Copper and Solids Removed Via Street Sweeping

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The Brake Pad Partnership is conducting a study whose purpose is to gain a better understanding of the sources of elevated copper concentrations in the San Francisco Bay. The overall effort includes assessing the magnitude of copper released in the Bay area, followed by modeling of the environmental fate and transport of these estimated releases. A previous report provides estimates of copper released to roadways in brake pad wear debris (Rosselot, 2006). The copper found in street sweeper dirt is landfilled and is therefore prevented from entering storm water runoff. This report provides estimates of releases of copper and solids removed from roadways in the San Francisco Bay area watersheds via street sweeping. These estimates are intended for use in the Brake Pad Partnership's modeling effort.

Most of the values used for estimating removal of copper via street sweeping were taken from a study conducted in New Bedford, Massachusetts (Breault et al, 205). This study included three field efforts: (1) measurement of street-dirt accumulation from two residential areas, after specific time intervals; (2) collection of street dirt for analysis of chemical composition; and (3) controlled measurement of street-sweeper efficiency. The authors of the study state that the most important result of this preliminary study is the similarity observed between this study's data and those collected by others from across the Nation. They note that

> [f]or example, average street-dirt-accumulation rates measured in this study (14 g/curb-m/d) are similar to those measured by others (9 to 15 g/curb-m/d); estimated total recoverable concentrations of arsenic (4 ppm), cadmium (0.9 ppm), chromium (261 ppm), copper (404 ppm), lead (335 ppm), nickel (31 ppm), and zinc (260 ppm) in street dirt collected in this study are for the most part similar to average concentrations of these contaminants measured by others…

The street-dirt-accumulation rates cited in the above paragraph are from Pitt et al, 2004, and the authors were comparing the concentrations they found to those of Sartor and Gaboury, 1984.

In the study, copper concentrations were measured as either "total recoverable copper" or "total copper." The authors describe the difference in these values as follows:

> Total concentrations are determined by using a strong acid digestion, which dissolves the mineral matrix; therefore, total concentrations include those elements that compose the minerals in the sample. Total recoverable concentrations are determined by using a weak acid digestion, which generally does not dissolve the mineral matrix; therefore, total recoverable concentrations include only those elements that are sorbed to the surface of particles in the sample. Elements measured by means of total recoverable methods are generally considered the result of human activities and are commonly considered to be the geochemically or biologically available fraction.

The above quote is included here to illustrate the authors' definitions of "total recoverable copper" and "total copper." However, the assumption made by the authors that total recoverable copper indicates copper from anthropogenic sources is questionable. This assumption is based on studies of metals/contaminants that have sorbed from an aqueous phase onto solid (natural) particulates such as soils and sediments. When the particulate materials themselves are the source of contaminants, and the contaminants are dispersed throughout the entire particle mass, then this means of distinguishing between anthropogenic and nonanthropogenic sources is no longer valid. Based on the work that has been done with brake pad wear debris for the Brake Pad Partnership (e.g., at Clemson University, by Jim Trainor, and at Clarkson University), it is known that it takes a very rigorous digestion to get all of the brake pad wear debris copper in a dissolved form for analysis. In fact, the required digestion process for dissolving copper from brake pad wear debris is much more rigorous than what the authors of the study used for their total copper measurements.

In this description of the methodology for estimating copper and solids removed via street sweeping in the San Francisco Bay area, "recoverable copper" refers to "total recoverable copper."

Average street-dirt-accumulation rates measured in this study were 14 g/curb-meter/d (or 8,200 kg/curb-mile/y). These rates were measured by washing a portion of a street before and after an accumulation period and sampling the wash water. The overall average street-sweeper efficiency, determined as a particle-size-weighted average, ranged from 20 to 31 percent for the mechanical sweeper. Street sweeper efficiency is the ratio of dirt recovered to dirt accumulated, and is measured by applying a known mass of dirt to a street and measuring the amount of dirt swept by a sweeper. The recoverable copper concentration in mechanical sweeper dust was found to be 43 ppm. Measurements of both total recoverable copper and total concentrations of copper in street dirt resulted in a ratio of total recoverable copper to total copper of about 60% for most size fractions.

These values, combined with information about the number of swept curb miles in Alameda County, taken from the 2000-2001 issue of "Clean Water," were used to calculate street dirt and copper removed via street sweeping for Alameda County. The number of sweeper miles in Alameda County was 266,000 curb miles for that year. Of course, nearly all of these sweeper miles were on streets that were swept more than once during the year. If it is assumed that the average swept street is swept on three out of four weeks, then there are an average of 39 sweep events per swept road per year. This means that the number of swept curb miles in Alameda County is 6,820. Note that there are no available data about the frequency with which swept roads are swept. Most swept streets are swept on a weekly basis with some swept more frequently and some swept less frequently. Street sweeping activities are suspended during rain. Thus, the assumption that the average swept street is swept on three out of four weeks is judgment-based.

Street sweeper efficiency was assumed to be the midpoint of the range found in the New Bedford study for mechanical sweepers. This is equivalent to 0.25 g sweepings/g dirt. Values along with their estimated standard uncertainties are given in Table 1. Statistically based uncertainties were not available, so standard uncertainties were calculated by assuming a flat distribution across a judgment-based range of potential "true" values for each variable. The standard uncertainty for such a distribution is half the range divided by the square root of three (NIST, 2005). The formulas for calculating solids and copper removed via street sweeping in Alameda County are:

$$\text{solids removed} = \left(8{,}200\,\frac{\text{kg dirt}}{\text{curb-mi}\cdot\text{y}}\right)\left(0.25\,\frac{\text{g sweepings}}{\text{g dirt}}\right)\left(6{,}820\text{ swept curb-mi}\right)$$

$$= 14\times10^{6}\text{ kg solids/y}$$

$$\text{recoverable Cu removed} = \left(8{,}200\,\frac{\text{kg dirt}}{\text{curb-mi}\cdot\text{y}}\right)\left(0.000043\,\frac{\text{g recoverable Cu}}{\text{g sweepings}}\right)\left(0.25\,\frac{\text{g sweepings}}{\text{g dirt}}\right)$$

$$\times\left(6{,}820\text{ swept curb-mi}\right)$$

$$= 600\text{ kg Cu/y}$$

$$\text{total Cu removed} = \left(\text{recoverable Cu removed}\right)\left(1.7\,\frac{\text{total Cu}}{\text{recoverable Cu}}\right) = 1000\text{ kg Cu/y}$$

These estimates are highly uncertain. If the Kline-McClintock equation is used to calculate a standard uncertainty in the calculated result, the standard uncertainties shown in Table 1 result in a standard uncertainty for solids removed of 4×10^{6} kg/y. The standard uncertainty calculated for recoverable copper and total copper removed is 300 kg/y and 600 kg/y, respectively. (The Kline-McClintock equation is the first term in the Taylor series approximation for the propagation of uncertainty and can be used to calculate the uncertainty in the result of a function if the variables in the function are not co-related.)

The values for dirt and copper removed in Alameda County were extrapolated to the sub-watersheds in the San Francisco Bay watershed based on the ratio of vehicle miles traveled in the sub-watershed to vehicle miles traveled in Alameda County, as shown in Table 2. Vehicle miles traveled are assigned to the sub-watersheds based on data that is available by county and by the population of the sub-watershed. Extrapolating by vehicle miles traveled introduces uncertainties. However, it is the most appropriate choice, partly because brake pad wear debris releases to roadways were apportioned according to vehicle miles traveled. It is recognized that for some of the less urbanized sub-watersheds, using this ratio to extrapolate from Alameda County results in an overly high estimate of copper and solids removed from roads by street sweeping. However, the overall amounts of copper removed by street sweeping relative to the copper released directly to roadways from brakes are small, and this bias is not expected to have a significant effect on the overall results. The uncertainty introduced by extrapolating according to the ratio of vehicle miles traveled was assumed to be such that the "true" extrapolation value would be between 0.5 and 1.5 of the ratio.

References

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Table 1. Tabulated values for calculating solids and copper removal via street sweeping in Alameda County and their uncertainty.

Parameter	Value	Range (Estimated)	Estimated Standard Uncertainty
Sweeper miles in Alameda County, mi	266,000	265,500-266,500	289
Number of sweep events per swept road	39	32-46	4
Street dirt accumulation, g/curb-meter/d	14	9-19	
Street dirt accumulation, kg/curb-mile/y	8,224		1,696
Sweeper efficiency (dirt removed:dirt accumulated)	0.25	20%-31%	0.03
Recoverable copper concentration in sweeper dust, mass fraction	0.000043	0.000039-0.000047	0.00002
Ratio of total copper to recoverable copper	1.7	1.5-1.9	0.1
Solids removed, kg/y	14 million		4 million
Recoverable copper removed, kg/y	603		361
Total copper removed, kg/y	1,005		605

Table 2. Estimated Solids, Recoverable Copper, and Total Copper Removed from San Francisco Bay Area Watersheds Via Street Sweeping.

Subwatershed	Vehicle Miles Traveled Ratio (for extrapolation from Alameda County to subwatersheds)	Uncertainty in Vehicle Miles Traveled Ratio	Solids Removed, kg/y	Uncertainty in Solids Removed, kg/y	Recoverable Copper Removed, kg/y	Uncertainty in Recoverable Copper Removed, kg/y	Total Copper Removed, kg/y	Uncertainty in Total Copper Removed, kg/y
Alameda County	1.000	0.000	14,022,544	3,693,818	603	361	1,005	605
Upper Alameda	0.152	0.044	2,136,917	570,702	92	55	153	92
Santa Clara Valley Central	0.254	0.073	3,560,697	973,597	153	92	255	155
Castro Valley	0.024	0.007	340,161	89,637	15	9	24	15
East Bay North	0.169	0.049	2,374,969	636,299	102	61	170	103
Upper Colma	0.069	0.020	965,799	255,134	42	25	69	42
Marin South	0.102	0.029	1,426,441	378,081	61	37	102	62
Coyote	0.417	0.120	5,849,799	1,694,350	252	153	419	257
East Bay Central	0.606	0.175	8,504,648	2,689,989	366	228	609	382
East Bay South	0.128	0.037	1,801,784	479,308	77	46	129	78
Solano West	0.117	0.034	1,639,289	435,351	70	42	117	71
Napa	0.139	0.040	1,951,579	520,030	84	50	140	84
North Napa	0.017	0.005	242,732	63,952	10	6	17	10
North Sonoma	0.006	0.002	90,076	23,728	4	2	6	4
Marin North	0.065	0.019	918,247	242,506	39	24	66	40
Contra Costa Central	0.329	0.095	4,609,942	1,290,756	198	120	330	201
Petaluma	0.045	0.013	636,905	167,981	27	16	46	27
Santa Clara Valley West	0.526	0.152	7,369,328	2,240,149	317	196	528	328
Upper San Lorenzo	0.024	0.007	337,202	88,857	14	9	24	15
Contra Costa West	0.118	0.034	1,650,773	438,450	71	43	118	71
Peninsula Central	0.374	0.108	5,238,856	1,491,203	225	137	375	230
Sonoma	0.021	0.006	297,883	78,490	13	8	21	13
Upper San Francisquito	0.009	0.003	127,473	33,580	5	3	9	6
Upper Corte Madera	0.021	0.006	289,603	76,307	12	7	21	12
Total SF Bay Watershed	3.734		52,361,104		2,252		3,753	