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The Role of Street Cleaning in Stormwater Management

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Abstract
The authors have been involved in numerous street cleaning research projects for over 30 years. This paper will give us a unique opportunity to highlight the historical use of street cleaning as a method for reducing stormwater pollutants, and will examine newly emerging street cleaning technologies. There have been many misconceptions concerning this potential stormwater management control. This paper will examine the limitations of street cleaning, and describe how it can be more effective. Street cleaning plays an important role in most public works departments as an aesthetic and safety control measure. Street cleaning is also important to reduce massive dirt and debris buildups present in the spring in the northern regions. Leaf cleanup by street cleaning is also necessary in most areas in the fall.

Early Street Cleaning Tests
Factors significantly affecting street cleaning performance include particle loadings, street texture, street moisture, parked car conditions, and equipment operating conditions (Pitt 1979). If the 500-1000 µm particle loadings are less than about 75 kg/curb-km for smooth asphalt streets, conventional street cleaning does little good. As the loadings increase, so do the removals: with loadings of about 10 kg/curb-km, less than 25 percent removals can be expected, while removals of up to about 50 percent can be expected if the initial loadings are as high as 40 kg/curb-km for this particle size. The removal performance decreases substantially for smaller particles, including those that are most readily washed off the street during rains and contribute to stormwater pollution.

Much information concerning street cleaning productivity has been collected previously in many areas. The early tests (Sartor and Boyd 1972) were conducted in controlled strips using heavy loadings of simulates instead of natural street dirt at typical loadings. Later tests, from the mid 1970s to mid 1980s, were conducted in large study areas (20 to 200 ha) by measuring actual street dirt loadings on many street segments immediately before and after typical street cleaning. These large-scale tests are of most interest, as they monitored both street surface phenomena and runoff characteristics. Many if these tests were conducted as part of the Nationwide Urban Runoff Program (NURP) directed by the EPA (1983). The following list briefly describes these large-scale street cleaning performance tests:

- San Jose, California, tests during 1976 and 1977 (Pitt 1979) considered different street textures and conditions; multiple passes, vacuum-assisted, and two types of mechanical street cleaners; a wide range of cleaning frequencies; and effects of parking densities and parking controls.

- Castro Valley, California, NURP tests during 1979 and 1980 (Pitt and Shawley 1982) considered street slopes, mechanical and regenerative-air street cleaners, and several cleaning frequencies.

• Reno/Sparks, Nevada, tests during 1981 (Pitt and Sutherland 1982) considered different land-uses, street textures, equipment speeds, multiple passes, full-width cleaning, and vacuum and mechanical street cleaners in an arid and dusty area.

• Bellevue, Washington, NURP tests from 1980 through 1982 (Pitt 1985) considered mechanical, regenerative-air, and modified regenerative-air street cleaners, different land-uses, different cleaning frequencies, and different street textures in a humid and clean area.

• Champaign-Urbana, Illinois, NURP tests from 1980 and 1981 (Terstriep, *et al.* 1982) examined spring clean-up, different cleaning frequencies and land-uses, and used a three-wheel mechanical street cleaner.

• Milwaukee, Wisconsin, NURP tests from 1979 to 1983 (Bannerman, *et al.* 1983) examined various street cleaning frequencies at five study sites, including residential and commercial land-uses and large parking lots.

• Winston-Salem, North Carolina, NURP tests during their NURP project examined different land-uses and cleaning frequencies.

Typical street dirt total solids loadings show a “saw-tooth” pattern with time between street cleaning and rain washoff events (Figure 1).

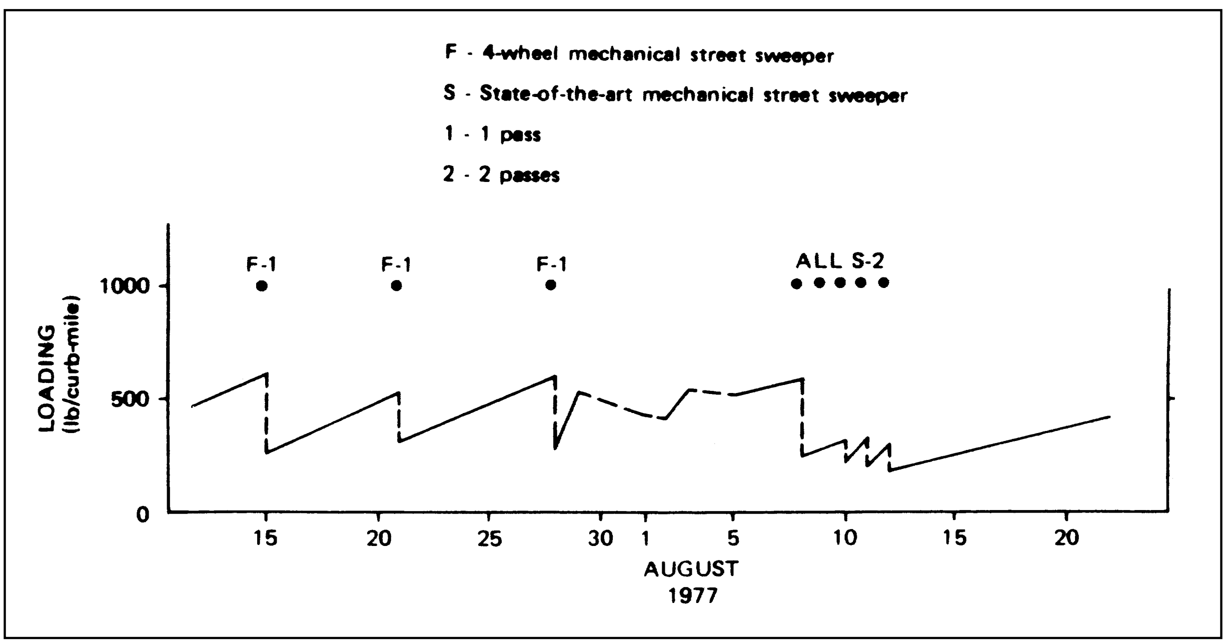

Figure 1. Saw-tooth pattern for accumulation and removal of street dirt by street cleaning, smooth asphalt street test area in San Jose, California, USA. (Pitt 1979).

Rain removes very little of the large particles, but can remove large amounts (about 50%) of the finest particles whose diameter is less than 100µm (Bannerman *et al.*, 1983; Pitt 1985) which contribute most significantly to stormwater pollution. Unfortunately, typical mechanical street cleaners remove much of the coarser particles in the path of the street cleaner, but they remove very little of the finer particles (Sartor and Boyd 1972; Pitt 1979 and 1985) (Table 1).

Table 1. Removal Rates for Street Cleaning for Various Particle Sizes

Particle size (µm)	removal efficiency (%)
0 – 40	16
40 – 100	0
100 – 250	48
250 – 850	60
850 – 2,000	67
>2,000	79

Factors significantly affecting street cleaning performance include (Pitt 1979):

- particle loadings;
- street texture;
- moisture;
- parked car conditions;
- equipment operating conditions
- frequency of cleaning.

Increased street cleaning performance was obtained with a modified regenerative-air street cleaner, especially at low loadings during tests in Bellevue, WA, as shown in Figure 2 (Pitt 1985). The improved performance was much greater for fine particle sizes, where the mechanical street cleaner did not remove any significant quantities of material. The larger particles were removed with about the same effectiveness for both street cleaner types. Other tests of vacuum street cleaners (Pitt 1979) and regenerative-air street cleaners (Pitt and Shawley 1982) showed very few differences in performance when compared to more standard mechanical street cleaners. These earlier tests were conducted in areas having much higher street loadings, especially for the larger particle sizes, than in Bellevue. It is expected that the high loadings of the large particles armored the small particles, so they could not be removed. For high loadings, it may be best to use a tandem operation, where the streets are first cleaned with a mechanical street cleaner to remove the large particles, followed by a regenerative-air street cleaner to remove the finer particles.

The pollutant removal benefits of street cleaning are a function of the relative contributions of pollutants from the streets. Table 2 shows the approximate contributions of different pollutants from different source areas in a mostly residential area in Bellevue, WA (Pitt 1985). Streets make up less than ten percent of the total solids, but much larger amounts of the COD and heavy metals. If street cleaning was able to completely clean the streets, the total solids at the outfall would have only a very small reduction. These contributions are very site specific, depending mostly on the rains in an area, the amount of directly connected impervious areas, and the erodability of the local soils.

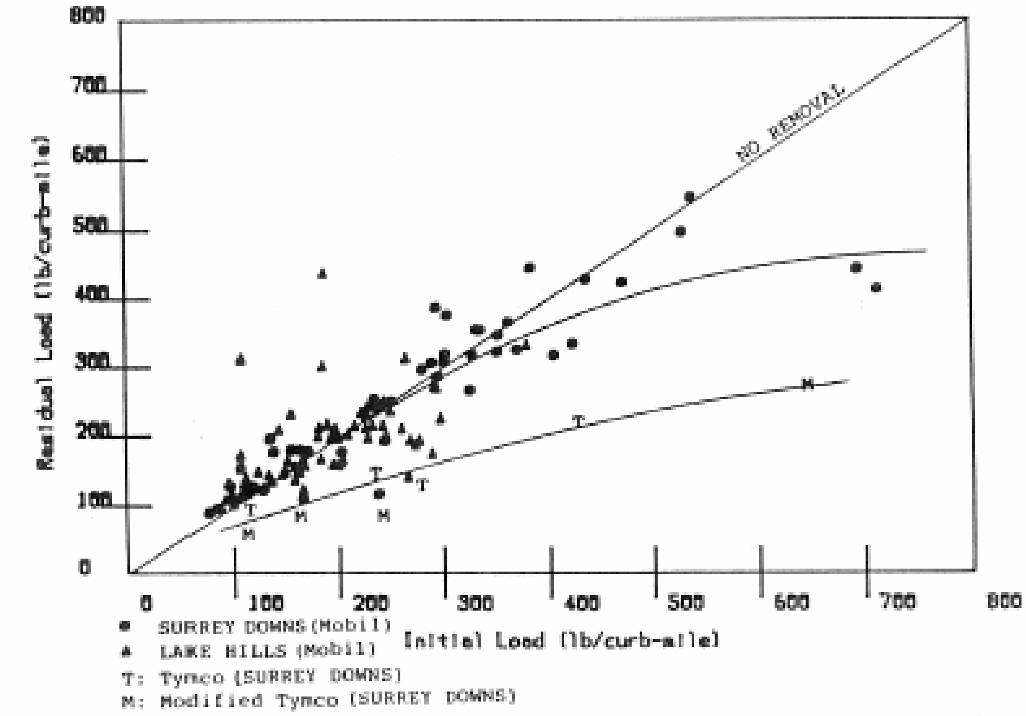

Figure 2. Street cleaner performance as measured in Bellevue, WA (Pitt 1985)

Table 2. Pollutant Contributions from Residential Source Areas, Bellevue, WA (Pitt 1985)

	Percent Outfall Contributions from Source Areas					
Source Area	Total Solids	COD	Phosphate	TKN	Pb	Zn
Streets	9%	45%	32%	31%	60%	44%
Driveways and parking lots	6	27	21	20	37	28
Rooftops	<1	3	5	10	<1	24
Front yards	44	13	22	19	<1	2
Back yards	39	12	20	20	<1	2
Vacant lots and parks	2	<1	<1	<1	<1	<1

In Paris, intensive studies of the Le Marais catchment have included detailed investigations of the solids and metals found from road surface inputs. The daily suspended solids pollutant load removed was found to be similar to the amount removed during one rainfall event. It was also shown that the total mass of pollutants stored on the street surface is significant, even with street cleaning, and the effects of street cleaning may therefore be limited (Gromaire, *et al.* 2000).

Effects of Street Cleaning on Outfall Stormwater Conditions

Figure 3 shows the measured washoff of street surface particulates during actual rains in Bellevue, WA (Pitt 1985). While conventional street cleaning equipment is effective in removing large particles, rains are most effective in removing small particles. Therefore, much of the street dirt that is removed by conventional street cleaning equipment would not contribute to outfall discharges. Pitt (1979) conducted mass balances of street dirt material, showing that much of the material would be removed from the street through fugitive dust, from the turbulence of winds and road traffic. This material can be blown several tens of meters from roads, usually to adjacent landscaped areas.

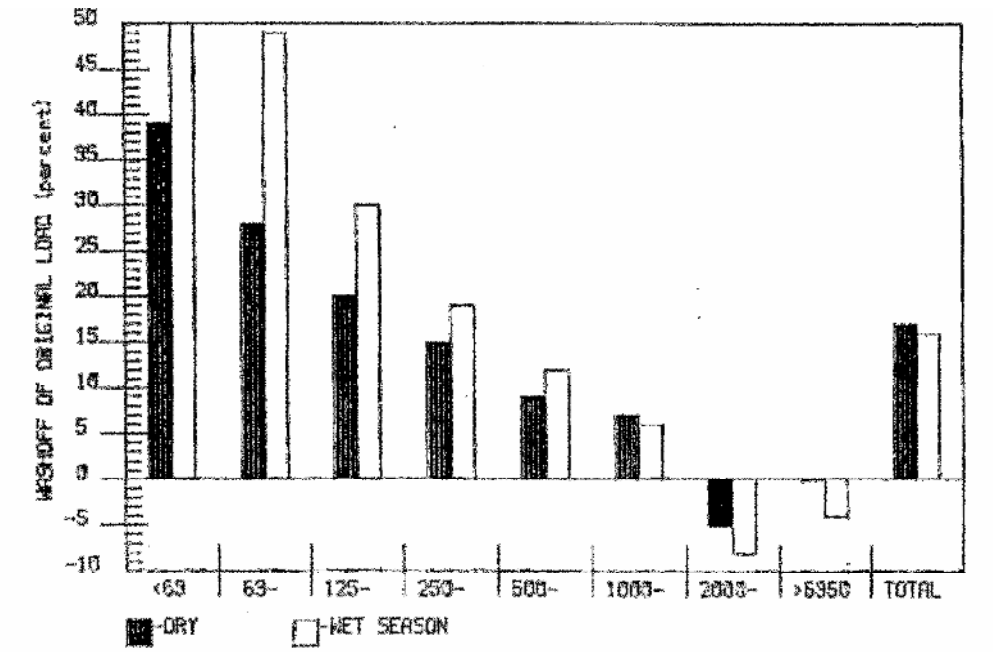

Figure 3. Washoff of street dirt particulates during monitored rains, Bellevue, WA (Pitt 1985).

During NURP (EPA 1983) the many street cleaning projects also compared outfall discharges from areas undergoing various amounts of street cleaning. Figure 4 is an example for Bellevue, WA, showing paired outfall solids concentration values, separated into the appropriate street cleaning categories, and the final fitted regression lines. This final data plot and analysis for the Bellevue street cleaning tests show that the benefits of street cleaning during these tests are ambiguous, although the statistical significance of the results are quite valid. When “no controls” were being used in both areas simultaneously, the outfall total solids concentrations were very similar. When street cleaning was being conducted in Surrey Downs and no controls were occurring in the other watershed, the Surrey Downs outfall total solids concentrations were a constant 100 mg/L (COV of 0.34), irrespective of Lake Hills concentrations. This implies potentially large street cleaning benefits for some of the events having the highest total solids concentrations. These results are both reasonable and support an acceptable hypotheses. Unfortunately, the contrasting situation where street cleaning occurred in Lake Hills and no controls occurred in Surrey Downs indicated almost no change in outfall total solids concentrations. It is possible that some features of the Lake Hills test area hindered street cleaning performance, but that is unlikely due to the careful selection and study of the test sites during this monitoring program. The conclusion is that the beneficial results of street cleaning were not repeatable, even when using a high level of control of the variables, and when obtaining large amounts of data.

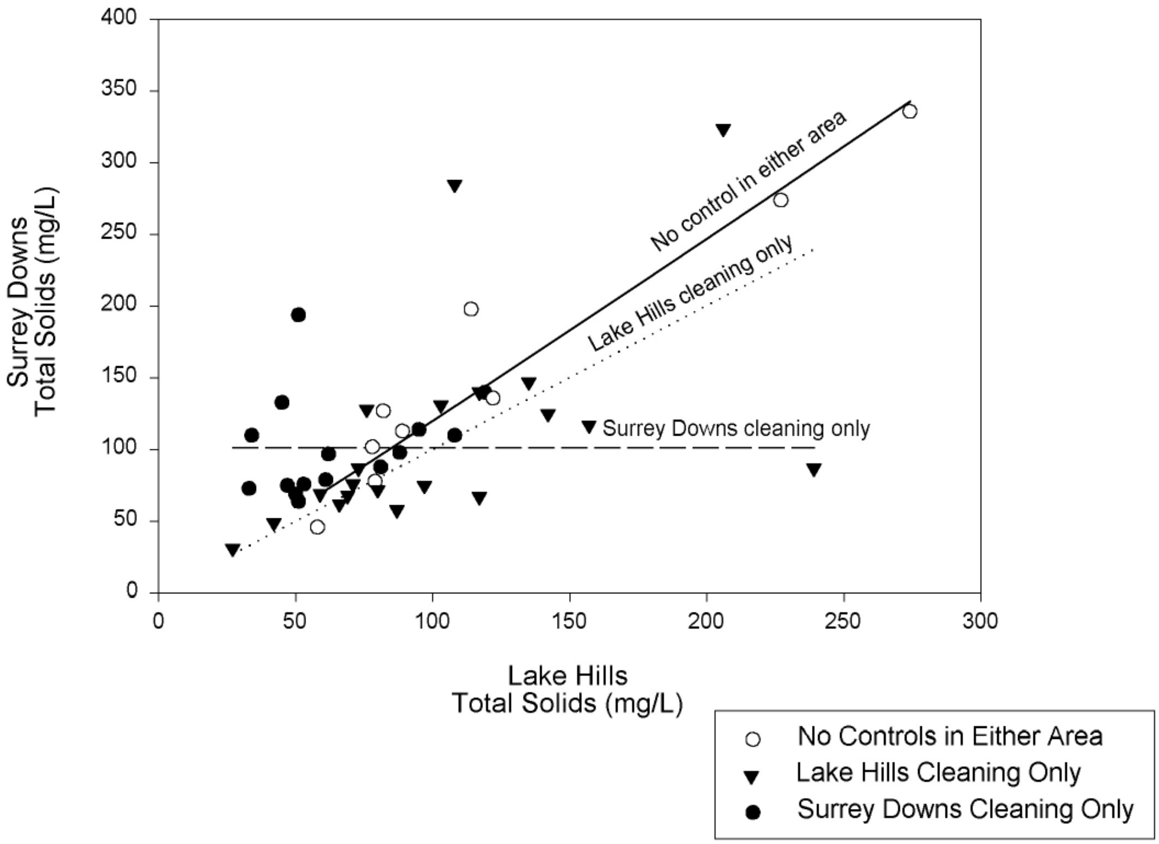

Figure 4. Final suspended solids plots for test and control sites, separated by treatment categories, and showing most appropriate regression relationships (data from Pitt 1985).

Recent Tests using Advanced Street Cleaning Equipment

Sutherland and Jelen (1996) have conducted more recent tests using a new style street cleaner that shows promise in removing large fractions of most of the street dirt particulates, even the small particles that are most heavily contaminated and most likely to be washed off streets during rains. The Enviro Whirl I, from Enviro Whirl Technologies, Inc. (Schwarze Industries) is capable of much improved removal of fine particles from the streets compared to any other street cleaner tested. This machine was also able to remove large fractions of the fine particles, even in the presence of heavy loadings of large particles. This is a built-in tandem machine, incorporating rotating sweeper brooms within a powerful vacuum head. Further field tests were conducted by the USGS and the WI Dept. of Natural Resources (Waschbusch 2003) at a highway test site in Milwaukee, WI. The following section describes some of the results of these tests.

The study area selected was one of the busiest stretches of roadway in the state of Wisconsin on interstate 894 in West Allis, just west of Milwaukee. Within the study area, a test basin and a control basin were monitored. The test basin had the street cleaning program implemented, while the control basin did not. The pavement on this stretch of freeway is concrete and was last resurfaced in the mid 1990s and was considered in generally good condition. The shoulders are concrete and were installed in the late 1970's.

The test basin had a drainage area of 4.56 acres, comprised of 4.31 acres of highway surface, 1.56 of which is shoulder, 2.67 is driving lane and 0.08 acres is median. In addition, 0.25 is non-highway grassy area. The control basin had a drainage area of 5.51 acres, comprised of 3.46 acres of highway surface, 1.45 of which is shoulder, 1.95 is driving lane and 0.06 acres is median. In addition, 2.05 is non-highway grassy area. Because of the slow speed of the street cleaner, only the highway shoulders were swept.

Samples of street dirt were collected from the outside shoulders using a 6-in. wide wand attached to a 9-gal. Milwaukee wet-dry vacuum cleaner. During each sample collection, the wand was pulled from the curb to the edge of the traffic lane twenty four times in each basin, twelve in each traffic direction, similar to the technique used by Pitt (1979) and Bannerman (1983). The street dirt samples were weighed, dried at 105°C and then reweighed. The samples were then sent to the University of Wisconsin Department of Geology Quaternary Laboratory in Madison, Wis., for sieving into 6.37-2.0 mm, 2.0-1.0 mm, 1-0.5 mm, 0.50-0.25 mm, 0.25-0.125 mm, 0.125-0.0625 mm, < 0.0625 mm size fractions. Two samples of the dirt collected by the Enviro Whirl street sweeper were also brought to the Wisconsin State Laboratory of Hygiene for Toxicity Characteristic Leachate Procedure (TCLP) analysis. Area velocity flow meters were the primary method used to measure the flow in the stormdrains. Flow composite water quality samples were collected using refrigerated automatic samplers.

Changes in dirt mass on the street surfaces before and after sweeping are shown in Figure 5. The average change in street dirt mass before and after sweeping at the test site was a 25 percent reduction. At the control site, the average change in street dirt mass on the same collection dates as the test site (although no street sweeping was occurring) was an increase of 160 percent. Figure 5 shows that the Enviro Whirl removed about half of the street dirt when the loading was about 500 lb/curb-mile, and reduced to about zero near 100 lb/curb-mile. This performance plot is very similar to the earlier regenerative air street cleaning tests conducted in Bellevue, and is much better than the conventional mechanical street cleaning equipment shown earlier.

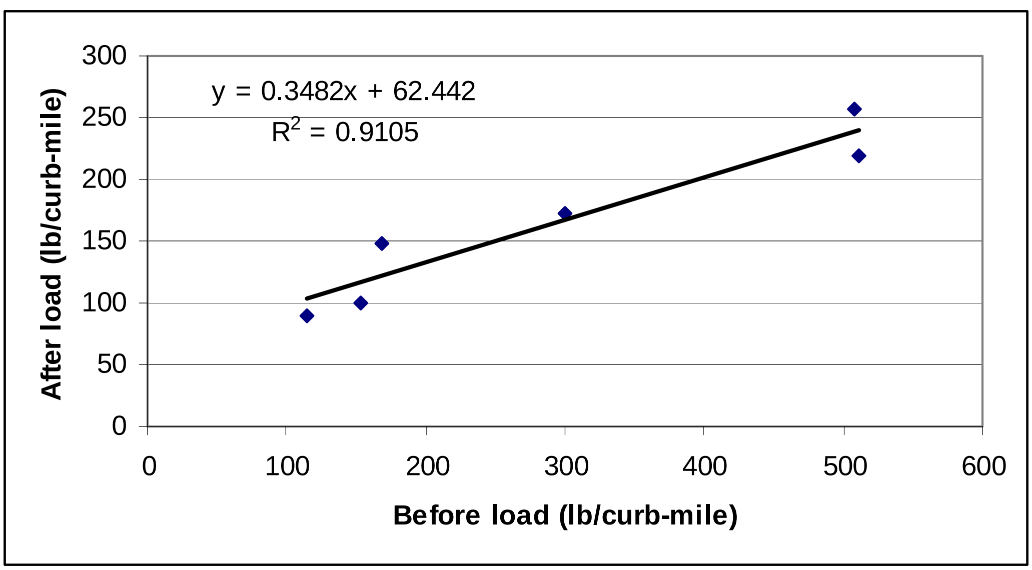

Figure 5. Before and after street dirt loadings during Enviro Whirl street cleaning tests in Milwaukee, WI (Waschbusch 2003).

The runoff particle size data from these test sites indicate that the highway runoff has larger particles than those typically seen at other USGS stormwater sites.

The findings of the study indicate that freeway sweeping with a high efficiency sweeper can be a good stormwater control practice for the reduction of stormwater pollutants from urban freeways. The study showed, at the 90% confidence interval, that there was a reduction in the total suspended sediment concentration in the runoff from a freeway section swept once per week with the EnvoroWhirl EV2 sweeper. Statistically, the suspended solids reduction was a 40% removal at a 80% confidence level. This was the first time that stormwater was statistically shown to benefit from street cleaning. This was likely due to the high efficiency of the street cleaning equipment used, especially for the small particle sizes, and the restricted study area that emphasized the paved area. It is expected that larger pollutant reductions could be obtained at a site having better roadway access for the street cleaning equipment.

A new generation of high efficiency street cleaners has recently been developed in Europe. Utilizing captive hydrology (recycling water), pavements are subjected to a deep cleaning using a high-pressure water-blasting system situated immediately in front of a powerful waste recovery vacuum. In a single pass, fine contaminants are blasted from the pavement and are collected in a debris container, along with the water, thus leaving the surface cleaned. There is no residual loading on the pavement after treatment with this type of equipment. The pavement is also left in a near-dry condition. Refer to these websites for more information:

http://buyersguide.dsvr.co.uk/profiles/a/associated_asphalt/ or
http://www.veegservice.nl/.

High efficiency street cleaners are appropriate for roadways that are sufficiently accessible, need fine particulate removal (<250 µm), and for which a sufficient frequency of cleaning can be maintained to achieve proper removals of street dirt. Mobility is a big advantage, as cleaning can be done where and when needed. This equipment is not currently available in the United States and it is much more expensive than traditional cleaners. It performs other tasks, such as porous pavement cleaning and rejuvenation, traditional pavement rejuvenation, paint removal, and surface layer stripping for overlays. A captive hydrology machine is currently being used as the pollutant control device for the controversial Cross Israel Highway.

Conclusions

Much information has been collected concerning the effects of street cleaning as a stormwater control practice. Unfortunately, there has been no statistically validated improvement in runoff quality associated with street cleaning until recently where newly available equipment has been tested. Conventional mechanical street cleaning equipment has been most effective in removing large particulates, while rains preferentially remove the small particles. The new equipment promises greater benefits because it can also remove the small particles, and can handle heavy loadings of larger debris. However, even with increased removal of fines, any street cleaning technology will be limited by the amount of the outfall pollutants originating from streets. In many areas, streets contribute less than half of the stormwater pollutants. Street cleaning equipment can be most effective in areas where the surface to be cleaned is the major source of contaminants. These areas include freeways, large commercial parking lots, and paved storage areas.

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