Article 121

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New Developments in Street Sweeper Technology

At one time, street sweepers were thought to have great potential to remove stormwater pollutants from urban street surfaces, and were widely touted as a stormwater treatment practice in many communities. Street sweeping gradually fell out of favor, largely as a result of performance monitoring conducted as part of the National Urban Runoff Program (NURP). These studies generally concluded that street sweepers were not very effective in reducing pollutant loads (USEPA, 1983).

The primary reason for the mediocre performance was that mechanical sweepers of that era were unable to pick up fine-grained sediment particles which carry a substantial portion of the stormwater pollutant load. In addition, the performance of sweepers is constrained by that portion of a street's stormwater pollutant load delivered from outside street pavements (e.g., pollutants that wash onto the street from adjacent areas or are directly deposited on the street by rainfall).

Street sweeping technology, however, has evolved considerably since the days of the NURP testing. Today, communities have a choice in three basic sweeping technologies to clean their urban streets:

- Traditional mechanical sweepers that utilize a broom and conveyor belt
- Vacuum-assisted sweepers
- Regenerative-air sweepers

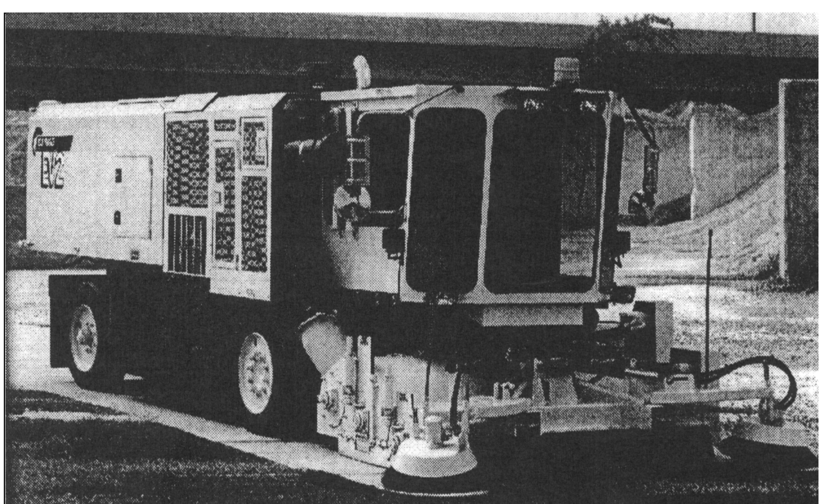

Figure 1: A Modern Waterless Vacuum-Assisted Street Sweeper

Traditional mechanical and vacuum-assisted sweepers use brushes to disturb street particles and a fine mist to moisten the pavement for dust control. Mechanical sweepers rely on a conveyor belt to carry the collected debris to a hopper. Vacuum-assisted sweepers suck up the loosened street particles with a vacuum and send them directly to the hopper. The most recent innovation has been a vacuum-assisted dry sweeper that uses a dry broom to loosen particles at the same time that a high-powered vacuum picks up nearly all particulate matter (Figure 1). The vacuum assisted dry sweeper, developed by Enviro Whirl Technologies, has the ability to pick up a very high percentage of even the finest sediment particles under dry pavement conditions and, unlike other sweepers, may work effectively in wet or frozen conditions (FHA, 1997). Regenerative air sweepers blast air onto the pavement surface to loosen particles and quickly vacuums them into a hopper. Sweeping can also be done in tandem—two successive passes are made over the street, the first by a mechanical machine followed by a vacuum-assisted or regenerative air machine.

The question naturally arises whether any of these technological improvements might actually translate into greater reductions of stormwater pollutants. Roger Sutherland and his colleagues have been assessing alternative sweepers in recent years in an attempt to answer this question. Roger has resorted to a modeling approach, since it is extremely difficult to design a controlled monitoring design in the field (i.e., while one can measure pollutant concentrations in runoff after sweeping, it is very hard to determine what the pollutant concentrations would have been if sweeping had never taken place).

As a surrogate, they employed a computer model, known as the Simplified Particulate Transport Model (SIMPTM), to evaluate potential sweeper performance. SIMPTM is a continuous stormwater model that simulates the accumulation and washoff of sediment and associated pollutants from urban land surfaces. Sutherland calibrated sediment accumulation and washoff rates for SIMPTM and used the model to estimate load reductions associated with street sweeping. Overall sweeper efficiency was derived in the model by multiplying a sweeping efficiency factor by the difference between the accumulated sediment and the residual sediment on the pavement after sweeping. This analysis is performed over a wide range of sediment particle sizes to arrive at an estimated overall efficiency. Some caution is needed in interpreting removal efficiencies derived from models, since the model may not fully incorporate all of the pollutant dynamics that occur in the real world.

Table 1 illustrates the potential sediment removal capability of five different sweepers, as estimated by the SIMPTM model (Sutherland and Jelen, 1997). Based on this analysis, it seems that the latest street sweeper technologies can pick up more street dirt and, what is more important, pick up finer-grained particles than their NURP-era predecessors (FHA, 1997). The vacuum-assisted dry and regenerative-air sweepers appeared to perform the best, although it is doubtful whether any sweeper could pick up all sediment particles from the street, as the modeling seems to imply.

While the model results suggest that sweeper improvements can pick up finer particles, debate continues as to whether this would materially improve their overall pollutant removal performance. Some of the key issues in the sweeper effectiveness debate are:

- How often do streets need to be swept?
- What kinds of streets are most appropriate for a sweeping program?
- What is the effect of "washon" of sediment and pollutants from uphill pervious surfaces?
- What percent of the annual pollutant load is associated with wetfall that sweeping misses?

Sweeping Frequency

How often should streets be swept? The answer to this question probably depends on what region the streets are located. The frequency and intensity of rainfall are the key variables that control how streets need to be swept to obtain a desired removal efficiency. Sutherland has evaluated this issue in the Pacific Northwest to determine an optimum sweeping frequency (Table 2). From the standpoint of pollutant removal, the optimum sweeping frequency appears to be once every week or two. More frequent sweeping operations yield only a small increment in additional removal. The model suggests that somewhat higher removal could be obtained on residential streets, compared to more heavily traveled arterial road.

What about "Washon"?

Street sweeping can do little to remove sediments that "washon" to the street during a rainfall event from upgradient surfaces. The significance of sediment washon has been widely debated among stormwater professionals. Some argue that sediments are transported only during the largest storm events and should not constrain street sweeper effectiveness during most of the year. Others suggest that smaller, high intensity storms do contribute a significant percentage of the annual sediment load.

The debate over washon is very important in evaluating potential street sweeper performance. If a large amount of sediment washes onto street surfaces during a storm, it doesn't matter how clean the street surface was before the storm. Source area monitoring by Dr. Robert Pitt in two test watersheds in Toronto, Canada and Milwaukee, Wisconsin showed that significant

Table 1: Relative Sweeper Effectiveness—Expressed in Terms of Residual Sediment Remaining After Sweeping (Lbs per Paved Acre) (Southerland and Jelen, 1997)

Sediment particle size (microns)	Street Sweeper Technology: NURP-era mechanical	Newer mechanical	Tandem sweeping	Regenerative air	Vacuum assist.-dry
< 63	9.0	5.8	2.0	0.0	0.0
< 125	12.0	5.8	2.0	0.0	0.0
< 250	18.0	5.3	2.3	0.9	0.0
< 600	18.0	2.5	2.3	1.9	0.0
< 1,000	12.0	0.4	0.8	0.7	0.0
< 2,000	4.2	0.5	0.6	0.7	0.0
< 6,370	3.6	0.3	0.5	0.0	0.0
> 6,370	1.8	0.0	0.0	0.0	0.0

amounts of runoff from pervious surfaces can occur for rains as small as a half-inch (Pitt, 1994). Clearly, this phenomenon is directly related to amount and intensity of rainfall, the slope of the pervious surface, and the infiltration capability of the underlying soils.

While the debate continues, one important point stands out. If the entire site is paved, and there are no upgradient areas, washon load cannot occur. Consequently, when looking at street sweeper programs, the higher the impervious area, the more effective street sweeping is likely to be. Conversely, in urban areas with a large percentage of imperviousness occurs as rooftop area, the overall pollutant load removal from street sweeping will be less.

Wetfall Contributes to Annual Pollutant Load

One of the apparent gaps in the Pacific Northwest research is how much annual pollutant load is missed by sweepers because it was deposited as wetfall and therefore cannot be swept. For some pollutants, wetfall can account for a substantial fraction of the annual load. Table 3 compares the annual wetfall load to the total annual stormwater runoff load for some key pollutants for the Mid-Atlantic region.

Clearly, wetfall is an important delivery source for several pollutants such as total solids, total nitrogen, chemical oxygen demand, and extractable copper. Consequently, these pollutants may not be effectively controlled by a street sweeping program. It should be noted that the wetfall data presented in Table 3 is not from the Pacific Northwest, where wetfall may be less important.

Port of Seattle Considers Street Sweeping as Alternative Stormwater Practice

A recent study by Kurahashi and Associates (1997) evaluated the feasibility of using a street sweeping program as an alternative to underground wet vaults to provide stormwater management for expansion of a marine cargo container yard. The Port of Seattle was planning a major expansion to its existing marine cargo container yard and wanted to evaluate whether or not new high efficiency street sweepers would be comparable to underground wet vaults in terms of removal efficiency.

Kurahashi used Sutherland's modeling technique and sediment accumulation data collected over a two-month period at nine locations within the terminal to calibrate the computer model. The calibrated model was then used to simulate the accumulation of sediment and associated pollutants on the site and the effect of street sweeping for pollutant load reduction. Wet vault pollutant removal efficiencies were estimated using a modification of Stoke's Law for the various particle sizes of the collected sediments.

Table 4 documents the results of the simulation. It was concluded that high efficiency sweeping on a weekly basis could provide comparable removal rates to wet vaults. From the viewpoint of the owner, the most significant finding of the study was the substantial cost savings street sweeping programs had over wet vaults. The anticipated life cycle cost of the sweeping programs was estimated to be about two million dollars. This can be compared to an estimated 18 million dollar price tag to construct underground wet vaults.

Table 2: Average Expected Sediment Load Reduction as a Function of Sweeping Frequency for Two High-Efficiency Sweeper Technologies* (Southerland and Jelen, 1997)

	Sweeping Frequency			
• Sweeper technology	Monthly	Bi-weekly	Weekly	More than once per week
Residential street				
• Regenerative air	42%	53%	64%	71%
• Vacuum assist.-dry	50%	63%	78%	88%
Major arterial road				
• Regenerative air	15%	18%	21%	22%
• Vacuum assist.-dry	50%	60%	77%	79%

* Expected load reduction based on computer model simulation using calibrated accumulation and washoff rates in Portland, Oregon.

Summary

Stormwater professionals are constantly seeking new practices to reduce urban stormwater pollution. Until recently, street sweeping was perceived as an ineffective tool. Improvements in the design and operation of street sweepers may be changing this perception. The experience in the Pacific Northwest suggests that street sweeping might be reconsidered, particularly in high density urban areas where the cost of alternative underground stormwater quality treatment is extremely high.

Some concerns need to be addressed before street sweeping is fully resuscitated as a stormwater practice. For example, more research is needed in other regions of the country to determine optimal sweeping frequency. Clearly, regions that have defined dry seasons would probably benefit the most from sweeping accumulated sediments before the onset of the next rainy season. Conversely, regions that have frequent high intensity thunderstorms may benefit less from sweeping since they are more likely to experience sediment washon. Additional wetfall research is needed to establish more representative pollutant removal efficiencies for street sweepers. Lastly, operational problems that diminish sweeper performance in the real world, such as speed, parked cars, and the ability to get at curb sediments, need to be explored. Roger Sutherland is currently involved in a field test of sweepers on Wisconsin highways that should shed more light on these concerns.

—RAC

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Table 3: Comparison of Total Annual Wetfall Load to Total Annual Stormwater Runoff Load for Several Common Pollutants in the Mid-Atlantic Region (MWCOG, 1983)

Pollutant	Annual wetfall load for urban/ suburban areas (lbs/acre)	Annual stormwater runoff load (lbs/paved acre)	% of annual wetfall load to runoff load for paved surfaces
Total solids	50	209	24
Total nitrogen	5.3	15.5	34
Total phosphorus	0.2	2.33	8.6
COD	92.5	504	18.4
Copper	0.5	4.0	12.5
Zinc	0.75	10.8	6.9
Lead	0.04	2.2	1.8

Table 4: Comparison of Pollutant Load Reduction of High Efficiency Street Sweepers to Wet Vaults (Kurahashi and Associates, Inc., 1997)

Parameter	Weekly street sweeping (% removal)	Wet vaults (% removal)
Total suspended solids	45-65	75-90
Total phosphorus	30-55	35-45
Total lead	35-60	65-80
Total zinc	25-50	35-45
Total copper	30-55	35-45