Chapter 9

Contrary to Conventional Wisdom, Street Sweeping Can be an Effective BMP

Roger C. Sutherland and Seth L. Jelen

Recent work suggests that street sweeping programs can be optimized to significantly reduce pollutant washoff from urban streets. The abilities of several different sweeping technologies to pick up accumulated sediment of various sizes were evaluated. In addition, the expected reductions in average annual washoff loads were evaluated using calibrated model simulations of the Simplified Particulate Transport Model (Sutherland and Jelen, 1993) for two stormwater sites in Portland, Oregon.

Results suggest that reductions of up to 80% in annual TSS and associated pollutant washoffs might be achieved using bimonthly to weekly sweepings. Frequencies and associated reductions would vary with patterns of precipitation sediment accumulation and resuspension, but it is clear that sweeping technology can have a profound effect on sweeping results and achieve meaningful runoff quality benefits.

These results stand in sharp contrast to earlier conclusions dating back to December 1983. At that time, street sweeping had been found to be generally ineffective as a technique for improving the quality of urban runoff. This conclusion resulted from the United States Environmental Protection Agency sponsored Nationwide Urban Runoff Program (NURP) in which over 30 million dollars was expended in an intensive three-year investigation of urban runoff quality at 28 locations throughout the United States (USEPA, 1983).

© *Advances in Modeling the Management of Stormwater Impacts - Vol. 5* W. James, Ed.
Pub. by CHI, Guelph, Canada 1997. ISBN 0-9697422-7-4. Fax: +519 767-2770

9.1 Previous Research

The NURP studies of street sweeping effects on stormwater quality (USEPA,1983) concluded that street sweeping was largely ineffective at reducing the event mean concentration (EMC) of pollutants in urban runoff. This conclusion was reached mainly because the street sweepers tested were not able to effectively pick up very fine accumulated sediments that can often be highly contaminated.

In general, street sweeping equipment of the era was unable to effectively pick up the very fine, highly contaminated, sediments that accumulate on impervious areas such as streets, driveways and parking lots. These same sediments, located on paved areas that are directly connected to a city's storm drainage system, have been identified over and over again as the primary source of urban nonpoint pollutants entering the receiving waters of the United States.

Broom sweepers of that era removed litter and large dirt particles well, but contaminants are known to concentrate primarily in the fine particle sizes (e.g. less than 63 microns). However, these finer and much more pollutant-laden particles were largely left behind, and moreover, they were left exposed to be even more readily entrained in washoff since their armoring shelter by larger sediment particles was removed.

However, recent studies by the authors over a period of four years show clearly that the NURP conclusions from the early 80's are no longer valid today. This is largely because of the considerable increase in street sweeping's effectiveness at removing the smallest particles. Examples of this improvement include the following:

1. Even most mechanical sweepers (i.e. broom and conveyor belt) now available are much more effective at picking up fine sediments.
2. Tandem sweeping operations (i.e. mechanical sweeping followed immediately by a vacuum-assisted machine) have been found to be even more effective at fine sediment pickup.
3. Regenerative air sweepers have been refined considerably since their infancy during the NURP era, have also been found to be effective at fine sediment pickup.
4. A revolutionary new vacuum-assisted dry sweeper has greatly advanced the technology of fine sediment pickup and containment.

These considerable advances in sweeping technologies result in a need to re-evaluate the NURP conclusions and incorporate new performance data and benefits that result from more demanding and water-quality-driven sweeping programs.

9.2 Sweeping Technologies

The pickup performance for the NURP era sweepers show typical values based on the authors' previous analysis (Sutherland, 1990) of the Bellevue, Washington NURP data, as summarized by Pitt (1985). Having been a consultant to the City of Bellevue during the NURP study, the author had direct access to the street sweeper pickup performance data collected as part of that study. The sweeper tested at that time was a *Mobil* standard mechanical broom street sweeper, probably manufactured around 1978. It provides the baseline against which several modern street sweeping technologies are compared for immediate pickup rate and expected long-term washoff load reduction.

Against this, the performance of a newer mechanical (i.e. broom and conveyor) sweeper was compared, in order to establish the level of improvement achieved in types of sweepers still in wide use. Data for this comparison was obtained when the authors measured the pickup performance of a newer mechanical sweeper, which was a 1988 *Mobil*, as a result of a Portland study mentioned later.

Research by the authors has identified three promising technologies that may provide significant improvements in performance beyond that observed for NURP era or mechanical sweepers. For each, the sediment pickup from sweepings by each technology was measured in the field by the authors under a variety of conditions. Resulting removals were obtained for each of eight particle size ranges. These show significantly greater removals for each of these new technologies than those typical for sweepers from the early 1980's.

The first technology is the use of a tandem sweeping operation. A tandem operation involves two successive cleaning passes, first by a mechanical (i.e. broom and conveyor belt) sweeper, then immediately followed by a vacuum-assisted sweeper. The pickup performance of a tandem operation using the *Mobil* broom sweeper followed by a *TYMCO* vacuum sweeper was monitored for over a year in a medium-density residential area located in Southeast Portland, Oregon. The detailed description of this study and its results can be found in HDR (1993) and were briefly summarized in Alter (1995).

The second technology is the stand-alone use of a regenerative air sweeper. Regenerative air sweepers blow air onto the pavement and immediately vacuum it back in order to entrain and filter out accumulated sediments. Regenerative air machines were just in their infancy during the NURP era, and to the author's knowledge were not extensively tested at any of the NURP sites. Regenerative air sweepers are generally considered to be good at removing fine sediment, if the accumulated loading is not too great. The authors measured the pickup performance of the Elgin Crosswind regenerative air sweeper in and near Seatac International Airport on April 21, 1995.

The third technology is the stand-alone use of a new, highly effective, vacuum-assisted dry sweeper called the Enviro Whirl I developed and manufactured by Enviro Whirl Technologies Inc., located in Centralia, Illinois. This sweeper applies technology developed and still used to remove spilled coal and coal dust along railroad tracks. The technology has also been applied to clean similar materials from industrial sites where complete removal without leakage of airborne particles is important.

From these demands have evolved a technology that is extremely efficient at removing the finest particles and preventing their escape into the air. In contrast, most other units, especially mechanical types, trail a visible cloud of dust behind in the air and on the street.

The Enviro Whirl I combines the important elements of tandem sweeping into a single unit. It uses rotating sweeper brooms within the powerful vacuum head to provide both mechanical and aerodynamic particulate removal. Data comparing the sweeping performance of this technology to others was measured by the authors on an April 24, 1995 test prepared by the City of Las Vegas, Nevada (during an air quality conference) and in Centralia, Illinois during September 1995.

This data reveals marked improvements in the street sweeping technology that result in much more effective pickup of accumulated sediments. Using the NURP-era broom sweepers as a baseline, performances are compared for improved mechanical sweepers and promising sweeping technologies. As a result, it becomes clear that street sweeping is now capable of removing significant pollutant loads from urban surfaces and effecting significant reductions in urban pollutant washoff.

9.3 Evaluation Procedure

The ability of street sweeping to reduce overall pollutant washoff loads depends on several things. First is the street sweeper's innate ability to remove accumulated sediment. Another is the environmental dynamics of sediment accumulation and resuspension, and of sediment washoff during storm events plus suspended sediment removal by downstream water quality controls.

The Simplified Particulate Transport Model (SIMPTM) can accurately simulate this complicated interaction of accumulation, washoff, and street sweeper pickup that occurs over a period of time (Sutherland, and Jelen, 1993). The remainder of this chapter presents the issues involved in applying the SIMPTM model to successfully evaluate the overall effectiveness of street sweeping technologies and programs as a water quality management practice. The following are addressed:

1. how to model street sweeper pickup performance;
2. how the SIMPTM model compares to real pickup performance data;
3. how various technologies can be compared using their calibrated SIMPTM model parameters; and
4. how technologies can be best compared using their average annual pollutant reductions, as simulated for two example stormwater basin sites in Portland, Oregon.

9.4 Pickup Performance Model

The street sweeping component of the SIMPTM model was based on the results of Pitt's street sweeping study conducted for the USEPA in San Jose, California (Pitt, 1979). This model was confirmed in additional studies conducted in Alameda County, California (Pitt and Shawley, 1982) and in Washoe County, Nevada (Pitt and Sutherland, 1982).

These studies found that sweeping removes little, if any, material below a certain base residual which was found to vary by particle size. Above that base residual, the street sweeper's removal effectiveness was described as a straight line percentage which varied by particle size.

Figure 9.1 illustrates the street cleaning component and equations used by SIMPTM. For each of eight size groups, the amount removed (*Prem*) is related linearly to the initial accumulation (*Po*) using two parameters - a base residual (*SSmin*) and a sweeping efficiency (*SSeff*):

$$Prem = SSeff \times (Po - SSmin) \; for \; Po > SSmin$$

Therefore, to describe a unique street sweeping operation, one simply needs to know the operations *SSmin* and *SSeff* values for each of the eight particle size ranges simulated by SIMPTM. Note that *SSeff* is dimensionless, while that for *SSmin* must match that for accumulation, usually either pounds per curb mile or pounds per paved acre. The initial accumulation *(Po)* is a simulated parameter, or may be measured in the field (from a similar surface near that swept) in order to evaluate the *SSmin* and *SSeff* parameters.

Figure 9.2 shows an example of how this model component actually compares to real pickup performance data for each of the eight particle size groups. The plotted points are the data obtained from monitoring the tandem street sweeping operation on Portland's Sellwood drainage basin (HDR, 1993). Note that the correlation coefficients (R^2) for the fits of the eight particle size

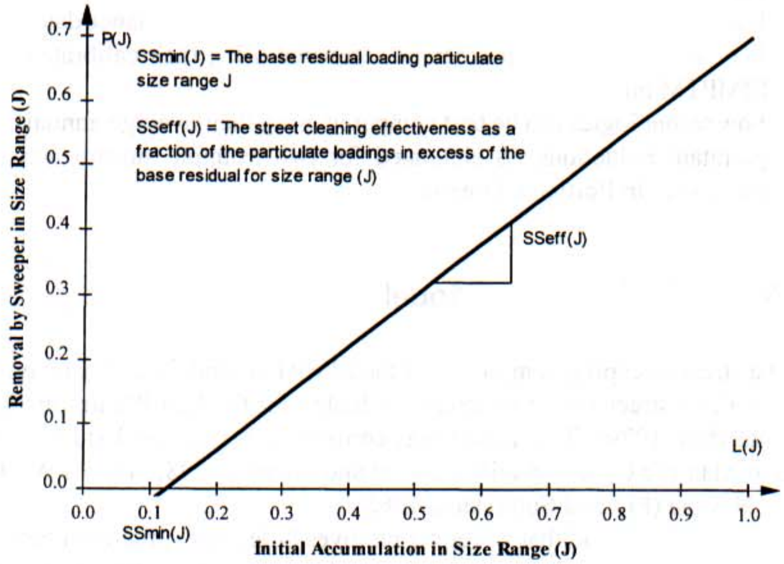

Figure 9.1 Street sweeping model component of SIMPTM.

groups ranged from 94.3% to 99.9%, so the model is doing an excellent job of reproducing the observations. These high R^2 values were typical of all of the model fits to the pickup data from the various sweeping technologies.

Table 9.1 compares the SSmin sweeping parameters calibrated to model each of the five sweeping technologies. It shows dramatic improvements in reducing residual loadings for all the newer technologies when compared to the NURP sweepers. While both tandem sweeping and the Elgin Crosswind regenerative air are very impressive, the across-the-board zero residual loadings for the Enviro Whirl I is the best possible.

Table 9.2 compares the corresponding marginal sweeping rate, SSeff, for sweeping loads that exceed the threshold SSmin. They were also calibrated to model each of the five sweeping technologies. The results mirror those for the SSmin parameter, and show impressive removal efficiencies above the residential loadings. Dramatic improvements are again evident since the NURP era. It must be recognized that this table shows only marginal removal rates. The overall removals must also incorporate the residual loading that always remains after sweeping. Thus although the rates of the Elgin Crosswind (regenerative air) and the Enviro Whirl I for the finer particle size groups may not be impressive, their residual loadings are very low, or even zero, resulting in overall removal efficiencies that are essentially the same as the rate shown. Other technologies with larger SSmin's would be significantly less efficient.

Table 9.1 Calibrated SSmin sweeping residuals for alternative technologies.

Particle Size Group	Size Range *microns*	*Street Sweeping Technology* NURP Mech.	Newer Mech.	Tandem Sweeping	Regenerative Air	Enviro-Whirl
1	<63	9.0	5.8	2.0	0.0	0.0
2	-125	12.0	5.8	2.0	0.0	0.0
3	-250	18.0	5.3	2.3	0.9	0.0
4	-600	18.0	2.5	2.3	1.9	0.0
5	-1000	12.0	0.4	0.8	0.7	0.0
6	-2000	4.2	0.5	0.6	0.7	0.0
7	-6370	3.6	0.3	0.5	0.0	0.0
8	>6370	1.8	0.0	0.0	0.0	0.0

Data from various studies, minimum pounds per paved acre remaining after street sweeping.

Table 9.2 Calibrated SSeff - marginal sweeping efficiencies for alternative technologies.

Particle Size Group	Size Range *microns*	*Street Sweeping Technology* NURP Mech.	Newer Mech.	Tandem Sweeping	Regenerative Air	Enviro-Whirl
1	<63	44%	100%	93%	32%	70%
2	-125	52%	100%	95%	71%	77%
3	-250	47%	92%	93%	94%	84%
4	-600	50%	57%	89%	100%	88%
5	-1000	55%	48%	84%	100%	90%
6	-2000	60%	59%	88%	100%	91%
7	-6370	78%	81%	98%	94%	92%
8	>6370	79%	70%	87%	92%	96%

Data from various studies, marginal removal rate *only* for accumulations *greater* than SSmin.

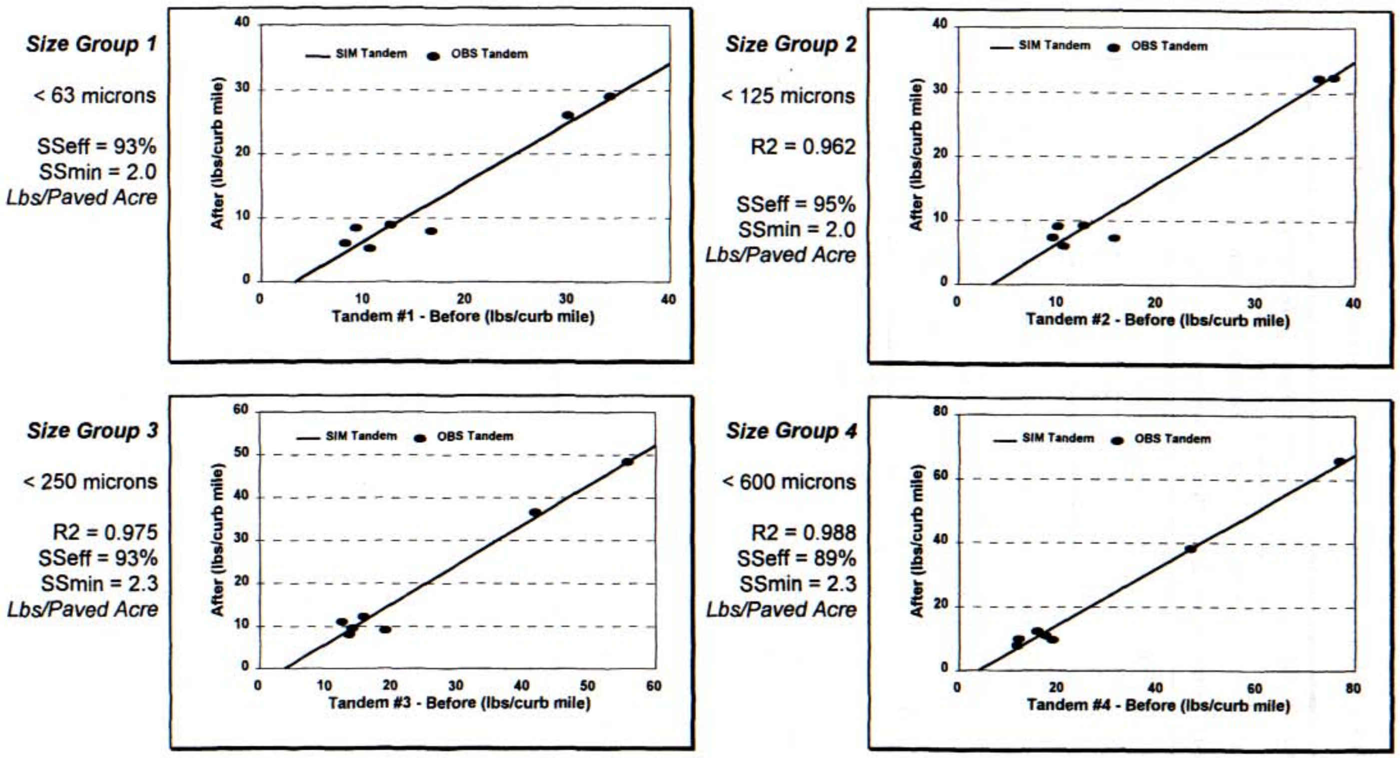

Figure 9.2 Tandem street sweeping model in SIMPTM, size groups 1-4.

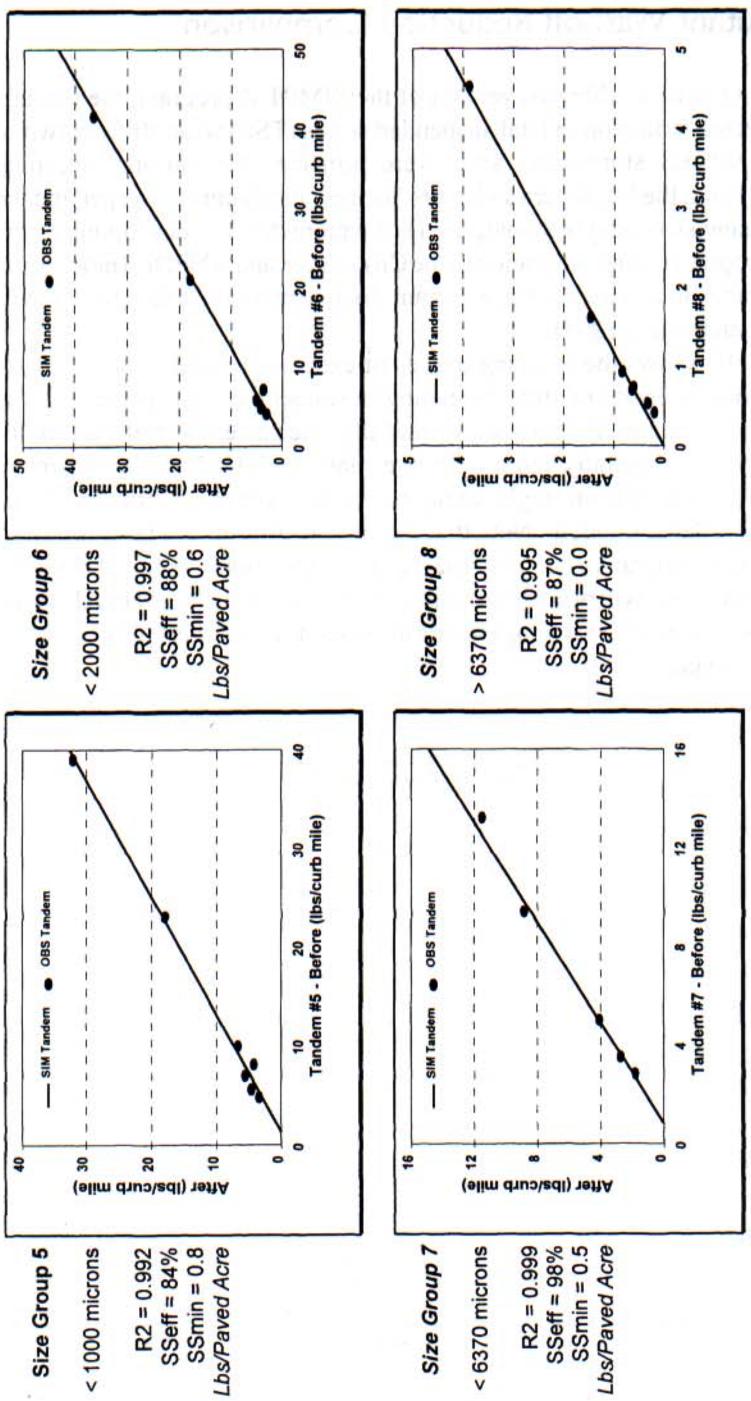

Figure 9.2 (continued) Tandem street sweeping model in SIMPTM, size groups 5-8.

9.5 Pollutant Washoff Reduction Comparison

Working with a calibrated version of the SIMPTM program, the average annual expected reduction in total suspended solids (TSS) washoff from two of Portland's NPDES stormwater sites were projected for varying sweeping frequencies using the NURP era sweepers, the new mechanical sweeper and the three promising sweeping technologies. (For a more detailed description of the SIMPTM program and its calibration to the City of Portland's NPDES monitoring sites, the reader is referred to the program documentation or the study report (Sutherland and Jelen, 1995).

Figure 9.3 shows the resulting curves of expected annual washoff reductions for varied intensity of street sweeping in residential areas by each of the alternative technologies. It clearly shows that all of the newer sweeping technologies would be significantly more effective than the NURP era sweepers in reducing TSS washoff from single family residential areas with curb and gutter drainage in Portland, Oregon. Note that the Enviro Whirl is the best, followed by the Elgin regenerative air and the tandem operation. Even the newer mechanical sweepers will provide reductions in the 20% to 30% range. Also note that weekly or biweekly sweeping appears to be optimum for this type of land use in Portland, Oregon.

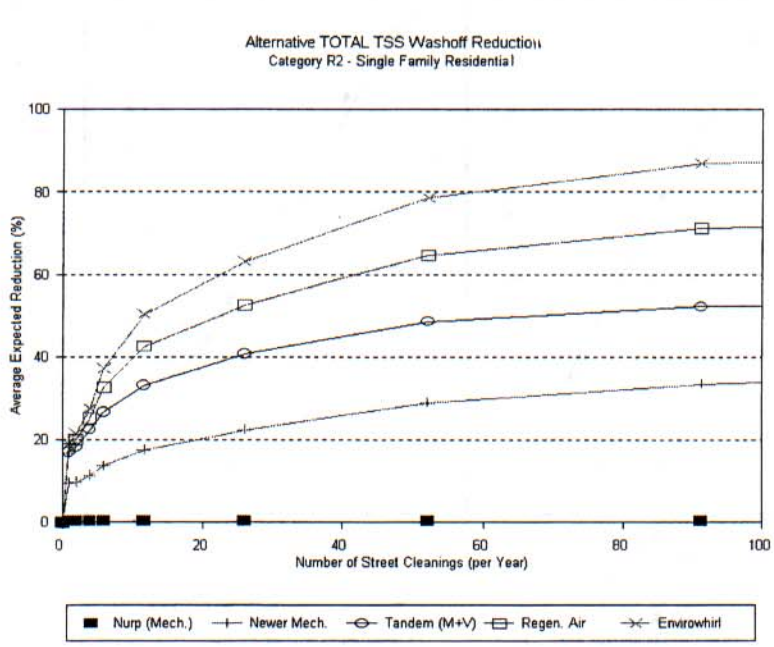

Figure 9.3 Alternative washoff reductions by sweeping residential streets.

Figure 9.4 shows how results change significantly when sweeping is applied to major arterials instead. It even more clearly demonstrates the superiority of the Enviro Whirl I sweeper in reducing TSS washoff from highly impervious major arterials with curb and gutter drainage in Portland, Oregon. The Elgin regenerative air provides some TSS reduction, whereas the other technologies appear to be largely ineffective on this type of land use. This same land use was found to provide the highest pollutant washoffs on a pound per paved acre basis of the six homogenous land uses studied (Sutherland and Jelen, 1995).

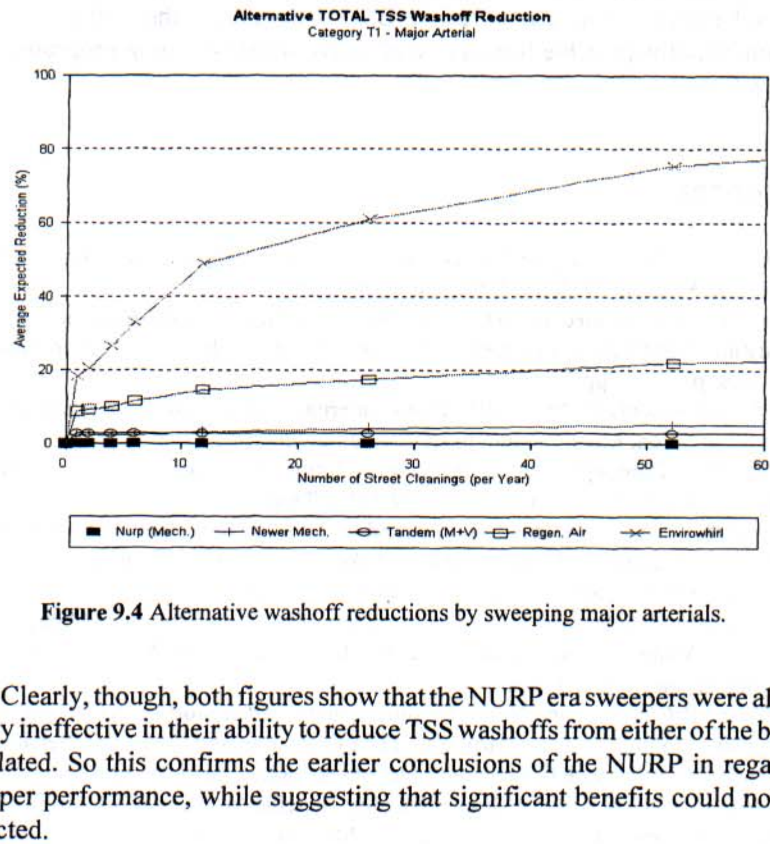

Figure 9.4 Alternative washoff reductions by sweeping major arterials.

Clearly, though, both figures show that the NURP era sweepers were almost totally ineffective in their ability to reduce TSS washoffs from either of the basins simulated. So this confirms the earlier conclusions of the NURP in regard to sweeper performance, while suggesting that significant benefits could now be expected.

9.6 Conclusions

Contrary to conventional wisdom, this chapter clearly demonstrates that street sweeping can be an effective best management practice (BMP). The actual pollutant reduction effectiveness of any given street sweeping operation will depend on characteristics of land use, precipitation, and the accumulation dynamics of contaminated sediments.

The SIMPTM program has been used successfully to account for all of those issues in order to project the potential performance of various street sweeping programs. It was used to evaluate the optimal level of effort to be implemented. Finally, it was used to evaluate the effect of employing updated technologies. In this regard, the Enviro Whirl I sweeper was found to be far superior to the other promising technologies reviewed.

Given the increased concern about the water quality related impacts of urban stormwater pollution throughout the country and the difficulty of identifying and implementing cost-effective BMP's to address them, the pollutant reduction benefits possible from a cost effective street sweeping program must be re-evaluated.

References

Alter, W., 1995. "The Changing Emphasis of Municipal Sweeping . . . May be Tandem," American Sweeper, Volume 4, Number 1, p6. 3pp.

HDR, Inc., 1993. Combined Sewer Overflow SFO Compliance Interim Control Measures Study and Final Report, prepared for the City of Portland, Bureau of Environmental Services, p17-1. 19pp.

Kurahashi and Associates, Inc., 1995. Seatac International Airport Stormwater Quality Characterization, Memorandum to HDR Engineering Inc., 53pp.

Pitt, R.E., 1979. Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices, EPA 600/2-79-161, 270pp.

Pitt, R.E.,1985. Characterization, Sources and Control of Urban Runoff by Street and Sewerage Cleaning, Contract Number R-80597012, U.S. Environmental Protection Agency, Offices of Research and Development, 467pp.

Pitt, R.E. and G. Shawley, 1982. A Demonstration of Nonpoint Pollution Management on Castro Valley Creek, Alameda County Flood Control and Water Conservation District, Hayward, California, 173pp.

Pitt, R.E. and R.C. Sutherland,1982. Washoe County Urban Stormwater Management Program - Volume II Street Particulate Data Collection and Analysis, Prepared by CH2M Hill for Washoe Council of Governments, Reno, Nevada, 124pp.

Sutherland, R.C., 1990. Water Quality Related Benefits to the City's Current Street Cleaning Program - Phase 2 Results, letter to Ms. Lori Faha, City of Portland, Bureau of Environmental Services, 12pp.

Sutherland R.C. and S.L. Jelen,1993. Simplified Particulate Transport Model-Users Manual, Version 3.1, 66pp.

Sutherland, R.C. and S.L. Jelen, 1996. Sophisticated Stormwater Quality Modeling Is Worth the Effort. Published in Advances in Modeling the Management of Stormwater Impacts, Edited by Dr. William James, Ann Arbor Press, p1-14.

U.S. Environmental Protection Agency, Water Planning Division, 1983. Results of the Nationwide Urban Runoff Program, Volume 1 - Final report, 186pp.