Road Surface Pollution and Street Sweeping

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Abstract Street surface pollution is a source of water and air quality degradation in urban areas. Street sweeping is practiced in most urban areas to remove debris and sediments from roads and to reduce pollutant export to the natural environment. The objective of this study was to investigate the environmental effects of not performing street cleaning in the urban environment. The cites of Berkeley and Oakland in California have an “Opt-Out” Program, which has allowed citizens to opt out of having street cleaning services performed on their streets. The composition of road dusts and sediments on opt-out streets were compared to that of those on streets that are swept. For streets that are swept, the before and after effect of street sweeping was also examined. Samples of road sediments were collected from street surfaces and analyzed for metal and polyaromatic hydrocarbon (PAH) pollutant loads. Pollutant levels on road surfaces were found to be site specific. Some opt-out streets have distinctly higher levels of sediments and/or pollutants, while others do not. Discontinuation of the Opt-out Program will likely contribute to some reduction in road surface pollutants, but not to a large extent. Though there does seem to be some environmental concern associated with the Opt-out Program, there is no immediate need to discontinue it.

Introduction

Street surface pollution is a known contributor to the degradation of water and air quality in urban areas (Christenson *et al*. 1978; de Luca *et al*. 1991; Sutherland and Tolosa 2000; US EPA 1983). Deposits from motor vehicle emissions and wear, industry, atmospheric fallout, soils, and plants accumulate on road surfaces. These deposits contain heavy metal and organic matter pollutants that are harmful to ecosystems and human health (Pitt 1979; Rogge *et al*. 1993; US EPA 1983). In wet weather, storm runoff carries road deposits and its associated contaminants from streets into storm drains and receiving waters. This heavy metal and organic input can adversely affect aquatic ecosystems and creates public health hazards from direct human contact with contaminated waters and groundwater infiltration, which leads to drinking water contamination (Christenson *et al*. 1978). In dry weather, wind and vehicular traffic disperse road dusts into the air, spreading particulates along with it. Airborne particulates pose concerns for public health due to inhalation (Dobroff 1999) and for vegetation due to settling in roadside soils.

Street surface pollution has multiple source contributions. The majority of street surface particulates are nutrients from soils and plants, such as nitrogen and phosphorus (Pitt 1979). Wear of brake linings of motor vehicles contributes high concentrations of lead, chromium, copper, and nickel to road sediments and wear of tires contributes high concentrations of lead and zinc (Pitt 1979; Rogge *et al*. 1993). Roadway abrasions and spills and leaks of vehicular fluids, such as gasoline, motor oil, lubricants, and antifreeze also contribute to street surface pollution (Pitt 1979; Rogge *et al*. 1993). Another source of contaminants is industry, as particulates in emissions are brought to street surfaces by atmospheric transport and fallout (Pitt 1979; Rogge *et al*. 1993). Other metals found in road sediments include cadmium, manganese, antimony, strontium, and iron (Sutherland and Tolosa 2000; Clark *et al*. 2000). There are many non-metal contaminants present in road sediments. Over one hundred organic compounds including a variety of hydrocarbons, polyaromatic hydrocarbons, and pesticides have been identified in road dust samples (Rogge et al. 1993).

Street cleaning is practiced in most urban areas to remove debris and sediments from roads and to reduce pollutant export to the natural environment. Under the U.S. Environmental Protection Agency's (EPA) Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) Stormwater Program requires municipal separate storm sewer systems (MS4) in urbanized areas to have a stormwater management program designed to prevent harmful pollutants from being washed by stormwater runoff into the MS4, then discharged from the MS4 into local waterbodies (Stormwater Phase I: Rule 55 FR 47990; November 16, 1990). Street cleaning is listed as a best management practice (BMP) to carry out pollution prevention. In Alameda County, California, the Alameda County Urban Runoff Clean Water Program, established in 1991, requires that BMPs are conducted to improve storm water quality. Street cleaning was identified as one of the key components of the program's municipal maintenance activities. Each municipality is required to clean streets on at least a monthly average (ACCWP 2003).

The cities of Berkeley and Oakland in Alameda County, California have allowed citizens to opt out of street sweeping services on their streets. Prior to 1994 in Berkeley and 1995 in Oakland, residents were given the option to maintain their street on their own or to receive city street sweeping services. If 66% of residents on a given street signed a petition agreeing that they would keep their street clean themselves, then sweeping on their street, along with its associated parking regulations, would be ceased. Residents are no longer permitted to opt out of street sweeping services, but those streets already under the opt-out program continue to have no street sweeping performed. In Oakland, this opt-out program began in 1987, before the Alameda County Clean Water Program and before the EPA's NPDES Stormwater Program. In Berkeley, it began in 1991. Failure to sweep these streets could undermine the performance of the entire county's stormwater runoff program. More importantly, it may have tragic effects on environmental quality.

The objective of this study was to investigate the environmental effects of not performing street sweeping in the urban environment by examining the City of Berkeley and the City of Oakland's Opt-Out Program. The composition of road sediments on unswept "opt-out" streets were compared to that of those on similar streets that are swept. For swept streets, the before and after effect of street sweeping was also investigated. Samples of road sediments were collected from street surfaces and analyzed for metal and PAH pollutants. Greater pollutant levels on opt-out streets than on swept streets would indicate that the Opt-out Program poses a threat to the environment and that street sweeping is an effective pollution control measure.

Extensive research under the National Urban Runoff Program (NURP), sponsored by the U.S. Environmental Protection Agency, was conducted on street cleaning practices in the late 1970s through the early 1980s. These studies found that street sweepers effectively removed litter and debris but were not very effective in removing pollutant loads (Pitt 1979, US EPA 1983). Street sweeping is more effective at picking up coarse particles than fine particles, so many contaminants are not removed and remain on the streets. Concentrations of heavy metals and nutrients are inversely related to the particle diameter, which means the highest concentrations are found in the smallest grain sizes that are not picked up by street sweepers (German and Svensson 2002; Revitt and Ellis 1980; Pitt 1979; Vaze and Chiew 2002). While improvements in street cleaning technology more efficiently remove small particles from the road surface (Claytor 1999; Sutherland 1995), other recent studies continue to show that street cleaning is not effective in reducing pollutant loads on street surfaces. In studies as recent as 2002, street sweepers still had difficulty in removing very fine sediments (German and Svensson 2002; Vaze and Chiew 2002). Additional studies have shown street sweeping to have no impact on the amount of airborne particulates near roads (Dobroff 1999; Kuhns *et al*. 2003).

Although previous research has generally found that street sweeping is not effective in significantly reducing pollutant levels on road surfaces, street sweeping may unseemingly be a useful pollution control measure when swept streets are compared to entirely unswept streets in a heavily populated urban area. If this is true, there will be no difference between pollutant levels before and after sweeping, but greater pollutant levels will be found on opt-out streets than on swept streets.

Methods Four sites were chosen for sampling locations (Fig. 1), each consisting of one opt-out block and one swept block, selected such that the paired blocks were located in the same general vicinity and had similar street characteristics (Table 1). There were two locations in Berkeley, Site B1 and Site B2, and two in Oakland, Site O1 and Site O2. All blocks ran in the north-south direction and the west side of the street was always used for sampling. Each block location had three sample areas. The first available spot on each end and the available spot closest to the center were used as sample areas. Areas having poor street conditions, such as large cracks or oil spots, were avoided.

For swept streets, samples were taken within 24 hours before and 24 hours after sweeping had taken place, no less than two hours after to allow for settling of dusts dispersed by the sweeper. There were two trials of data collection. In Oakland, residential areas are swept twice a month, so the second trial took place two weeks after the first. In Berkeley, residential areas are

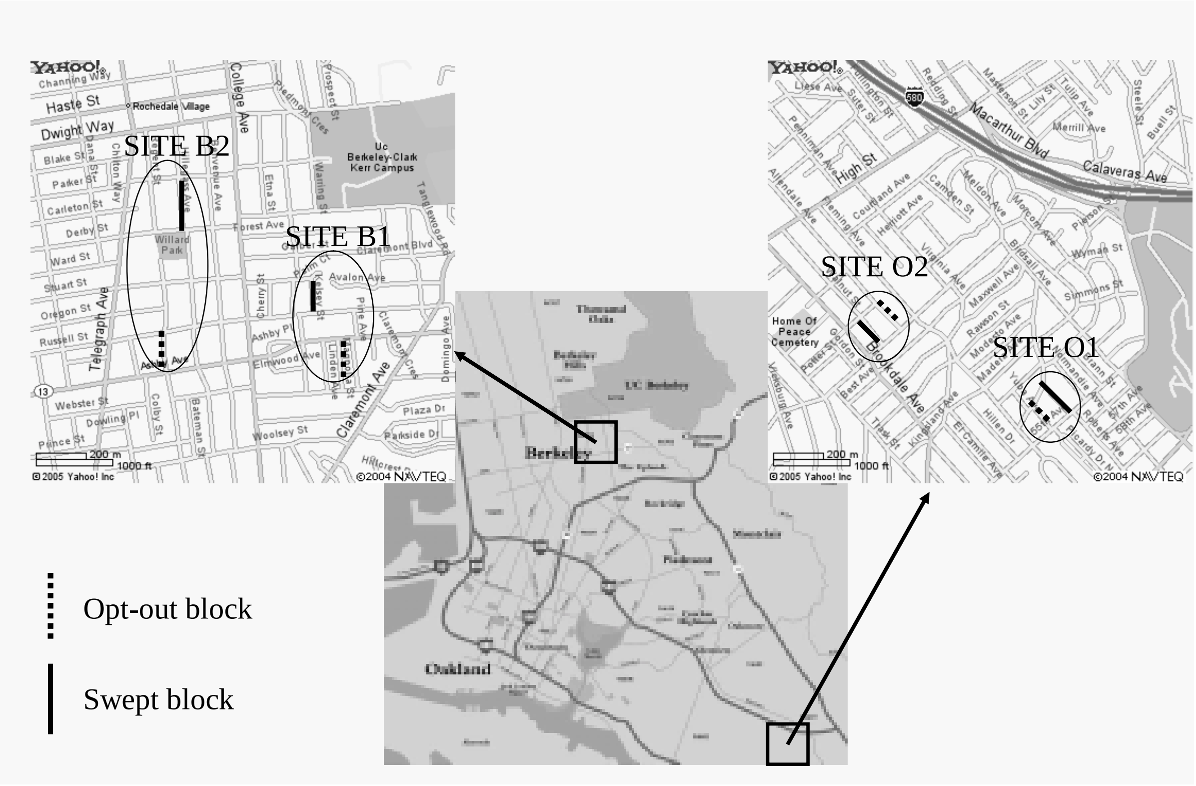


Fig. 1. Sample site locations

swept monthly, so the second trial was one month after the first trial. Samples were collected over a four week period starting 02/22/2005 and ending 03/24/2005.

Nine samples (three opt-out, three before sweeping, and three after sweeping) at each of four sites with one replicate gave a total of 72 samples.

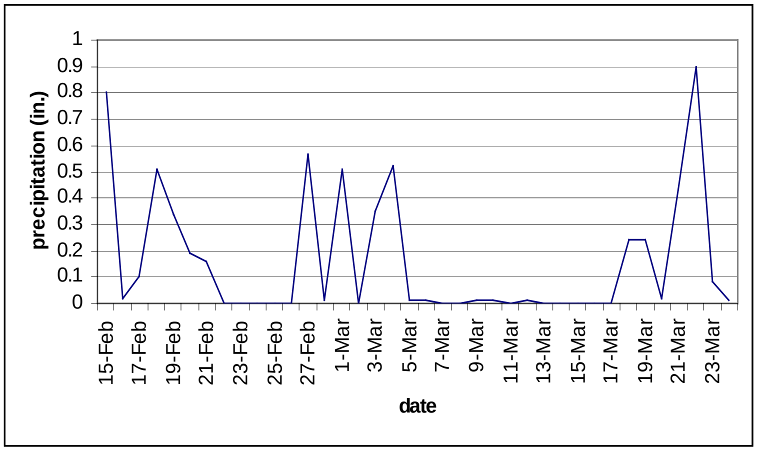
Road sediment samples were collected from curbside road surfaces following the methods developed by Bris et al. (1999). Samples were collected using a conventional domestic wet/dry vacuum cleaner (Stinger, model WD2010) with the filter removed. The vacuum was powered by a 120 volt AC generator (Honda, model EU100i). Samples were taken on the street right

Table 1. Site characteristics

	block location	sweeping effect	traffic frequency	smoothness of road	soil & vegetation	drainage along curb
Site B1	2900 Magnolia	opt-out	low	fair	high	no
	2800 Kelsey	swept- 1/month	low	good	high	no
Site B2	2900 Regent	opt-out	med.	fair	med.	yes
	2600 Hillegass	swept- 1/month	med.	fair	med.	yes
Site O1	5400 Yuba	opt-out	low	fair	med.	no
	5400 Roberts	swept- 2/month	low	fair	med.	no
Site O2	4800 Allendale	opt-out	low	very good	med.	yes
	4800 Walnut	swept- 2/month	low	fair	med.	no

against the curb, where sediments accumulate, and were contained in a 0.5 by 0.5 m area by a three-sided wood frame placed against the curb. The samples were taken by pouring 2 L of distilled water, little by little, into the sample area, hand brushing the area to loosen fine particles bound to the road surface, and then sucking up the water along with loosened road sediments into the vacuum. Samples were stored in clean plastic containers at 10°C. Between each sampling, the vacuum's collection container was rinsed three times with distilled water.

Sample collection took place during a rainy season with many rainy days (Fig. 2). Some streets have pipes that drain rain water out from the curb onto the street. When it rains, water drains out from these pipes and there is a constant flow of water running along the curb.



sample dates	Feb 22-24	Mar 01-03	Mar 15-17	Mar 22-24
samples collected	trial I sites B1 & B2	trial I sites O1 & O2	trial II sites O1 & O2	trial II sites B1 & B2

Figure 2. precipitation during sampling period

Road sediment samples were measured and analyzed for the following parameters: total suspended solids (TSS), pH, electrical conductivity, the metals: cadmium, chromium, lead, nickel, copper, zinc, and iron, and the PAHs: naphthalene (NAP), acenaphthylene (ACY), acenapthene (ACE), fluorine (FLT), anthracene (ANT), phenanthrene (PHE), fluoranthrene (FLT), pyrene (PYR), benz[a]anthracene (BAA), chrysene (CHR), benzo[b]fluoranthene (BBF), benzo[k]fluoranthene (BKF), benzo[*a*]pyrene (BAP), indeno[1,2,3-cd]pyrene (ICP), dibenz[a,h]anthracene (DBA), and benzo(ghi)perylene (BGP). These represent pollutants of the greatest concern to the environment. The metals are all toxic and cadmium, chromium, lead, and nickel are carcinogenic. Seven of the PAHs: BAA, CHR, BBF, BKF, BAP, ICP, and DBA, are listed as probable human carcinogens by the EPA.

The samples were filtered through a 106 µm sieve to remove the larger particles, since pollutants are mostly bound to fine particles and it is these fines that are transported into natural water bodies by storm runoff and into the air by wind and traffic. After filtering, pH and electrical conductivity were measured and TSS was determined for each of the samples. For the metals and PAHs analyses, the three samples taken from each block location were combined to get one collective sample representative of that block location. Due to time and cost limitations, this reduced the number of samples to 24: 3 samples (1 opt-out, 1 before sweeping, and 1 after sweeping) at each of 4 sites and 2 trials.

TSS analyses and metals analyses were conducted at the University of California at Berkeley in the Doner Laboratory in the Environmental Science and Policy Management (ESPM) department. For TSS analyses, a vacuum filtration system was used with 45mm Whatman 42 filters and 35 mL of each of the 72 samples. The 24 combined samples were analyzed for metals. Metals were extracted by an HCl acid leach. HCl was added to 15 mL of each sample to obtain a final concentration of 0.5M HCl. Samples were then shaken for 90 minutes and filtered through 0.45 µm Millipore filters. The solutions were analyzed by inductively coupled plasma-mass spectroscopy (ICP-MS).

PAHs analyses were conducted at the University of California at Berkeley School of Public Health in the Hammond Laboratory. Due to the lengthy analysis procedure, only one trial of samples (12 samples) was analyzed for PAHs. The samples were filtered by vacuum filtration using tissu-quartz filters to remove the water and obtain the particles. The PAHs were then extracted from the particles by sonication in dichloromethane. The extracts were vacuum filtrated through 0.45 µm Millipore Type FH filters and then concentrated by evaporation under helium gas to a volume of about 500 µL. Sample extracts were analyzed by gas chromatography/mass spectroscopy (GC/MS).

Residents of the opt-out streets sampled in this study were surveyed to find out what activities are being carried out to clean the streets as well as their general outlook on the environment and the Opt-Out Program. Mail-in surveys were distributed to each residence on the opt-out streets after all sample collection had been completed.

Results

The sweeping effect does not appear to have an effect on pH and electrical conductivity (Table 2). However, the Oakland sites had higher pH and electrical conductivity than the Berkeley sites, indicating a more basic and salty environment in Oakland. Sites with no drainage pipes had higher pH and electrical conductivity than the sites with drainage pipes.

Table 2. mean values (n=6) for total suspended solids, pH, and electrical conductivity

	Site B1			Site B1			Site O1			Site O2		
	opt out	before sw.	after sw.	opt out	before sw.	after sw.	opt out	before sw.	after sw.	opt out	before sw.	after sw.
pH	7.11	6.51	6.77	6.59	6.66	6.68	6.96	7.69	7.65	7.33	6.96	6.98
EC (dS/m)	0.22	0.07	0.08	0.08	0.13	0.09	0.12	0.26	0.15	0.17	0.11	0.10

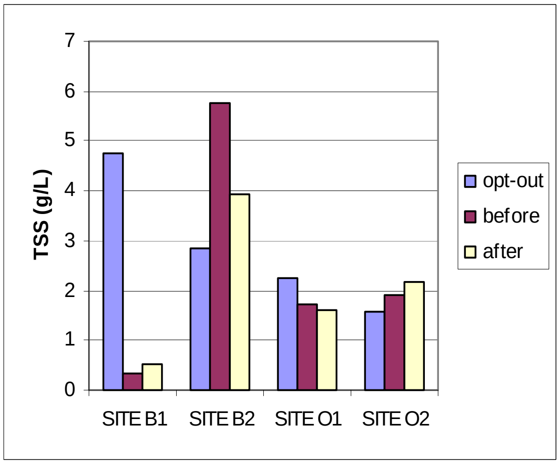


Figure 3. Mean total suspended solids (n=6) of samples taken at each site for opt-out, before, and after sweeping effect

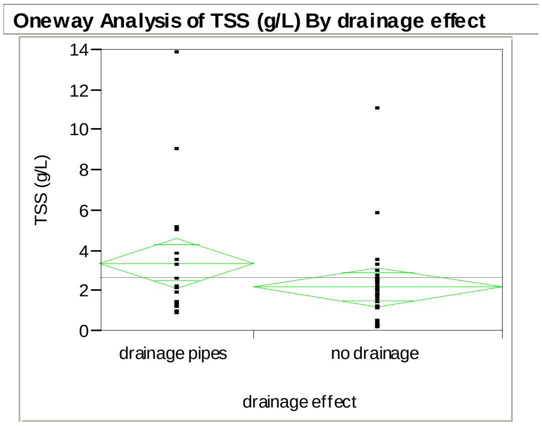


Figure 4. TSS on streets with and without drainage pipes draining rain water out along curb

TSS patterns varied between sites (Fig. 3). If street sweeping serves its purpose, it should reduce TSS. The after TSS values were not always reduced and when they were, it was only by a small amount. On a whole, no significant difference was found in TSS before and after street sweeping (0.6008<P). Thus the before values can be used to make a comparison between the swept and the opt-out effects. It was expected that TSS would be higher on the opt-out than on the swept streets. TSS were higher on opt-out for two sites and lower for the other two. The drainage effect explains this outcome (Fig. 4). The sites without drainage pipes, site B2 and site O2, had higher TSS than those without (P<0.1348). The frequent flow of rain water along the curb removes sediments from the street, reducing TSS.

Iron had the highest levels at all sites and copper had the least(Table 3). Metals also showed variable patterns by site (Fig. 5). There was a contamination problem with cadmium, chromium, and nickel, so their results are not reported. The before and after metals values were not found to be statistically different for either load (0.9810>P) or concentration (0.7747>P). Behavior of metal loads and concentrations are site specific. Differences between opt-out and swept streets can not be seen as a whole with all samples combined, but only when observed site by site. Site

Table 3. Metal loads and concentrations at each site, for before, after, and opt-out sweeping effect

		Site B1			Site B2			Site O1			Site O2		
		opt out	before sw.	after sw.	opt out	before sw.	after sw.	opt out	before sw.	after sw.	opt out	before sw.	after sw.
Cu	conc..(mg/kg)	0.15	0.20	0.21	0.32	0.14	0.16	0.21	0.15	0.14	0.13	0.12	0.10
	load (mg/m^2)	3.92	0.33	0.51	4.98	5.44	4.23	3.96	1.65	1.63	2.04	1.65	1.76
Fe	conc..(mg/kg)	10.31	19.68	28.30	8.45	8.19	9.52	10.93	15.14	14.8	21.0	10.31	10.65
	load (mg/m^2)	298.8	36.35	69.71	154.9	340.8	271.0	185.5	153.4	186.7	191.8	142.5	173.6
Pb	conc..(mg/kg)	0.48	2.41	2.01	0.63	0.37	0.41	0.59	0.63	0.71	0.87	0.76	0.68
	load (mg/m^2)	13.61	4.85	5.14	12.15	13.67	11.73	10.22	7.53	7.75	8.51	10.72	11.03
Zn	conc..(mg/kg)	0.68	4.38	2.54	0.95	1.02	0.85	0.71	1.11	1.24	2.56	0.72	0.60
	load (mg/m^2)	18.50	7.07	6.43	17.89	33.72	23.73	12.89	13.34	12.48	23.67	10.35	10.38

B1 consistently had higher loads on the opt-out street than on the swept street for each metal. But by concentration, the opt-out streets had much lower values. Site O2 had both higher surface loads and higher concentrations of most metals on the opt-out street than on the swept street. Site O1 had some metals with a higher load on the opt-out street than the swept street. The concentrations did not show much of a difference. Site O2 had the opposite patterns observed in Site B1. In Site O2, most of the loads were lower on the opt-out street than on the swept street, but for concentrations, most were higher.

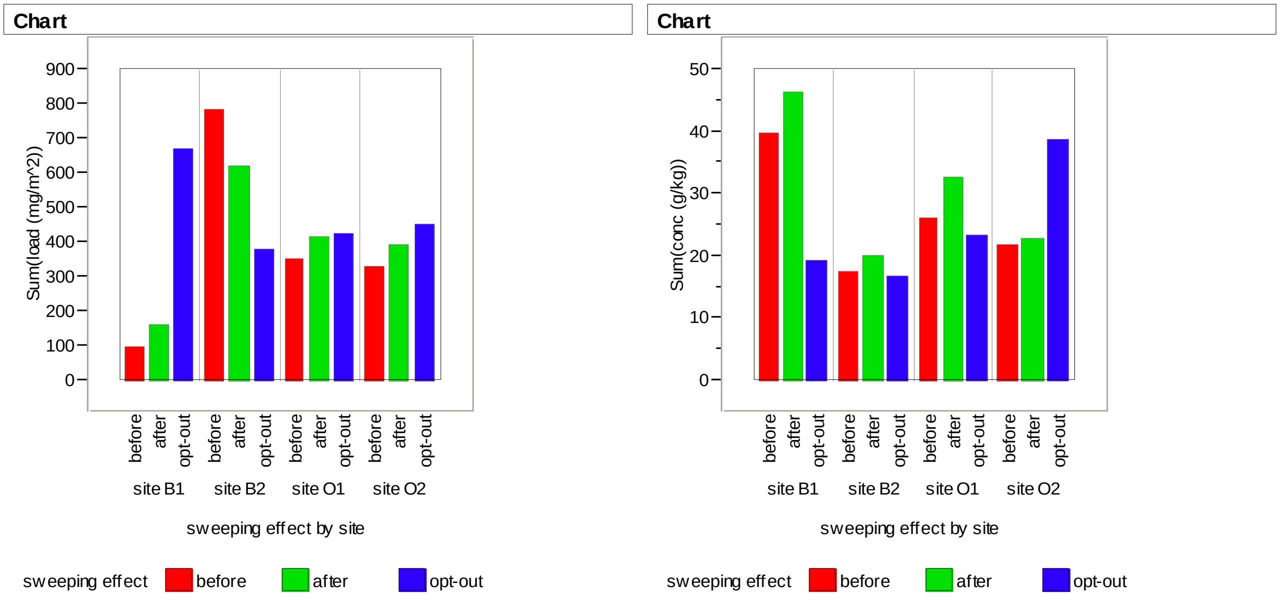


Figure 5. Total metals (Cu, Pb, Zn, Fe) by load (left) and by concentration (right) at each site for before, after, and opt-out sweeping effect

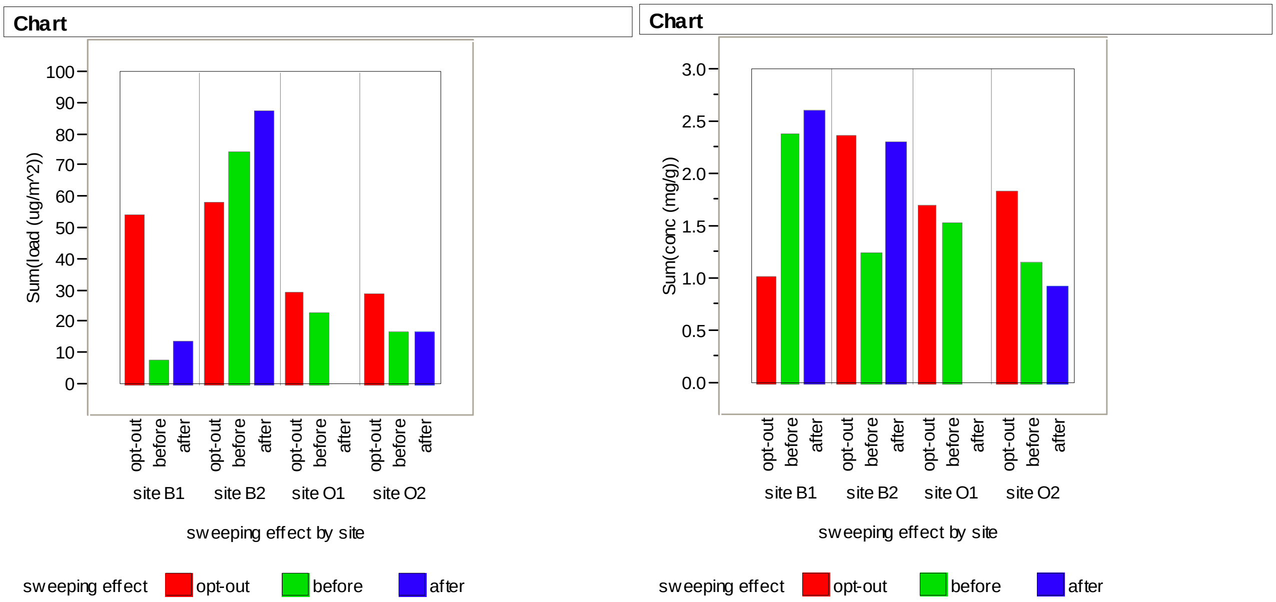


Figure 6. Total PAHs (FLT, PYR, BAA, CHR, BBF, BKF, BAP, ICP, DBA, and BGP) by load (left) and by concentration (right) at each site for before, after, and opt-out sweeping effect

PAH loads and concentrations were higher in Berkeley than in Oakland. Results for total PAHs include only four, five, and six ring PAHs since these are predominantly in the dominant phase and most of them are carcinogenic. The two and three ring PAHs are in the vapor phase and are not included. Data is missing for the after sweeping effect at site O1 due to error in the laboratory anlayses. PAH behavior is also site specific. For site B1, PAHs were higher for opt-out by load, but not by concentration. For site B2, they were higher for concentration, but not by load. For site O1 and site O2, they were higher by both load and concentration.

Of 83 surveys distributed, 29 were returned, yielding a 35% return rate. Survey responses indicate that most residents are active in keeping their streets clean. 75% reported that they remove debris, remove leaves, and /or sweep with a broom on a regular basis. Attitudes toward the environment and toward the Opt-out Program were split right down the middle. 48% were aware that the accumulation of sediments on street surfaces contributes to degradation of water and air quality, while 48% were not (4% no response). 48% are concerned about the potential threat that the Opt-out Program poses to the environment and to human health and 48% were not (4% no response). 44% would be willing to have their street removed from the Opt-out Program, if doing so would reduce pollutant loads on the street and their transport to the environment. This would mean enforcement of parking regulations for street cleaning. 55% do not want their street removed from opt-out. Many of them do want their street swept, but feel that the city parking regulations and enforcement are “absurd” and “offensive.

Discussion Street sweeping is thought to remove contaminants found on road surfaces before they flow into receiving waters or are dispersed into the air. Since street sweeping is the standard method used by most cities to control street surface pollution, its effectiveness as a pollution control measure is of great interest. Results of this study show that street sweeping did not effectively reduce pollutant levels. This agrees with previous research.

Differences were observed between opt-out streets and swept streets, but patterns varied by site. The abundance of pollutants on roads is site specific. Some opt-out streets have distinctly higher levels of sediments and/or pollutants, while others do not. The composition of road sediments is a function of several variables, such as weather, smoothness of street, street activity, water flow, etc.

Road sediment pollution also depends on street sweeper technology. The city of Berkeley uses a mechanical street sweeper. Traditional mechanical street sweepers, also called broom sweepers, use brushes to loosen street particles and conveyor belts to carry debris into collection hoppers. They spray water onto the pavement for dust control. Due to the wetness, a thin layer of road dust sludge remains on the surface of the road. While they effectively clean litter and debris from streets, they fail to significantly reduce pollutant loads (Claytor 1999). The city of Oakland operates both mechanical and regenerative air sweeper equipment. Regenerative air sweepers blast air onto the street to loosen particles and a vacuum sucks them up. They are more effective in removal of fine particles, but do not pick up larger particles as well. They also use water to suppress dispersion of dust, leaving behind a layer of sludge.

An important distinction must be made between pollutant load and concentration. If sweeping reduces the total amount of sediment and hence metal and nutrient loads on streets, but fail to pick up the finer particles, the remaining sediment becomes increasingly fine-grained and the concentration, or proportion of metals and nutrients present in road sediment, increases (German and Svensson 2002; Vaze and Chiew 2002).

Discontinuation of the Opt-out Program will likely contribute to some reduction in road surface pollutants, but not to a large extent. Though there does seem to be some environmental concern associated with the Opt-out Program, there is no immediate need to discontinue it. Other methods of pollution control should be considered.

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