 m Lengths (10 Ft)	$4.90 / m ($1.50 / LF)
Plastic (PVC)	10 Yrs	6.2 m Lengths (20 Ft)	$0.33 / m ($0.10 / LF)
Coated Steel	20 Yrs	3.1 m Lengths (10 Ft)	$2.30 / m ($0.70 / LF)
Aluminum	20 Yrs	6.2 m Lengths (20 Ft)	$0.67 / m ($0.20 / LF)

Notes: Costs are per unit length for a typical 230 sqm (2,500 sqft) home. Installation adds 100% or more. Attachment to the building is accomplished with brackets and either screws or nails. These fasteners are usually made of copper or galvanized steel.

2.5 Other Copper Features

Copper is used for spires, cupolas, doors, lights, signs, railings, weather vanes and other exterior ornamental features (photo), concrete inserts, water stops, and garden edging strips. Copper releases from these small features are believed to be less significant than that from complete roofs made of copper.

These features appear in perhaps 1% of all structures in the RWQCP service area.

3. Wood Preservatives

3.1 Factory-Preserved Lumber

Wood preservation products are discussed in an earlier RWQCP technical memorandum by Bill Johnson of EIP Associates. [6] These products often are formulated with either copper arsenate (CCA) or copper quaternary ammonium chloride (ACQ). Factory-preserved wood is pressure treated with one of these compounds, dried, and then shipped to lumber suppliers. [9]

Factory-preserved lumber is specified by building codes for situations where moisture contact is expected, such as wood foundation sills and exterior decks. Foundation lumber used to construct the typical 2,500 square feet home on a flat lot will require about 3 gallons of factory-applied preservative. Since this product has 0.67 lbs of copper per gallon, the preserved lumber is estimated to contain 2 lbs of copper.

3.2 Wood Preservatives Used During Construction

Exposed areas are created when preserved lumber is sawn or drilled during installation. These areas can be treated at the job site with new preservative that is brushed, wiped, or sprayed onto the wood. Construction of a new 2,500 square feet home may consume about 1/2 gallon of preservative if the contractor takes care to fully reseal the exposed lumber. This preservative contains 0.33 lbs of copper.

3.3 Factory-Preserved Wood Shingles

Copper arsenate is mentioned in the literature as a preservative used in wood shingles made of pine. [7] Conversations with local roofing suppliers suggests that redwood and cedar shingles are more commonly used in the Bay Area. These two woods do not typically need a preservative, although fire retardant chemicals that sometimes include preservatives are required by code. It is recommended that samples of these shingles be tested for copper content.

4. Release of Copper To The Environment

This section of the report presents a *very rough (order-of-magnitude) estimate* of the amounts of copper that rainfall will release from roofs, gutters, downspouts, and other architectural features in the Palo Alto RWQCP service area. The estimate is in five parts:

1. Local Rainfall Data
2. Background Copper (Wet & Dry Deposition)
3. Unit Amounts of Copper from Individual Building Features
4. Copper from Representative Buildings
5. Total Amount of Copper Released in the Service Area

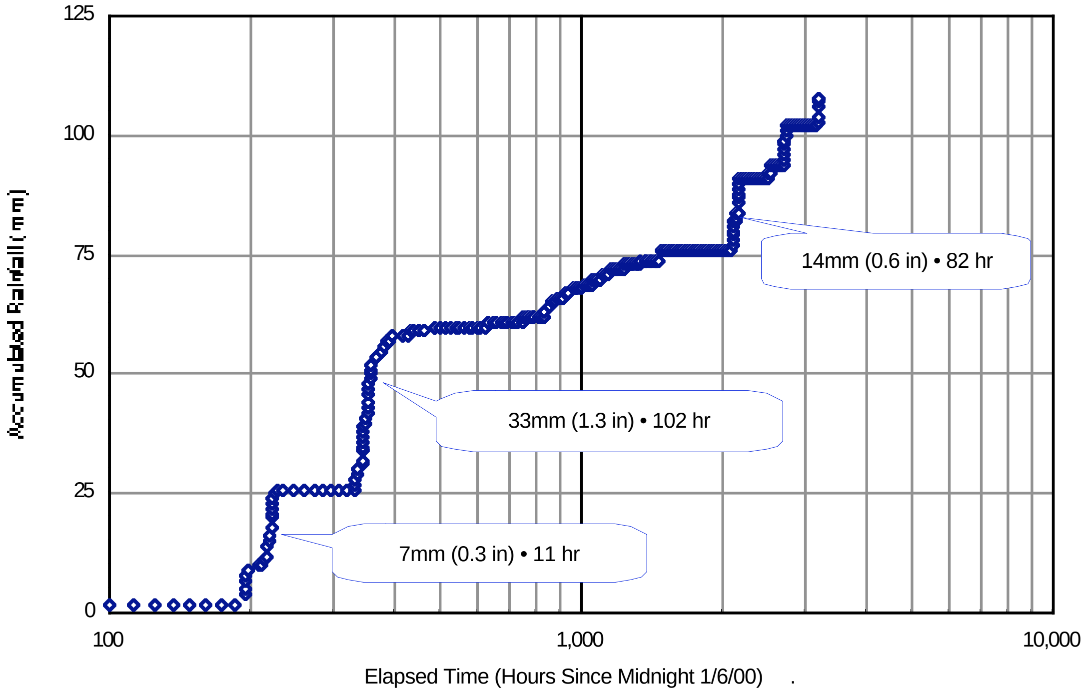
Monitoring data from various researchers contribute to the estimates of copper deposited from the atmosphere and also released by corrosion of individual features. However, the extent to which these building features are actually used in the RWQCP service area is not yet known. Therefore, the overall estimate of total copper released in the service area is only approximate.

4.1 Local Rainfall Data

The State of California publishes real-time internet weather data for a number of observation points throughout the San Francisco area, including one located at the Palo Alto Airport. Rainfall amounts and intensities reported at this site for the 1999 - 2000 winter are summarized in Exhibit 4. [32]

About 110 mm (4 in) of rain fell in Palo Alto during January - May 2000. Half of this amount (54 mm) occurred in three major storms that ranged in duration from 11 to 102 hours. Intensities for these highlighted storms varied from 0.17 to 0.64 mm/hr. The latter value is used later in the report to conservatively estimate the flow capacity required of alternative copper removal treatment systems. [29]

Exhibit 4
Accumulated Rainfall (1/00 - 4/00) - Palo Alto Airport



	Rainfall		Runoff	
	Intensity (mm/hr)	Duration (hr)	Rate (liters/sqm/hr)	Volume (liters/sqm)
Storm 1	0.64	11	0.64	7.1
Storm 2	0.32	102	0.32	33
Storm 3	0.17	82	0.17	14
Other Rainfalls	0.36	817	0.36	296
Full Year		1,012		350

These data show that local rainfall occurs with an average intensity of about 0.35 mm/hr spread over 1,012 hours per year. [32] This rainfall has a pH of about 5.1 [see Exhibit 5], and according to local monitoring data [16] contains 0.0005 mg/l of copper. See Appendix A-2 for details.

Source of rainfall data: <http://cdec.water.ca.gov>. The station ID is "PAA".

Rain fell for a total of 312 hours during January - May 2000 (i.e., about 10% of the total time), with an average intensity of 0.35 mm/hr. On this basis it is estimated that the annual rainfall of 14 inches occurs in a total of 1,012 hours.

The National Atmospheric Deposition Program (NADP) maintains two field monitoring stations in California that are within about 100 km (62 mi) of Palo Alto. Exhibit 5, obtained from the indicated NADP website, shows that pH values at these stations were in the range of 5.1 to 5.8 for Calendar 1998.

Exhibit 5

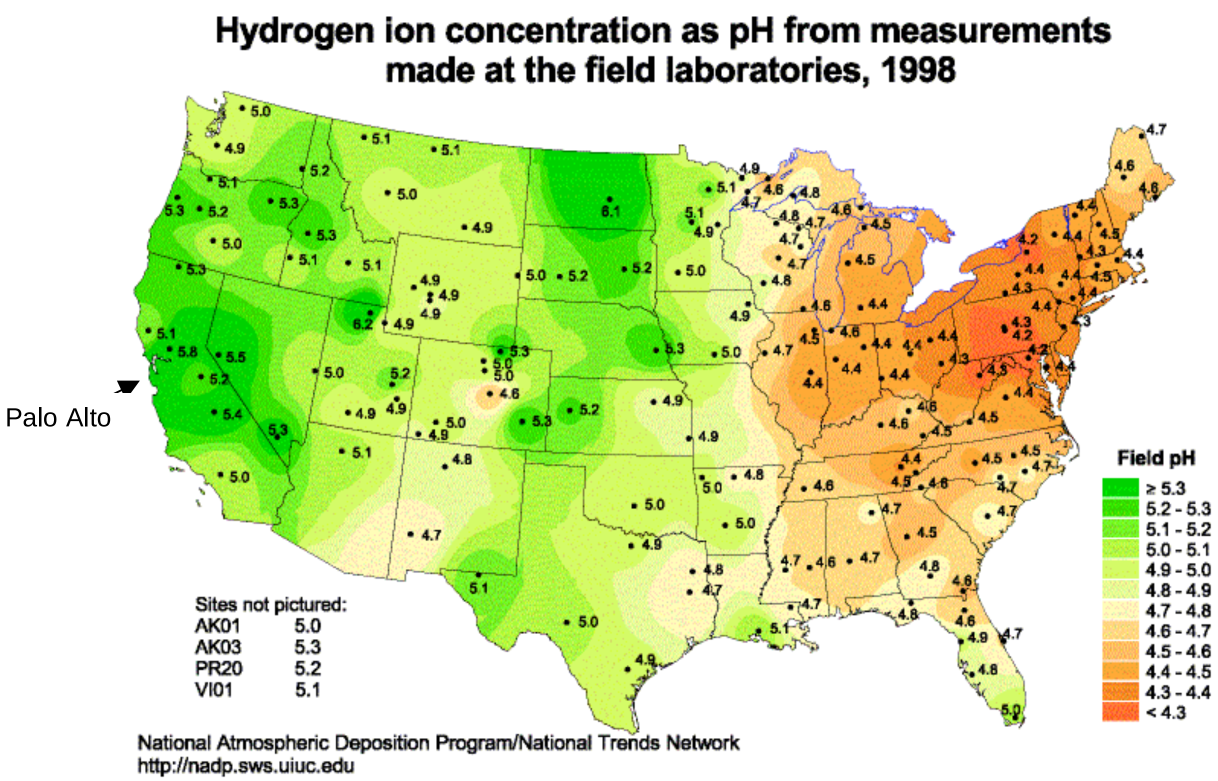


Exhibit 6, also adapted from the referenced NADP website, shows that the sodium content of local rainfall is in the range of 400 µg/l. Exhibit 7 is a composite satellite image from the US Geological Survey which emphasizes that this salinity level results from the proximity of the Palo Alto RWQCP service area to the San Francisco Bay and the Pacific Ocean to.[38]

Exhibit 6

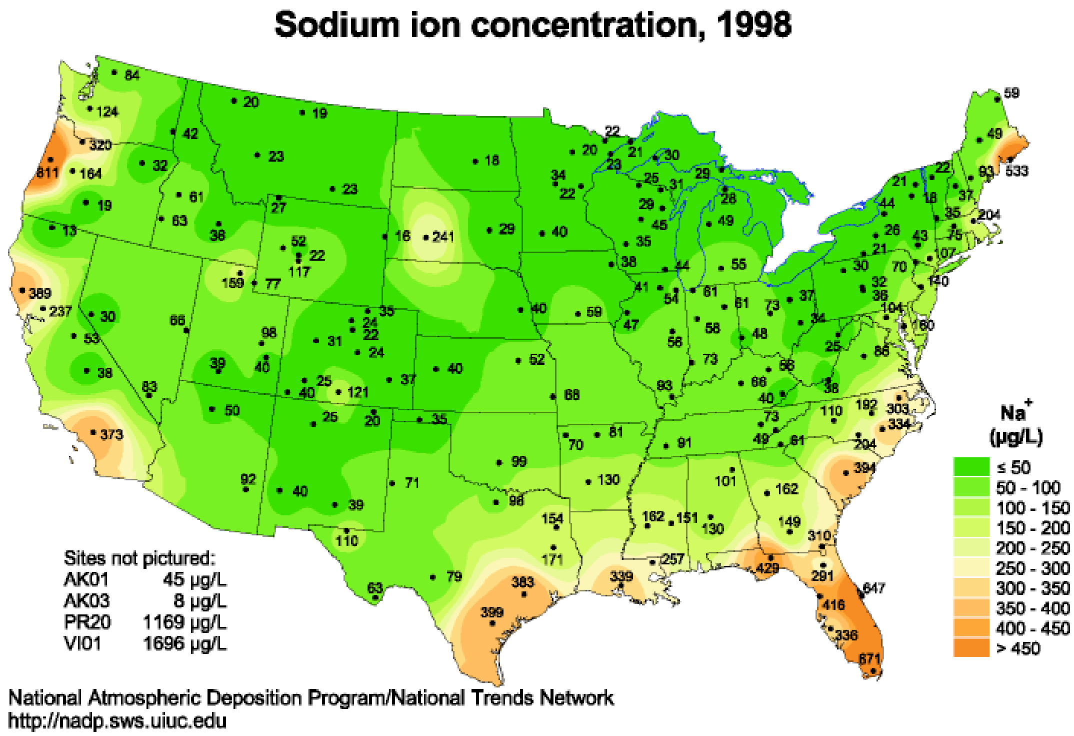


Exhibit 7
Palo Alto RWQCP Service Area

4.2 Background Copper (Dry & Wet Atmospheric Deposition)

As shown by Exhibit 8, copper is present in rainfall and airborne dust. These background levels are excluded from subsequent estimates in this report of copper released by rainfall from building roofs.

The San Francisco Estuary Institute (SFEI) is monitoring atmospheric copper deposition at the NASA Ames Research Center, which is just south of the RWQCP service area. The following SFEI data for August - December 1999 are used to adjust the estimates that appear later in this report. [16]

- Dry Deposition: 2 μgrams per square meter per calendar day, which is equivalent to 728 μg/sqm/yr; and
- Wet Deposition: 3.1 μgrams for 24 hours of rainfall, which is equivalent to 130 μg/sqm/yr.

Exhibit 8
Background Copper Levels (Dry & Wet Atmospheric Deposition)

Parameter	Deposition (μg/sqm) per day	per year	Conc. mg / l	Rainfall pH	Source of Data
Dry Deposition *					
(Airborne Dust)	2.0				South San Francisco Bay; Tsai [16]
	5.6				Switzerland; Zobrist [12]
(per calendar day)	8.7 - 18				Switzerland; Mason [14]
	9.3				Alameda County Woodward-Clyde [15]
	3.8	1,400			Sweden; Mohlander [34]
Used for this study	***2***	***728***	• • •	• • •	***SFEI Observations [16]***
Wet Deposition **					
(Rainfall)	3.1	130	0.0005	• • •	South San Francisco Bay; Tsai [16]
	4		0.001	5.3 - 6.2	Switzerland; Zobrist [12]
(per rainfall day)	11		0.003	6±	Switzerland; Boller [13]
	6.0 - 6.7		0.002	6.9	Switzerland; Mason [14]
				6.4	Alameda County; Woodward-Clyde [15]
				5.4	Oregon; Bullard [18]
				• • •	Sweden; Mohlander [34]
		1,200		**5.1**	Nat'l. Atmospheric Deposition Proj. [38]
Used for this study	***3.1***	***130***	***0.0005***	***5.1***	***SFEI [16]; NADP [38]***

* Dry deposition occurs every day of the year, so annual amounts are 364 times the number shown. The estimates made for this report use a dry deposition rate of 2 μg/sqm/day, or 728 μg/sqm/yr.

** Wet deposition obviously occurs just during rainfall events. The numbers shown here are expressed as μg/sqm per each full 24 hours of rainfall. Rain actually falls in the South San Francisco Bay only about 1,000 hours (42 days) per year, or 11% of the time. Therefore, the wet deposition rate used in this report is 42 times the daily amount of 3.1 μg/sqm/rainfall day, or 130 μg/sqm/yr. The pH is from NADP measurements.

4.3 Estimated Copper Releases From Individual Features

Exhibit 9 lists the parameters that influence the amount of copper released from roofs, gutters, downspouts, and other architectural features.

Exhibit 9
Factors Affecting Copper Releases

Factor	Pertains To	Anticipated Effects
Initial copper content	Algae resistant composition shingles	More granules --> More Cu released Larger granules --> Cu released longer
Age of feature	All Features	Copper release lower in new features
Weathered patina	Copper metal	Patina consists of copper sulfides, etc., that slow development of copper corrosion after 30+ years [24]
Physical orientation	Gutters & Downspouts; Ornamentals	North facing or somewhat sheltered features may not dry, thereby increasing corrosion rate [18, 19, 37]
Galvanic action	All	Adjacent use of incompatible metals or presence of electrically induced currents will increase corrosion rates
Nearness to ocean	All	Salt content of air will increase corrosion rate [18] [20]
Rainfall chemistry	All	Low pH rain removes more copper
Rainfall frequency	Roof	More frequent and intense rainfall: more Cu removed
Rainfall frequency	Gutters	More frequent rainfall: less Cu removed from gutters where organic matter would otherwise accumulate and increase corrosion
Maintenance	All	Re-exposed / re-soldered copper features corrode faster than untouched features
Runoff or groundwater	Foundation wood	Higher flows -> increased leaching of copper-containing wood preservative. However, this source releases much less copper than a roof made of that metal.

Exhibit 10 provides various estimates of the unit amounts of copper that may be released from individual architectural features. These data, which are from published literature sources and a few experiments performed at the Palo Alto RWQCP, were evaluated in the process of selecting approximate runoff release rates for use in this report. This selection was based upon:

- rainfall amounts, pH, and salinity;
- typical copper corrosion rates reported for each type of feature; and
- typical copper release rates for the corrosion products that do form.

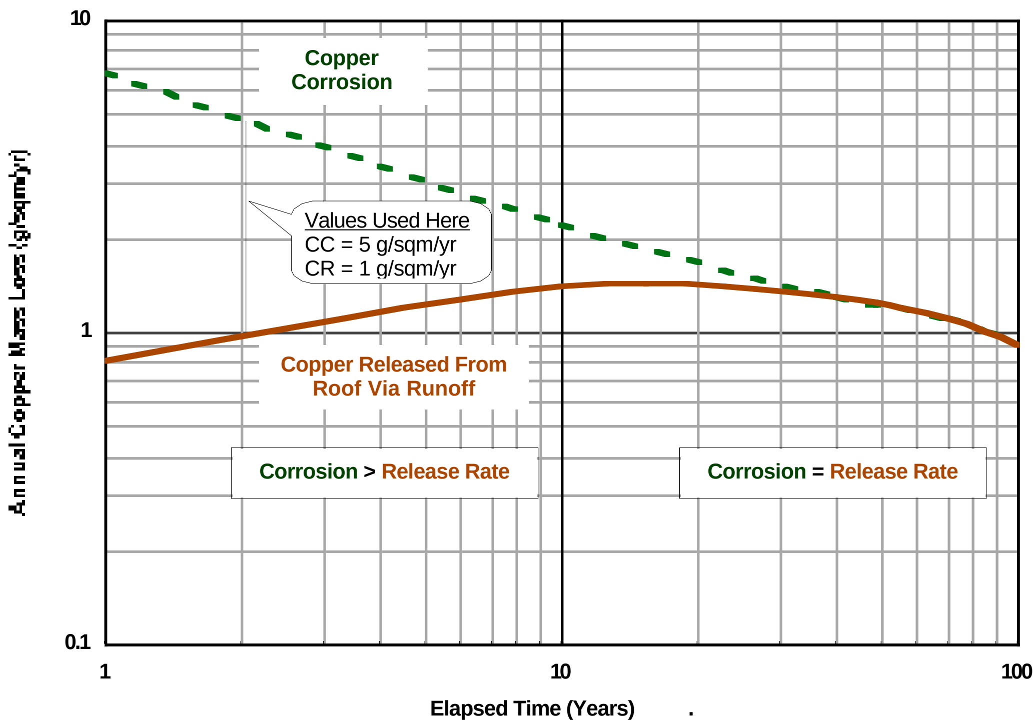
Exhibit 10
Estimates of Unit Copper Releases - Individual Building Features

	Corrosion	Released In Runoff			
	Mass (g/sqm/yr)	Mass (g/sqm/yr)	Conc. (mg / l)	Rainfall (m / year)	Source of Data
Copper Roof (Per sqm of roof)	8.4 - 11.7			2.03	Oregon • Unsheltered test coupons 1km - 50km from ocean [18]
		1.1	0.9	1.19	Connecticut • 10/98 Data for 6 yr old 1,100 sqm roof. [23]
		3.6	2.1	1.19	Connecticut • 2/2/99 Data for 6 yr old 1,100 sqm roof. [21, 22]
		5.2	2.0 - 8.7	1.19	Connecticut • 2/18/99 Data for 7 yr old 1,100 sqm roof. Conc. = 8.7 mg/l is 'first flush', while 2.0 mg/l after 120 minutes. [24, 29]
	12.0	1.8			Sweden • Fresh test coupons. [25]
		2.0		1.19	Connecticut • Data for 71 yr old copper roof with full patina. [24]
	6.3	1.4		0.53	Sweden • 2 Yr coupons. [25, 34, 35]
Used for this study --->	***5.0***	***1.0***		***0.35***	
Copper Gutter & Downspout (Per sqm of feature, not sqm of roof)	7.8		0.22	1.29	Switzerland • New gutter. [12]
	7 - 15		0.22	1.29	Switzerland • New gutter [13]
	3.5		0.07	1.29	Switzerland • 15 yr old Gutter. [12]
		4.4	0.1 - 2.1	0.35	Palo Alto • Various ages [27]
Used for this study --->	***10***	***2.0***		***0.35***	***In terms of roof area this load is equivalent to 0.066 g/sqm/yr***
Algae-Resist Shingles -		0.17	0.1 - 1.0	0.35	Field tests at the Palo Alto RWQCP, 4/00 - 5/00 [see Appendix A-3].
Used for this study --->	• • •	***0.17***		***0.35***	
Regular Comp. Shingles -		0.009	0.01 - 0.04	0.35	Field tests at the Palo Alto RWQCP, 4/00 - 5/00. These tests produced inconclusive results, and so will be repeated.
Used for this study --->	• • •	***tbd***		***0.35***	***tbd = to be determined***

Exhibit 10, above, provides average annual copper releases measured for metal roofs, gutters, and downspouts. The amount of copper actually released from these features during a particular storm depends upon the daily corrosion rate, type and solubility of corrosion products that form, number of days since last rainfall, and both the intensity and amount of current rainfall. [24, 25]

This variability is illustrated by Exhibits 11 and 12. Exhibit 11 shows how the annual rate of copper corrosion decreases through time as a patina forms and begins to protect the surface. The amount of corrosion byproducts that rainfall washes from the roof is initially small, and then increases over a period of years to reach a steady state equal to the rate of corrosion. [35] Salt in the air and acidic rainfall tend to increase both the corrosion and copper release rates. [18]

Exhibit 11 [Revision 1]
Typical Relationship Between Corrosion and Copper Removed By Runoff



Note: This chart is for illustration only. It does not portray data obtained from actual field measurements.
CC = Copper Corrosion. CR = Copper Release.

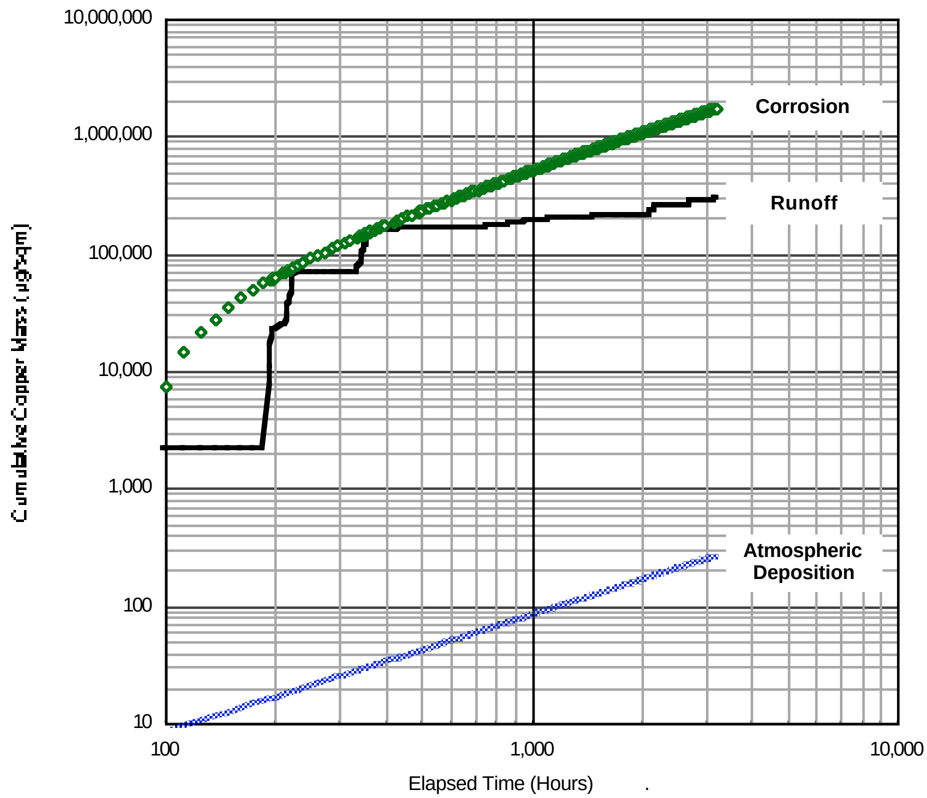
Exhibit 12 shows accumulative corrosion and runoff releases predicted for a hypothetical building in Palo Alto with a newly-installed copper roof. These estimates conservatively reflect the impacts of airborne salt from the Pacific Ocean, local rainfall chemistry, and atmospheric deposition. [33]

Exhibit 12 also shows the key conclusion that, overall, the copper mass released from corrosion is about 1,000 times the amount of copper added to the roof via wet and dry atmospheric deposition. In addition:

- The line of diamond symbols represents cumulative corrosion of copper from an example roof, which reaches an estimated total of about 1,800,000 µg/sqm in the first 3,000 hours of the Year 2000.
- This amount is equivalent to an estimated annual corrosion rate of 5 g/sqm/yr [see Exhibit 10].
- The upper solid line represents the intermittent release of copper mass in rainfall runoff from the example roof. This copper mass totals an estimated 300,000 µg/sqm in the first 3,000 hours of the year.
- Annually the copper mass runoff rate is estimated as 1 g/sqm/yr.
- The graph shows that for the first several hundred hours almost all of the corrosion products are removed during two storm events. Thereafter, copper releases continue, but at a rate that is less than the corrosion.
- The lower line in Exhibit 12 shows that atmospheric deposition of copper totals about 300 µg/sqm in 3,000 hours.
- Annually, combined wet and dry atmospheric deposition will together add 860 µg/sqm/yr to the roof surface. [see Exhibit 8]

This evaluation concludes that atmospheric deposition is significantly less per unit area than the amount of copper mass released by corrosion from a roof of that metal. Therefore, wet and dry deposition are neglected in the estimates that follow.

Exhibit 12
Predicted Unit Copper Mass Loss in Rainfall Runoff



Note: The runoff curve matches storm events during the first 3,000 hours of the Year 2000.

4.4 Estimated Annual Copper Release From One Building

Exhibit 13 provides estimates of how much copper could be released each year from new structures that have various architectural features. These estimates are based upon average rainfall and ocean air exposure conditions in the Palo Alto RWQCP service area, and reflect amounts leaving the downspout.

- Copper releases from bare metal roofs in later years will be significantly less than the amounts shown here when a protective patina develops.
- Copper releases from gutters will also decrease over time, but may stay above that of the roof itself because of acidity from organic debris.
- Releases from algae resistant shingles will vary according to the amount of rainfall in each year.

Exhibit 13
Predictions of Annual Copper Releases from Various Example Buildings

	Building Type		Copper Release (grams/year)	Basis of Estimate
1	**2,500 sqft Home with Copper Gutter & Downspout**		0	Slate Roof
	(232 sqm of total roof area)		14	New copper gutters & downspouts
		Total g/yr	14	= 0.06 g/sqm/yr = 0.01 lbs/1,000 sqft/yr
2	**2,500 sqft Home with Copper Roof, Gutter & Downspout**		232	New bare copper roof
	(232 sqm)		14	New copper gutters & downspouts
		Total g/yr	246	= 1.06 g/sqm/yr = 0.22 lbs/1,000 sqft/yr
3	**2,500 sqft Home with Algae-Resist Shingle Roof**		39	New algae-resist shingles
	(232 sqm)		0	Steel gutters & downspouts
		Total g/yr	39	= 0.17 g/sqm/yr = 0.03 lbs/1,000 sqft/yr
4	**10,000 sqft Retail with Copper Roof, Gutter & Downspout** (928 sqm)		928	New bare copper roof
			56	New copper gutters & downspouts
		Total g/yr	984	= 1.06 g/sqm/yr = 0.22 lbs/1,000 sqft/yr

See Appendix A-3 for details of these estimates.

4.5 Estimated Total Service Area Copper Release

Exhibit 14 presents an order-of-magnitude estimate showing that about 136 kg/yr (298 lbs/yr) of copper in a dissolved form are released from roofs, gutters, and downspouts in the Palo Alto RWQCP service area. A fraction of this copper release may be captured by plants and soil, while the rest is carried into the stormwater system. The actual amount of such capture is unknown.

The dissolved copper released into the environment from corrosion of architectural products is about 20% of the 700 kg/yr (1,540 lbs/yr) total copper load (i.e., particulate + dissolved copper) observed in local creeks flowing through the Palo Alto RWQCP service area. [39]

Exhibit 14 [Revision 2]
Estimates of Copper Releases - All of Palo Alto RWQCP Service Area

Building Type	Annual Copper Load kg / year	Basis of Estimate
Architectural Copper		
Copper Roofs	124	Est. 70 homes + 11 other structures with bare metal copper roofs that all together have a total area of 124,000 sqm
Algae-Resist Shingles	2	Est. 42 homes with these roofs (total area of 9,600 sqm)
Regular Composition Shingles	to be determined	Est. 83,000 homes and 54 other buildings (total 20,000,000 sqm).
Gutters & Downspouts	10	Est. 118 structures with copper gutters, downspouts, etc. (equiv. roof area of 160,000 sqm)
Total Copper Release	**136** (Primarily Dissolved)	(298 lbs/year)
Copper In Creeks	**700** (Dissolved + Particulate)	(1,540 lbs/year) Copper mass contained in annual flows from San Francisquito, Adobe, Barron, and Matadero Creeks. [see Table 4-3 of Ref. 39, and Note 43]

Cautions Regarding This Order-Of-Magnitude Estimate (See Appendix, Page A-4)

This estimate is based upon extrapolations from studies done elsewhere.

Service area contains 37,800 acres (15,303 hectares), of which an estimated 70% are residential, 15% other developed land, and 15% open space. [28] Roof coverage is believed to be 30% for residential land, and 50% for commercial, industrial and other developed land. [15]

Numbers of copper roofs are very roughly estimated to be 0.05% of residential roof area, 0.3% of industrial/commercial building roof area, and 1.5% of other structures. [2, 3, 5] To improve this estimate, an inventory of copper roofs could be made from digital aerial photographs, as has been done in Stockholm. [40]

Algae-resistant composition shingles are estimated by a manufacturer to be used on 0.03% of home roof area. [5]

Regular composition shingles are estimated to be 60% of residential and 10% of commercial & industrial roofs. [2]

Assumes that all 136 kg released from the downspout reach the stormwater system. The ability of local plants and soil to capture copper from runoff needs to be verified. The 700 kg of copper measured in streams is "total mass", i.e., comprising dissolved plus particulate copper, while the copper from roofs is essentially all dissolved.

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5. Ways to Reduce Copper Releases

Using other building materials is one obvious way to avoid having any copper releases in the first place. A number of manufacturers offer coated steel roofs, gutters, and downspouts with green colors that look like mature copper. Coated steel is a much newer and less expensive construction material that probably has a practical service life approaching that of copper.

A small metals treatment system may also be feasible as a way of removing copper from runoff before it is released into the environment.

- A combination metallic and ion exchange unit, such as is commonly used in photo shops and dental offices, will readily capture half or more of the copper from the example home mentioned before.

- One such unit costs an estimated $2,500, with much of that amount being needed for excavation and placement of piping and an underground cistern to accumulate rainfall.

- Maintenance of the system involves cleaning filters annually, and replacing the exchange media every 5 years.

- This approach is expected to have a total cost about $2,200 per kg ($1,000 per lb) of copper that is diverted from the environment.

Several alternative schemes were considered, but rejected as unworkable.

- Filtration of the rainwater will not work because most of the copper washed off of a roof is in a dissolved form.

- Electrically active cathodic protection schemes are often used to impress a current between buried pipes and soil to counter the migration of metal ions. Such a technique would not work for roofs because there is no effective way of completing a circuit into the air.

- Sacrificial coatings, such as lead or zinc, could be applied over the entire roof (i.e., between the copper and the air). However, the zinc coating obviously looks much different from bare copper.

Exhibit 15 lists alternative best management practices ("BMPs") that, depending upon site conditions, may effectively reduce the amount of copper released into the environment from building roofs, gutters, and downspouts.

Exhibit 15
Alternative BMPs for Decreasing Copper Releases

BMP	Impact on Copper Release	Comments
Copper Roof		
Use coated steel roof instead	- 100%	Costs less; appearance similar to but not exactly same as copper patina; may have somewhat shorter life
Use Pre-Patinated Copper Materials	- 50%	Costs more; patina is fragile
Clear-Coat Copper Surface	-75% or more	Unproven technique, although used to some extent with field-applied patinas
Treat all rainfall	- 75%	- Metallic Exchange - Ion Exchange - Both
Treat 1st hour of rainfall	- 50%	- Metallic Exchange (Smaller pump) - Ion Exchange - Both
Route runoff to planted area	Unknown	The ability of planted areas to permanently capture copper from runoff over time is not known.
Algae-Resist Shingle Roof		**Use standard shingles**
Composition Shingle Roof		**No measures recommended yet**
Copper Gutter & Downspout		
Use coated steel features instead	- 100%	Costs less; appearance similar to but not exactly same as copper patina; may have somewhat shorter life
Plastic Insert in Gutter & Downspout	Unk.	Not yet commercially available
Use Pre-Patinated Copper Materials	- 50%	Costs more; patina is fragile
Avoid Use of Field-Applied Patina Chemicals	Unknown	Field applied patinas are fragile and may fail, thereby releasing copper
Treat all rainfall	- 75%	- Metallic Exchange - Ion Exchange - Both
Treat 1st hour of rainfall	- 50%	- Metallic Exchange (Smaller pump) - Ion Exchange - Both
Route runoff to planted area	Unknown	The ability of planted areas to permanently capture copper from runoff over time is not known.

Exhibit 16 summarizes the costs associated with alternative BMPs for reducing the copper load in runoff from a 928 sqm (10,000 sqft) office or school building with copper gutters, downspout, and roof. The metals removal treatment unit is a pump-through device that requires a buried cistern for collecting runoff.

Exhibit 16
Costs of Alternative BMPs for Decreasing Copper Releases - 10,000 sqft Building

BMP	Cost	Description	Copper Reduction (lbs/yr)
Change to pre-patinated copper (possibly with clear-coat)	$12,000	10,000 sqft @ $1.00 per sqft extra cost + 20% extra spoilage	- 1.1 (50%)
Change to coated steel roof	($15,000)	10,000 sqft @ $1.50 per sqft savings	-2.2 (100%)
Install metals removal treatment *	$10,500	Combined metallic / ion exchange; 10 l/min pump	-1.6 (75%)
Install metals removal treatment sufficient to handle small storms*	$10,250	Combined metallic / ion exchange; 5 l/min pump	-1.1 (50%)

* Refer to Appendix , Page A-6 for details of these estimated costs.

Photo: School With Coated Steel Roof

Exhibit 17 summarizes the costs associated with alternative BMPs for reducing the copper load in runoff from a 232 sqm (2,500 sqft) residence with copper gutters, downspout, and roof. The metals removal treatment system uses gravity-flow and does not require a buried cistern or pump.

Exhibit 17
Costs of Alternative BMPs for Decreasing Copper Releases - 2,500 Sqft Residence

BMP	Cost	Description	Copper Reduction (lbs/yr)
Change to pre-patinated copper (possibly with clear-coat finish)	$3,000	2,500 sqft @ $1.00 per sqft extra cost + 20% extra spoilage	-0.27 (50%)
Change to coated steel roof	($3,750)	2,500 sqft @ $1.50 per sqft savings	-0.54 (100%)
Install metals removal treatment*	$1,200	Four gravity flow metallic exchange units	-0.32 (60%)

* Refer to Appendix, Page A-8 for details of these estimated costs.

6. Footnotes

[1] Copper, steel and other roofs offered by a number of manufacturers are described in detail on the Sweets Catalog website at: <http://www.sweets.com>. Links are provided from that site to the individual home pages of each manufacturer.

[2] Personal communication with Mr. William Good, National Roofing Contractors Association, 5/00. Also see: Kane, Karen, "Another Strong Year for the Industry", Professional Roofing Magazine, 4/99. <http://professionalroofing.net/past/apr99/>

[3] Personal communication with Mr. Tyler Radonich, Roofer's Supply Co., San José, 12/99. RSC is a specialty contractor that does copper roofing projects.

[4] Sales Literature, Copper Coats, Inc., San Diego. CCI is a manufacturer of copper patina chemical products.

[5] Personal communication with Ms. Patrice Rose, Malarkey Roofing Company, 1999. MRC manufactures both standard and algae-resistant composition shingles.

[6] Johnson, Bill, "Alternatives to Pentachlorophenol-Treated Utility Poles", EIP Associates, Palo Alto RWQCP, 4/99.

[7] Chang, Mingteh, and C. Crowley, "Preliminary Observations on Water Quality of Storm Runoff from Four Selected Residential Roofs", Water Resources Bulletin, Amer. Water Res. Assoc., v29n3, 10/98.

[8] A description of typical laminated zinc-polyester coating systems for steel roofs is available at the Vic West Steel Corporation website: <http://www.vicwest.com/>.

[9] Chen, Abraham, "Evaluating ACQ as an Alternative Wood Preservative System", EPA/600/SR-94/036, 4/94. This report discusses how much ACQ leaches from preserved wood timbers exposed to rainfall.

[10] Composition shingle roofs are described in detail on the Sweets Catalog website at: <http://www.sweets.com>. Links are provided to the individual home pages of each manufacturer.

[11] Personal communications with J. Medaris and G. Hechler, ATAS International, Inc. ATAS makes both copper and steel roofing products, together with matching gutters and downspouts.

[12] Zobrist, J., et al., "Quality of Roof Runoff for Groundwater Infiltration", Water Resources (v34,N.5,pp1455-1462), Enselvier, 2000.

[13] Boller, Marcus, "Tracking Heavy Metals Reveals Sustainability Deficits of Urban Drainage Systems", Water Science & Technology, (v35,N.9,pp77-87), Enselvier, 1997.

[14] Mason, Yael, et al., "Behavior of Heavy Metals, Nutrients, and Major Components During Roof Runoff Infiltration", Environmental Science & Technology, (v33, N.10,pp1588-1597), American Chemical Society, 1999.

[15] Woodward-Clyde, "Roof Runoff Water Quality: A Literature Review", Alameda County Urban Runoff Clean Water Program, 8/94.

[16] Tsai, Pam, "Connecting the Estuary with Its Watersheds and Airsheds", presentation to the RMPTS Annual Meeting, San Francisco Estuary Institute, 3/00.

[17] "Metals Content of Fertilizer Products", Washington State Department of Agriculture, 2000. Available at <http://www-app2.wa.gov/agr>.

[18] Bullard, Sophie, et al., "Copper Corrosion in Coastal Oregon", Corrosion Proceedings 1998 Conference, National Association of Corrosion Engineers, 1998.

[19] Holcomb, Gordon, et al., "Microclimate Corrosion Effects in Coastal Environments", Proceedings 1996 Conference, National Association of Corrosion Engineers, 1996.

[20] Personal communication with Dr. Stephen D. Cramer, Chemical Engineer, U.S. Department of Energy, 2/00.

[21] Boulanger, Bryan, et al., "Evaluation of the Hydrologic and Chemical Mass Balances of Copper Within an Urban Watershed", University of Connecticut, 11/99.

[22] Personal Communication with Bryan Boulanger, 1/00.

[23] Nikolaidis, Nikalaos, et al., "Yearly Report: Contribution of Copper-Based Architectural Material to Copper Concentrations and Toxicity in Storm Water Runoff", International Copper Association, 11/99.

[24] Boulanger, Bryan, and N. Nikolaidis, "Mobility and Aquatic Toxicity of Copper in an Urban Watershed", University of Connecticut, 5/00.

[25] Wallinder, Odenevall, and C. Leygraf, "A Study of Copper Runoff in an Urban Atmosphere", Corrosion Science (v39,N.12,pp2039-2052), Elsevier, 1997.

[26] Rainwater and runoff data from tests conducted April - June, 2000, upon two roofing panels (each 1.14 sqm). The first panel is algae-resistant, while the other is a standard composition shingle. Both are located at the Palo Alto RWQCP. See Appendix for photo.

[27] Uribe & Associates, Copper Roof and Gutter Runoff Study, Palo Alto RWQCP, 8/99.

[28] Donley, Michael, et al., Atlas of California, Pacific Book Center, Culver City, CA, 1979.

[29] The conversion from rainfall intensity to runoff is 1mm/hr = 1 liter/sqm/hr.

[30] VicWest Steel product literature and personal communication with sales representatives, 5/00.

[31] RWQCP tests indicate the following bulk copper contents and release rates for ordinary and algae-resist composition shingles:

	Ordinary Shingles	Algae-Resist Shingles
Bulk Copper Content (mg/kg)	12.7	24.5
Copper Release via Rainfall (g/sqm/yr)	0.009	0.13

Additional tests are planned to refine upon these release rates.

[32] Weather data for California is available at <http://cdec.water.ca.gov>. The station ID for Palo Alto is "PAA".

[33] The key value of 1.0 g/sqm/yr for copper release from roofs is conservatively adapted from the tests made in Connecticut, Oregon, Sweden, and Switzerland. Tests conducted on gutters of uncertain age indicate somewhat higher values.

[34] Annual wet and dry copper deposition rates in Stockholm are 1.2 mg/sqm/yr and 1.4 mg/sqm/yr, respectively. Local rainfall is 0.5 m/yr. Personal e-mail communication with U. Mohlander, Env. Health Protection, City of Stockholm, 9/26/00.

[35] He, W., et al., "Comparison Between Corrosion Rates and Runoff Rates From New And Aged Copper And Zinc As Roofing Material", Department of Materials Science & Engineering, Royal Institute of Technology, Stockholm, 2000.

[36] He, W., et al., "A Laboratory Study Of Copper And Zinc Runoff During First Flush And Steady State Conditions", Department of Materials Science & Engineering, Royal Institute of Technology, Stockholm, 2000.

[37] He, W., et al., "Effects Of Exposure Direction On The Runoff Rates Of Copper And Zinc Roofs", Department of Materials Science & Engineering, Royal Institute of Technology, Stockholm, 2000.

[38] This and other satellite photos of the San Francisco Bay area are available from a project website sponsored jointly by the US Geological Survey and Pacific Gas and Electric Company. The internet address is: <http://www.sqftbayquakes.org/thumbnails.html>.

[39] "Metal Control Measures Plan", Santa Clara Valley Runoff Pollution Prevention Program, 2/12/97. Table 4-3 presents data on total metals loading measured in local creeks. The MCMP report is available at: <http://www.city.palo-alto.ca.us/cleanbay/publications.html>.

[40] Ekstrand, E., et al., "Digital Air Photo Processing For Mapping of Copper Roof Distribution And Estimation Of Related Copper Pollution, Swedish Environmental Protection Agency, 1999.

[41] Appreciation and thanks to these individuals who provided comments and suggestions for improving this report.

Bryan Boulanger, Claire Elliott, Judy Kennedy, Ulf Mohlander, Kelly Moran, and Pamela Tsai.

[42] Ghaffari, Javad, "Pretreatment Program Annual Report 1999", City of Palo Alto RWQCP.

[43] Maintenance instructions for coated steel roofs, provided by ATAS International, include:

- periodic washing with water and mild soap (solvent cleaners to be avoided);
- mildew treatment with bleach if necessary; and
- repainting where the coating has failed. Under normal conditions, refinishing might be needed every 50 to 100 years, would involve several steps, and may be either for a small area that is damaged or for an entire roof:
    - sand blast old coating to bare metal,
    - pressure wash exposed metal to remove residues,
    - treat bare surface with an epoxy chromate primer,
    - hand clean factory-applied wax off of the roof at edges of the refininshing work area using small amounts of a xylene-containing solvent, and
    - apply finish coats of acrylic paint (about 400 sq ft per gallon per coat, with two coats typically being required).

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Page vi	Map of RWQCP Service Area - City of Palo Alto
Page 4	© ATAS International, Inc. < http://www.atas.com> Coated Steel Shingle Roof On A Home
Page 9	Exhibit 5 - Nat'l. Atmospheric Deposition Program (Public Domain)
Page 10	Exhibit 6 - Nat'l. Atmospheric Deposition Program (Public Domain)
Page 10	Exhibit 7 - US Geological Survey (Public Domain)

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Cover	Hotel Roof, New York City
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Page 21	Coated Steel Roof • School, Redwood City CA
Page A4	Algae-Resist Shingle Test Stand at RWQCP

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Appendix - Calculations

The following tables summarize corrosion, rainfall, atmospheric deposition, runoff, and BMP cost estimates that were made as part of this study.

Calculations in these appendices are presented to three or four decimal places in order to show the arithmetic involved, not to imply that the estimates have an accuracy to that many significant digits.

Dry Deposition Data For Exhibit 8

Dry Deposition	Sample 1 Concentration (ug/L) in 10 mls	ug/ Sample	SAMPLE 1 µg/M2/DAY	Sample 2 Concentration (ug/L) in 10 mls	ug/sample	SAMPLE 2 µg/M2/DAY	AVERAGE OF ALL VALUES µg/M2/DAY
8/31/99	10.9	0.109	2.2	9.5	0.095	1.9	2.0
9/14/99	7.4	0.074	1.5	8.6	0.086	1.7	1.6
9/28/99	22.3	0.223	4.5	17.7	0.177	3.5	4.0
10/13/99	7.3	0.073	1.5	7.4	0.074	1.5	1.5
10/26/99	1.8	0.018	0.4	2.4	0.024	0.5	0.4
11/9/99	11.3	0.113	2.3	9.0	0.090	1.8	2.0
11/23/99	9.4	0.094	1.9	11.0	0.110	2.2	2.0
12/7/99	8.1	0.081	1.6	16.1	0.161	3.2	2.4
12/21/99	11.0	0.110	2.2	10.4	0.104	2.1	2.1

Average Dry Deposition (µg/sqm/day):	2.0

Average Dry Deposition (µg/sqm/yr):	728

Source: Pam Tsai, SFEI, via e-mail 6/19/00 [16]

A photo of the SFEI dry deposition test stand is at <http://www.sfei.org/rmp/reports/air_dep/air_dep.html>.

Wet Deposition Data For Exhibit 8 and 12

Wet Deposition Data*	Gauge (inches)	(mm)	(ng/l)	(ng/sqm)
09/14/99-09/28/99	0.00		na	na
09/28/99-10/13/99	0.00		na	na
10/13/99-10/26/99	0.00		na	na
10/26/99-11/09/99	0.78	19.69	317	5,357
11/09/99-11/23/99	0.27	6.86	699	4,580
11/23/99-12/07/99	0.19	4.70	676	3,017

Extrapolation Of Copper Deposition Via Rainfall For Palo Alto Service Area ***

	μg/sqm/2wks	μg/sqm/rain hr**	μg/sqm/yr
10/26/99-11/09/99	5.4	0.16	163
11/09/99-11/23/99	4.6	0.14	138
11/23/99-12/07/99	3.0	0.09	90.4

Average Wet Deposition (μg/sqm/rain hour):	0.13

Average Wet Deposition (μg/sqm/yr):	130

* Source: Pam Tsai, SFEI, via e-mail 6/19/00 [16]

** Assumed that rain fell 10% of the time (1,012 hr/yr), as was observed at Station PAA from 1/6/00 - 6/6/00.

*** These data from late 1999 are extrapolated into 2000.

Copper Release From Unit Area Of Algae-Resistant Shingles

Results of tests at Palo Alto RWQCP - 2000.

Weather Station PAA Rainfall Data

Date	Time 24hrt	∑ ∂t hr	Rainfall hr	Event in	m	liters[1]	Accum in	m	liters [1]
3/23/00									
4/13/00	4:23	12.2	12.2	0.24	0.0061	6.95	0.24	0.0061	6.9
4/14/00	6:51	26.5	26.3	0.07	0.0018	2.03	0.31	0.0079	9.0
4/17/00	7:13	72.4	48.4	0.35	0.0089	10.13	0.66	0.0168	19.1
5/8/00	14:27	21.3	26.7	0.12	0.0030	3.47	0.78	0.0198	22.6
5/15/00	12:43	166.3	7.7	0.19	0.0048	5.50	0.97	0.0246	28.1
5/16/00	18:00	3.0	7.1	0.12	0.0030	3.47	1.09	0.0277	31.6
6/9/00	15:30	452.5	9.9	0.24	0.0061	6.95	1.33	0.0338	38.5

Results of Composition Shingle Runoff Tests

		Measured Copper Concentrations					
		Open Container [5]		Plain Roof [5]		Algae-Resist	
Date	Time 24hrt	Total µg/l	Dissolved µg/l	Total µg/l	Dissolved µg/l	Total µg/l	Dissolved µg/l
3/23/00	Pair of 1.14 sqm roof panels installed @ RWQCP.						
4/13/00	4:23	• • •	• • •	26	19	406	386
4/14/00	6:51	• • •	• • •	13	15	182	173
4/17/00	7:13	66	23	10	10	615	96
5/8/00	14:27	16	10	42	28	952	973
5/15/00	12:43	38	27	21	11	238	163
5/16/00	18:00	94	12	21	25	145	137
6/9/00	15:30	59	• • •	15	• • •	629	• • •

Estimate of Copper Releases - Based Upon Weather Station PAA Rainfall Data

Date	Plain Shingle Roof [5]				Algae-Resist Shingle Roof			
	[1] ml	[2] µg	[3] µg/sqm/d	[4] g/sqm/yr	ml	[2] µg	[3] µg/sqm/d	[4] g/sqm/yr
4/13/00	6,949	178	307	0.0129	6,949	2,821	4,869	0.2053
4/14/00	2,027	27	22	0.0009	2,027	369	295	0.0125
4/17/00	10,135	101	44	0.0019	10,135	6,233	2,713	0.1144
5/8/00	3,475	147	116	0.0049	3,475	3,308	2,608	0.1100
5/15/00	5,502	114	313	0.0132	5,502	1,309	3,580	0.1510
5/16/00	3,475	72	216	0.0091	3,475	504	1,505	0.0634
6/9/00	6,949	105	223	0.0094	6,949	4,368	9,288	0.3916
		Average:	170	0.0075		Average:	2,595	0.1497

Estimate of Copper Releases - Based Upon RWQCP Test Stand Rainfall Data

Date	Plain Shingle Roof [5]				Algae-Resist Shingle Roof			
	ml	µg	µg/sqm/d	g/sqm/yr	ml	µg	µg/sqm/d	g/sqm/yr
4/13/00	6,521	166.9	288	0.0121	5,434	2206	3,807	0.1605
4/14/00	1,813	24.1	19	0.0008	2,517	458	367	0.0155
4/17/00	9,438	94.4	41	0.0017	10,525	6473	2,817	0.1188
5/8/00	5,834	246.2	194	0.0082	5,834	5554	4,379	0.1847
5/15/00	7,608	158.2	433	0.0182	7,608	1811	4,951	0.2088
5/16/00	5,091	105.9	316	0.0133	5,091	738	2,204	0.0930
6/9/00	6,178	93.3	198	0.0084	9,038	5680	12,079	0.5094
		Average:	215	0.0090		Average:	3,088	0.1844
Used in Study:		**Average:**	**tbd**	**tbd**		**Average:**	**2,841**	**0.167**

[1] vol (liters) = rainfall (m) * 1.14 sqm * 1,000 (l / cubic m)

[2] µgrams of copper = liters * µg/l

[3] µg/sqm/rain day = (µgrams / 1.14 sqm) / (24 hrs per day / hours of rainfall)
[4] g/sqm/yr = [(µg/sqm) • (1,012 total rainfall hours / hours of this rainfall)] / 1,000,000

[5] Open bucket and plain shingle roof may reflect influence of nearby sludge incinerator at the RWQCP.

Standard and Algae-Resistant Composition Shingles

This photo shows the test stand located at the Palo Alto RWQCP that was used to measure copper in rainfall runoff. Each side of the test stand measures about 1.1 sqm. The left half of the stand is covered with standard shingles, while the right half is covered with algae-resistant shingles.

Service Area Copper Releases For Exhibit 14

Land Areas

Geographic data from ABAG and other sources [29] suggest that something on the order of 85% of the Palo Alto RWQCP service area is developed land that contains buildings. These buildings are classified here as: residential, industrial/commercial, and other (schools, offices, hospitals, etc.).

Numbers in these tables have extra digits to show arithmetic, not to imply accuracy. The reader is cautioned that these are very rough estimates only intended to show "order-of-magnitude" results, and to answer the question: "Is the probable amount of copper from roofs a significant fraction of the copper measured in local streams?".

	Land Use Type				
	Residential	Industrial	Other	Open Land	Total
%	70%	7%	8%	15%	100%
Acres	26,460	2,646	3,024	5,670	37,800
Hectare (10k sqm)	10,712	1,071	1,224	2,295	15,303

Roofs of All Kinds

The Woodward-Clyde study in Alameda County [15] provides approximate roof coverages for each land use type. In the absence of local data, it is assumed here that the RWQCP service area has similar roof coverages. Average roof areas per type of building are based upon anecdotal input from suppliers, contractors and building inspectors.

	Land Use Type				
	Residential	Industrial	Other	Open Land	Total
Roof area as % of land area	30%	50%	50%	0%	
Area of All Roofs (sqm)	32,135,621	5,355,937	6,121,071	0	43,612,628
Avg. Area per Structure (sqm)	232	965	965	0	
No. of Structures	138,516	5,550	6,343	0	150,409

Copper Roofs

No data could be found to quantify copper roof areas either locally or elsewhere in the US. Therefore, annecdotal accounts by suppliers, contractors, and building inspectors were used to estimate the rough (order-of -magnitude) areas shown here. The result that residnetial and industrial areas are the same is coincidental.

Copper releases shown here are based upon the judgement that corrosion field tests in Oregon, Connecticut, and Sweden are representative of roof behavior in the RWQCP service area. The rate of 1.0 grams/sqm/year is from Exhibit 10.

	Land Use Type				
	Residential	Industrial	Other	Open Land	Total
% of All Roof Area	0.05%	0.30%	1.50%		
Total Roof Area (sqm)	16,068	16,068	91,816		123,952
Avg. Area per Structure (sqm)	232	965	965		
No. of Structures	69	17	95		181
Cu Corrosion (g/sqm/yr)	1.0	1.0	1.0		
Cu Release (g/yr)	16,068	16,068	91,816		**123,952**
Cu Release (lbs/yr)	35	35	202		**273**

Algae-Resistant Composition Shingle Roofs

The amount of roof area covered by algae-resistant shingles was estimated by a West-coast manufacturer [5]. The release of copper from such shingles is based upon a limited number of tests perfromed at the RWQCP. See Appendix A-3, above.

	Land Use Type				
	Residential	Industrial	Other	Open Land	Total
% of All Roof Area	0.03%	0.00%	0.00%		
Roof sqm	9,641	0	0		9,641
Avg. Area per Structure (sqm)	232				
No. of Structures	42	0	0		42
Cu Release (g/sqm/yr)	0.17	0.17	0.17		
Cu Release (g/yr)	1,610	0	0		**1,610**
Cu Release (lbs/yr)	4	0	0		**4**

Copper Gutters, Downspouts, Etc.

No data could be found to quantify the number and sizes of local copper gutters & downspouts. Therefore, annecdotal accounts by suppliers, contractors, and building inspectors were used to estimate the rough (order-of -magnitude) areas shown here.

Copper releases shown here are based upon the judgement that corrosion field tests in Oregon, Connecticut, and Sweden are representative of corrosion in the RWQCP service area. See Exhibit 10.

	Land Use Type				
	Residential	Industrial	Other	Open Land	Total
% of All Roof Area	0.06%	0.30%	1.88%		
Roof sqm	19,281	16,068	114,770		150,119
Feature sqm	632	526	3,760		4,918
No. of Structures	83	17	119		219
Cu Corrosion (g/sqm/yr)	2.0	2.0	2.0		
Cu Release (g/yr)	1,263	1,053	7,519		**9,835**
Cu Release (lbs/yr)	3	2	17		**22**

Costs Of BMPs For Copper Roof on a 10,000 Sqft Office

Retrofit Metals Removal System

Technology: Combined Metallic Exchange & Ion Exchange

	Units	Qty	Unit $	Cost
Excavation/Disposal	cy	12	$35.00	$420
Concrete	cy	4	$400.00	$1,600
Paving	sq yd	5	$500.00	$2,500
Piping (0.75- & 3-in. plastic)	ft	250	$1.25	$313
Fittings	lot	1	$50.00	$50
Cistern (55 gal/plastic)	ea	4	$125.00	$500
Pump (1.0 gpm; 110V)	ea	4	$75.00	$300
Conduit	lot	4	$25.00	$100
Wiring	lot	4	$50.00	$200
Cabinet	lot	4	$150.00	$600
Metal Exch. Unit (10 liter/min)	ea	4	$100.00	$400
IX Resin	lot	4	$75.00	$300
			Materials:	$6,983
Laborer	hr	144	$10.00	$1,440
Craftsman	hr	24	$25.00	$600
			Labor:	$2,040
			Permit Fee & Misc.:	$1,350
			Total:	$10,373

Annual Costs (10,000 sqft office building)

	Units	Qty	Unit $	Annual Cost
5-Year Amortization	lot	0.20	$10,373	$2,075
Electricity (350 hrs/yr)	kWhr	524	$0.15	$79
Maintenance	hr	12	$10.00	$120
ME & IX Ctgs (4-yr life)	lot	1	$100.00	$100
				$2,373
			lbs of Copper removed per year	1.6
			Cost per lb	$1,521

Performance Of Metal Removal BMPs (Exhibits 16 & 17)

Metallic Exchange / Ion Exchange System - 10,000 sqft Office Building

Rainstorm No. 1 (11 hours on 1/16/00)

Time	Start Vol.	Rain In	Pump Out	O'flow	End Vol.	Cu In	Cu Fixed	Cu Out
hr			<-------- liters -------->				<-------- mg -------->	
0	0	600	600	0	0	1,714	1,234	480
1	0	600	600	0	0	1,714	1,234	480
2	0	600	600	0	0	1,714	1,234	480
3	0	600	600	0	0	1,714	1,234	480
4	0	600	600	0	0	1,714	1,234	480
5	0	600	600	0	0	1,714	1,234	480
6	0	600	600	0	0	1,714	1,234	480
7	0	600	600	0	0	1,714	1,234	480
8	0	600	600	0	0	1,714	1,234	480
9	0	600	600	0	0	1,714	1,234	480
10	0	600	600	0	0	1,714	1,234	480
	Totals:	6,600				18,856	13,576	5,280

Removal Efficiency: 72%

Discharge copper concentration (mg/l): 1.0

Costs Of BMPs For Copper Roof on a 2,500 Sqft House

Retrofit Metals Removal System

Technology: Combined Metallic Exchange & Ion Exchange

	Units	Qty	Unit $	Cost
Excavation/Disposal	cy	2	$35.00	$70
Concrete	cy	0	$400.00	$0
Paving	sq yd	0	$500.00	$0
Piping (0.75- & 3-in. plastic)	ft	10	$1.25	$13
Fittings	lot	1	$25.00	$25
Cistern (55 gal/plastic)	ea	0	$125.00	$0
Pump (1.0 gpm; 110V)	ea	0	$75.00	$0
Conduit	lot	0	$25.00	$0
Wiring	lot	0	$50.00	$0
Cabinet	lot	0	$150.00	$0
Metal Exch. Unit (1 liter/min)	ea	4	$100.00	$400
IX Resin	lot	0	$75.00	$0
			Materials:	$508
Laborer	hr	8	$10.00	$80
Craftsman	hr	4	$25.00	$100
			Labor:	$180
			Permit Fee & Misc.:	$500
			Total:	$1,188

Rainfall Data Used In Exhibits 4 & 12

Date	Time	∑ Rainfall (in)	Rainfall (In)	Rainfall (mm)	∂t (hours)	Intensity (in/hr)	Intensity (mm/hr)
Storm 1							
01/15/2000	17:08	10.90	0.00	0.00	12.2	0.00	0.00
01/16/2000	1:09	10.98	0.08	2.03	8.0	0.01	0.25
01/16/2000	1:39	11.02	0.04	1.02	0.5	0.08	2.03
01/16/2000	1:52	11.10	0.08	2.03	0.2	0.37	9.38
01/16/2000	2:20	11.14	0.04	1.02	0.5	0.09	2.18
01/16/2000	3:50	11.18	0.04	1.02	1.5	0.03	0.68
Storm 2							
01/22/2000	20:13	11.89	0.04	1.02	0.3	0.13	3.21
01/22/2000	20:45	11.93	0.04	1.02	0.5	0.07	1.90
01/22/2000	23:23	11.97	0.04	1.02	2.6	0.02	0.39
01/22/2000	23:55	12.01	0.04	1.02	0.5	0.07	1.90
01/23/2000	6:21	12.05	0.04	1.02	6.4	0.01	0.16
01/23/2000	6:50	12.09	0.04	1.02	0.5	0.08	2.10
01/23/2000	7:51	12.16	0.07	1.78	1.0	0.07	1.75
01/23/2000	8:06	12.16	0.00	0.00	0.3	0.00	0.00
01/23/2000	8:27	12.20	0.04	1.02	0.3	0.11	2.90
01/23/2000	8:47	12.24	0.04	1.02	0.3	0.12	3.05
01/23/2000	9:09	12.28	0.04	1.02	0.4	0.11	2.77
01/23/2000	9:17	12.32	0.04	1.02	0.1	0.30	7.62
01/23/2000	9:57	12.36	0.04	1.02	0.7	0.06	1.52
01/23/2000	12:34	12.40	0.04	1.02	2.6	0.02	0.39
01/23/2000	14:41	12.44	0.04	1.02	2.1	0.02	0.48
01/23/2000	15:19	12.48	0.04	1.02	0.6	0.06	1.60
01/23/2000	16:05	12.52	0.04	1.02	0.8	0.05	1.33
01/23/2000	16:30	12.56	0.04	1.02	0.4	0.10	2.44
01/23/2000	17:39	12.64	0.08	2.03	1.2	0.07	1.77
01/23/2000	18:48	12.68	0.04	1.02	1.2	0.03	0.88
01/23/2000	19:04	12.72	0.04	1.02	0.3	0.15	3.81
01/23/2000	20:18	12.76	0.04	1.02	1.2	0.03	0.82
01/23/2000	20:29	12.80	0.04	1.02	0.2	0.22	5.54
01/23/2000	21:58	12.84	0.04	1.02	1.5	0.03	0.68
01/23/2000	23:42	12.87	0.03	0.76	1.7	0.02	0.44
01/24/2000	8:29	12.95	0.08	2.03	8.8	0.01	0.23
01/24/2000	16:19	12.99	0.04	1.02	7.8	0.01	0.13
01/24/2000	21:32	13.03	0.04	1.02	5.2	0.01	0.19
01/25/2000	4:30	13.07	0.04	1.02	7.0	0.01	0.15
01/25/2000	8:53	13.07	0.00	0.00	4.4	0.00	0.00
01/25/2000	12:58	13.11	0.04	1.02	4.1	0.01	0.25
01/26/2000	9:17	13.11	0.00	0.00	20.3	0.00	0.00

01/26/2000	21:29	13.11	0.00	0.00	12.2	0.00	0.00
01/27/2000	1:47	13.15	0.04	1.02	4.3	0.01	0.24
Storm 3							
04/12/2000	16:21	13.82	0.00	0.00	12.2	0.00	0.00
04/12/2000	22:09	13.86	0.04	1.02	5.8	0.01	0.18
04/12/2000	22:10	13.90	0.04	1.02	0.0	2.40	60.96
04/12/2000	22:14	13.94	0.04	1.02	0.1	0.60	15.24
04/12/2000	22:56	13.98	0.04	1.02	0.7	0.06	1.45
04/12/2000	23:18	14.02	0.04	1.02	0.4	0.11	2.77
04/13/2000	0:23	14.06	0.04	1.02	1.1	0.04	0.94
04/13/2000	4:33	14.06	0.00	0.00	4.2	0.00	0.00
04/13/2000	16:45	14.06	0.00	0.00	12.2	0.00	0.00
04/14/2000	4:57	14.06	0.00	0.00	12.2	0.00	0.00
04/14/2000	6:35	14.09	0.03	0.76	1.6	0.02	0.47
04/14/2000	6:51	14.13	0.04	1.02	0.3	0.15	3.81
04/14/2000	17:09	14.13	0.00	0.00	10.3	0.00	0.00
04/15/2000	5:21	14.13	0.00	0.00	12.2	0.00	0.00
04/15/2000	17:32	14.13	0.00	0.00	12.2	0.00	0.00
04/16/2000	17:56	14.13	0.00	0.00	0.4	0.00	0.00
04/16/2000	21:57	14.21	0.08	2.03	4.0	0.02	0.51
04/16/2000	23:10	14.25	0.04	1.02	1.2	0.03	0.84
04/16/2000	23:38	14.29	0.04	1.02	0.5	0.09	2.18

These rainfall data are for Weather Station PAA [32].

Cumulative Copper Release in Runoff - Exhibit 12

∑ Time	Deposition		Corrosion		Release		Runoff	
		∑		∑		∑		∑
hrs	µg/sqm	µg/sqm	µg/sqm	µg/sqm	µg/sqm	µg/sqm	l/sqm	l/sqm
13.6	1	1			0	0	0	0
14.0	0	1			0	0	0	0
26.2	1	2			0	0	0	0
38.4	1	3			0	0	0	0
50.6	1	4			0	0	0	0
62.8	1	5			0	0	0	0
75.0	1	6			0	0	0	0
75.4	0	6	0	0	0	0	0	0
86.7	1	7	6,487	7	2,903	2,903	1	1
87.6	0	7	496	503	0	2,903	0	1
88.5	0	7	553	1,057	2,177	5,080	1	2
100	1	8	6,429	7,486	0	5,080	0	2
112	1	9	6,973	14,459	0	5,080	0	2
124	1	10	6,983	21,442	0	5,080	0	2
136	1	11	6,983	28,424	0	5,080	0	2
149	1	12	6,983	35,407	0	5,080	0	2
161	1	13	6,983	42,389	0	5,080	0	2
173	1	14	6,983	49,372	0	5,080	0	2
185	1	15	6,983	56,355	0	5,080	0	2
193	1	16	4,588	60,943	5,806	10,886	2	4
194	0	16	286	61,229	2,903	13,789	1	5
194	0	16	124	61,353	5,806	19,594	2	7
194	0	16	267	61,620	2,903	22,497	1	8
196	0	16	859	62,479	2,903	25,400	1	9
197	0	16	859	63,337	0	25,400	0	9
198	0	16	219	63,557	0	25,400	0	9
208	1	17	5,743	69,299	2,903	28,303	1	10
210	0	18	1,240	70,539	0	28,303	0	10
214	0	18	2,080	72,619	2,903	31,206	1	11
215	0	18	582	73,201	2,903	34,109	1	12
216	0	18	887	74,088	5,806	39,914	2	14
217	0	18	763	74,851	2,903	42,817	1	15
218	0	18	401	75,251	2,903	45,720	1	16
220	0	18	1,288	76,539	5,080	50,800	2	18
221	0	18	353	76,892	5,806	56,606	2	20
221	0	18	219	77,112	2,903	59,509	1	21
222	0	18	105	77,216	2,903	62,411	1	22
222	0	19	143	77,360	2,903	65,314	1	23
222	0	19	124	77,484	2,903	68,217	1	24
222	0	19	38	77,522	0	68,217	0	24
223	0	19	439	77,961	2,903	71,120	1	25
228	0	19	3,100	81,061	2,903	74,023	1	26
234	1	20	3,444	84,504	0	74,023	0	26

247	1	21	6,983	91,487	0	74,023	0	26
259	1	22	6,983	98,470	0	74,023	0	26
271	1	23	6,983	105,452	0	74,023	0	26
283	1	24	6,973	112,425	0	74,023	0	26
295	1	25	6,983	119,408	0	74,023	0	26
308	1	26	6,983	126,390	0	74,023	0	26
320	1	27	6,983	133,373	0	74,023	0	26
332	1	28	6,983	140,356	0	74,023	0	26
332	0	28	181	140,537	2,903	76,926	1	27
333	0	28	305	140,842	2,903	79,829	1	28
335	0	28	1,507	142,349	2,903	82,731	1	29
336	0	28	305	142,655	2,903	85,634	1	30
342	1	29	3,682	146,337	2,903	88,537	1	31
343	0	29	277	146,613	2,903	91,440	1	32
344	0	29	582	147,195	5,080	96,520	2	34
344	0	29	143	147,338	0	96,520	0	34
344	0	29	200	147,539	2,903	99,423	1	35
345	0	29	191	147,729	2,903	102,326	1	36
345	0	29	210	147,939	2,903	105,229	1	37
345	0	29	76	148,015	2,903	108,131	1	38
346	0	29	382	148,397	2,903	111,034	1	39
349	0	29	1,498	149,895	2,903	113,937	1	40
351	0	29	1,211	151,106	2,903	116,840	1	41
351	0	29	362	151,469	2,903	119,743	1	42
352	0	29	439	151,907	2,903	122,646	1	43
353	0	29	238	152,146	2,903	125,549	1	44
354	0	30	658	152,804	5,806	131,354	2	46
355	0	30	658	153,462	2,903	134,257	1	47
355	0	30	153	153,615	2,903	137,160	1	48
356	0	30	706	154,321	2,903	140,063	1	49
356	0	30	105	154,426	2,903	142,966	1	50
358	0	30	849	155,275	2,903	145,869	1	51
360	0	30	992	156,267	2,177	148,046	1	52
368	1	31	5,027	161,294	5,806	153,851	2	54
376	1	31	4,483	165,777	2,903	156,754	1	55
382	0	32	2,986	168,763	2,903	159,657	1	56
389	1	32	3,987	172,750	2,903	162,560	1	57
393	0	33	2,509	175,259	0	162,560	0	57
397	0	33	2,337	177,596	2,903	165,463	1	58
417	2	35	11,628	189,224	0	165,463	0	58
429	1	36	6,983	196,207	0	165,463	0	58
434	0	36	2,461	198,668	2,903	168,366	1	59
442	1	37	4,522	203,189	0	168,366	0	59
454	1	38	6,983	210,172	0	168,366	0	59
466	1	39	6,973	217,145	0	168,366	0	59
489	2	41	13,049	230,195	2,903	171,269	1	60
490	0	41	916	231,110	0	171,269	0	60
503	1	42	6,983	238,093	0	171,269	0	60
515	1	43	6,983	245,076	0	171,269	0	60
527	1	44	6,983	252,058	0	171,269	0	60
539	1	45	6,983	259,041	0	171,269	0	60
551	1	46	6,983	266,023	0	171,269	0	60

564	1	47	6,973	272,996	0	171,269	0	60
576	1	48	6,983	279,979	0	171,269	0	60
588	1	49	6,983	286,962	0	171,269	0	60
600	1	50	6,983	293,944	0	171,269	0	60