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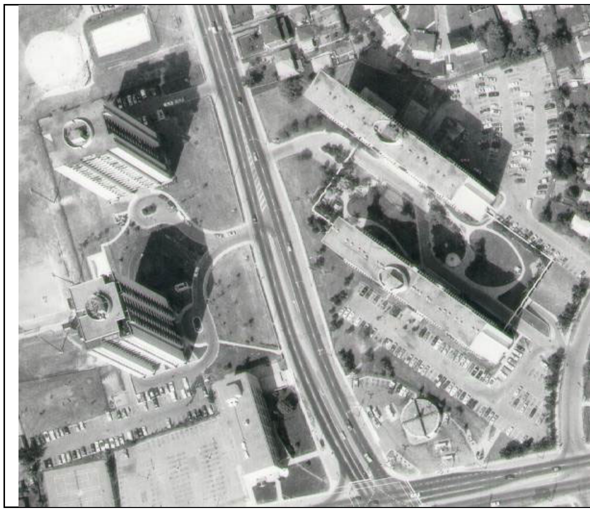
# Cleaning of Parking Lots, Loading Docks, and Storage Areas
## Notes for WinSLAMM Modifications

Contents



### Introduction
This white paper describes data and proposed methods that can be used to modify WinSLAMM to include pavement cleaning at paved parking and storage areas. Street and parking lot cleaning equipment are quite different, but this proposed model modification assumes that the smaller pavement cleaners have similar efficiencies as the larger street cleaners. Summaries of re-distribution of street dirt across streets during street cleaning tests include some unit area performance data that are compared to measured sediment loading on paved areas. Discussions of how a paved site can be evaluated include the need to subdivide the area based on the presence of curbs, driving lanes, and obstructions. Several numeric examples are also presented showing how these calculations can be used in calculating the benefits of cleaning pavement.

### Parking Lots at Different Land Uses
Parking lot cleaning with a variety of equipment is common, mostly in commercial and institutional areas, and rarer in industrial and residential areas. Many apartments have parking areas near the buildings without large open areas for parking, while industrial areas can have small to large open employee parking areas, with possibly large trucking loading docks or storage areas. The following are photographs of example parking areas for different land uses.

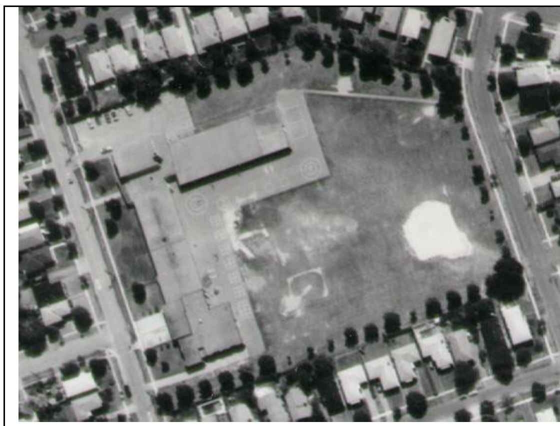


Apartments with parking along edges of parking areas and an open parking area.

Commercial parking lots

Industrial parking areas near buildings for employees and large truck parking area.

Institutional parking areas; small parking area for staff at elementary school and large parking area (with curbed dividers) for students at junior college.

### Parking Lot Pavement Cleaners

The street cleaning information in WinSLAMM is based on modern full-size broom, vacuum, and regenerative air street cleaners, originally based on the Pitt (1979) and later tests, and updated with the more recent Madison tests using the equipment below (the blue unit is in Moscow in front of the Palace of Engineers, shown just for kicks).




Full-size modern street cleaners (broom, vacuum, and regenerative air)

It is rare for these full-sized street cleaners to be used in parking lots or storage areas, due to their poor maneuverability and the need to transport between distant jobs by the cleaning contractors which usually requires trailers. The following are examples of smaller cleaners designed for parking lots, from the Haaker Equipment Company (https://haaker.com/products/parking-lot-sweepers/). The smaller cleaners are more maneuverable and can be transported on trailers.

Nite-Hawk Raptor II

Nite-Hawk Osprey II

| | |
|---|---|
| <br>Advance SW8000 | <br>Madvac® LS175 |
| <br>Madvac LN50 Vacuum Litter Collector | <br>Madvac® PS300 Pedestrian Vacuum Litter Sweeper |

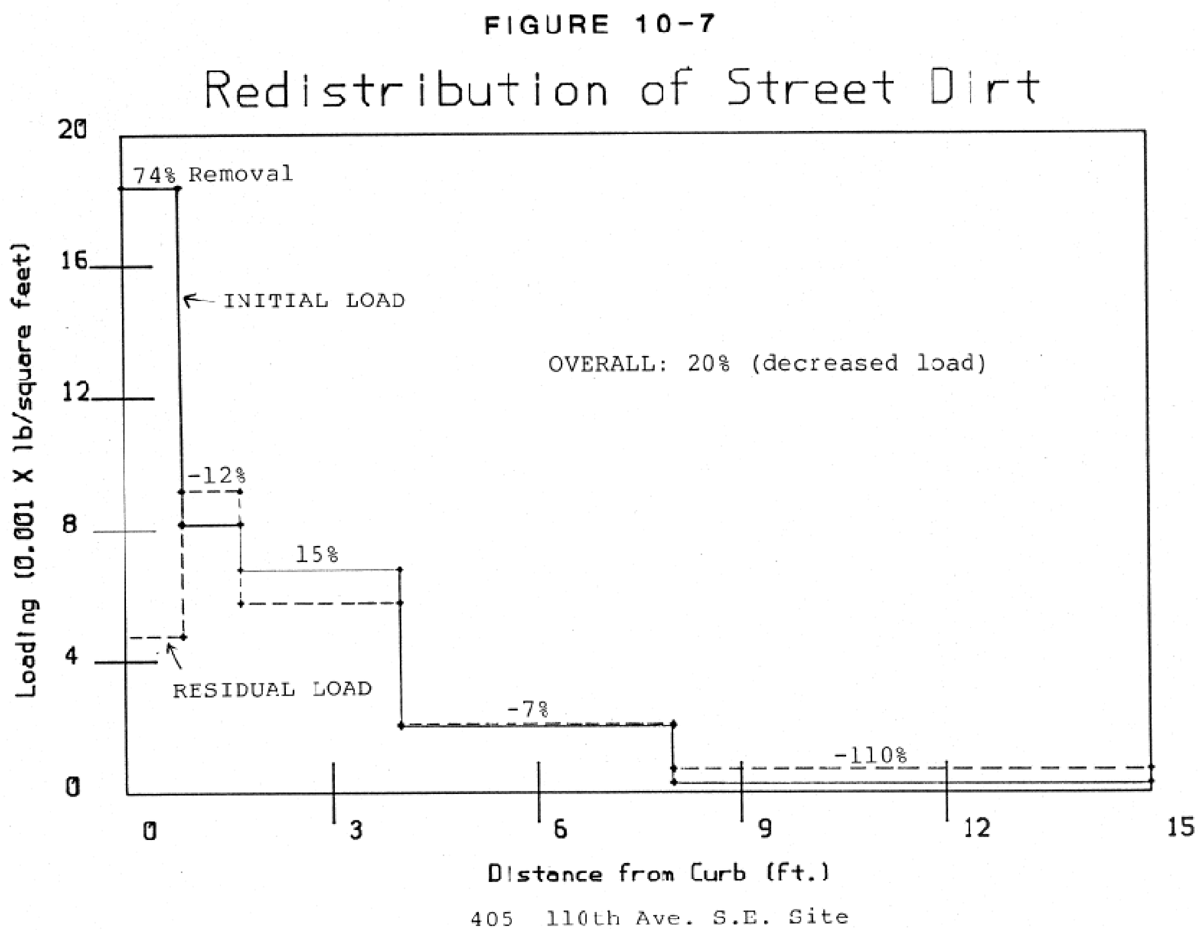
Modern small pavement cleaners (https://haaker.com/products/parking-lot-sweepers/).

As noted above, the street cleaning performance data available are based on full-scale street cleaners on city streets, while parking lot and other large paved areas are usually cleaned using smaller pavement cleaners, but with greater maneuverability. It may be possible to estimate the benefits of cleaning these other paved areas with the following assumptions: the performance of the new small cleaners is similar to the full-sized modern street cleaners tested, and maneuverability restrictions (such as not being able to clean into corners, are related to parked car presence. The following discusses how WinSLAMM could be modified to address pavement cleaning.

## Street Cleaning along Curbs and Distribution of Pavement Particulates

Paved parking lots and storage areas have several characteristics that differ from streets, where street cleaning data exists. The faster vehicle speeds on streets create turbulence which tend to blow street dirt towards the street edges. This moving material is somewhat obstructed by the parked cars, although some continues to move under the vehicles towards the curb. Also, in most residential areas, the streets are not completely full of parked cars. In the absence of parked cars, the blown street dirt migrates to the curbs. In parking lots or storage areas, the speed of the vehicles is much less with possibly less material moving towards the curb edges.

During my street cleaning research projects, I conducted many measurements of the distribution of street dirt across the street, both before and after street cleaning. The following is an example from Bellevue, WA (Pitt 1983) for a conventional mechanical broom street sweeper. In this example, the greatest street dirt load is seen within a few feet of the curb, tapering off to very low loadings in the driving lanes. The street cleaning operation was not very effective away from the heavy curb-side loads (most street cleaners can clean out about 8 to 10 ft from the curb). The loadings away from the curb were seen to increase after street cleaning as the equipment ejected some of the material from the brooms out to the street.




Re-distribution of street dirt during street cleaning in Bellevue, WA (Pitt 1983).

The following figure is from my earlier street cleaning project in San Jose, CA (Pitt 1979) showing the effects of parked cars and pavement texture. The distribution showing the highest loads closest to the curb (the Tropicana good asphalt sites) had very few parked cars, allowing the traffic induced turbulence to blow street dirt towards the curb. In the Keyes good asphalt site, moderate numbers of parked cars prevented the blown material from fully reaching the curbs, as the parked cars formed a barrier. Most of the material was still with about 5 ft from the curb. The Keyes oil and screens street had very rough pavement which also partially prevented street dirt from being blown to the curbs. Even in this case, about 75% of the street dirt was within 10 ft from the curb.

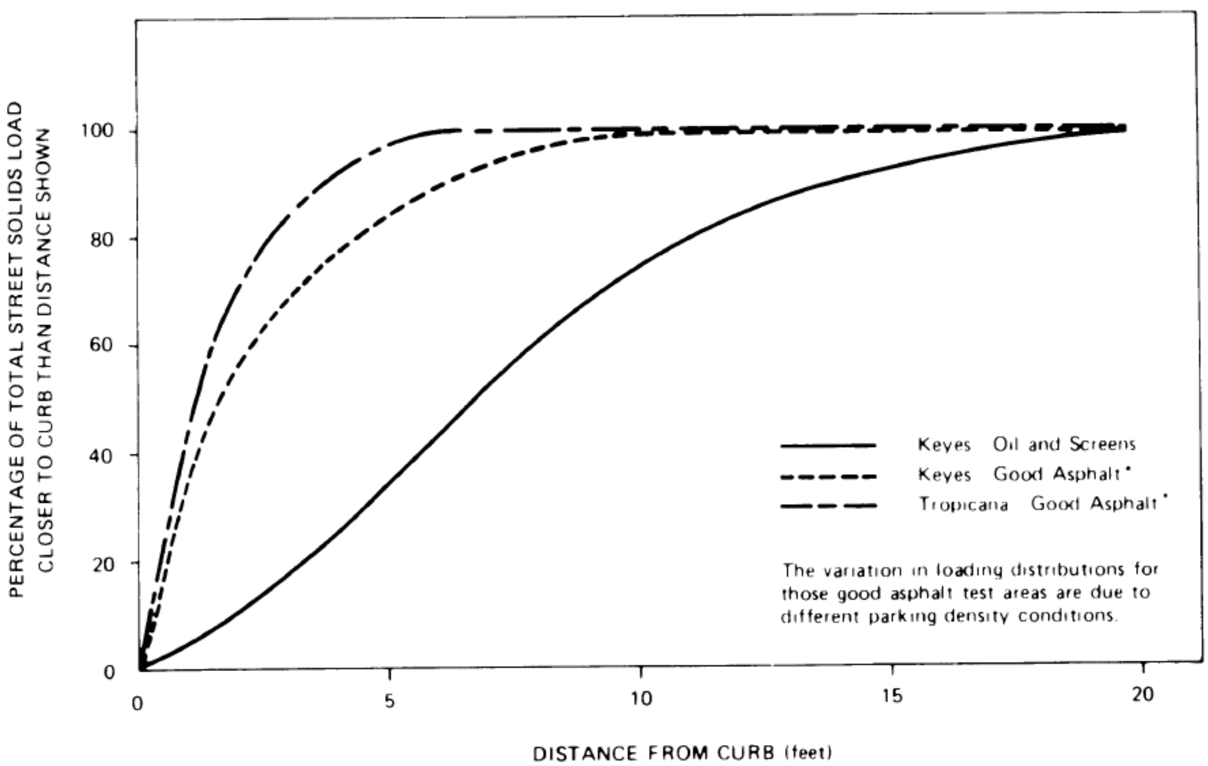



Figure 3-14. Loading distribution across the street.

Pitt 1979

## Pavement Cleaning away from Curbs

Few data exist for street cleaning benefits away from curbs. During street cleaning tests in Reno and Sparks, Nevada, Pitt and Sutherland (mid 1980s, but can't locate the reference or the report), did some street cleaning tests across the entire streets. There were insignificant additional benefits associated with the increased cleaning. However, several of my older projects sampled pavement at parking lots and other paved surfaces. It is possible to compare these pavement loading values with the unit area street cleaning performance data during the across-the-street special tests.

The following table summarizes the particulate samples collected at paved surfaces in residential, commercial, and industrial locations in the Toronto area (Pitt and McLean 1986).

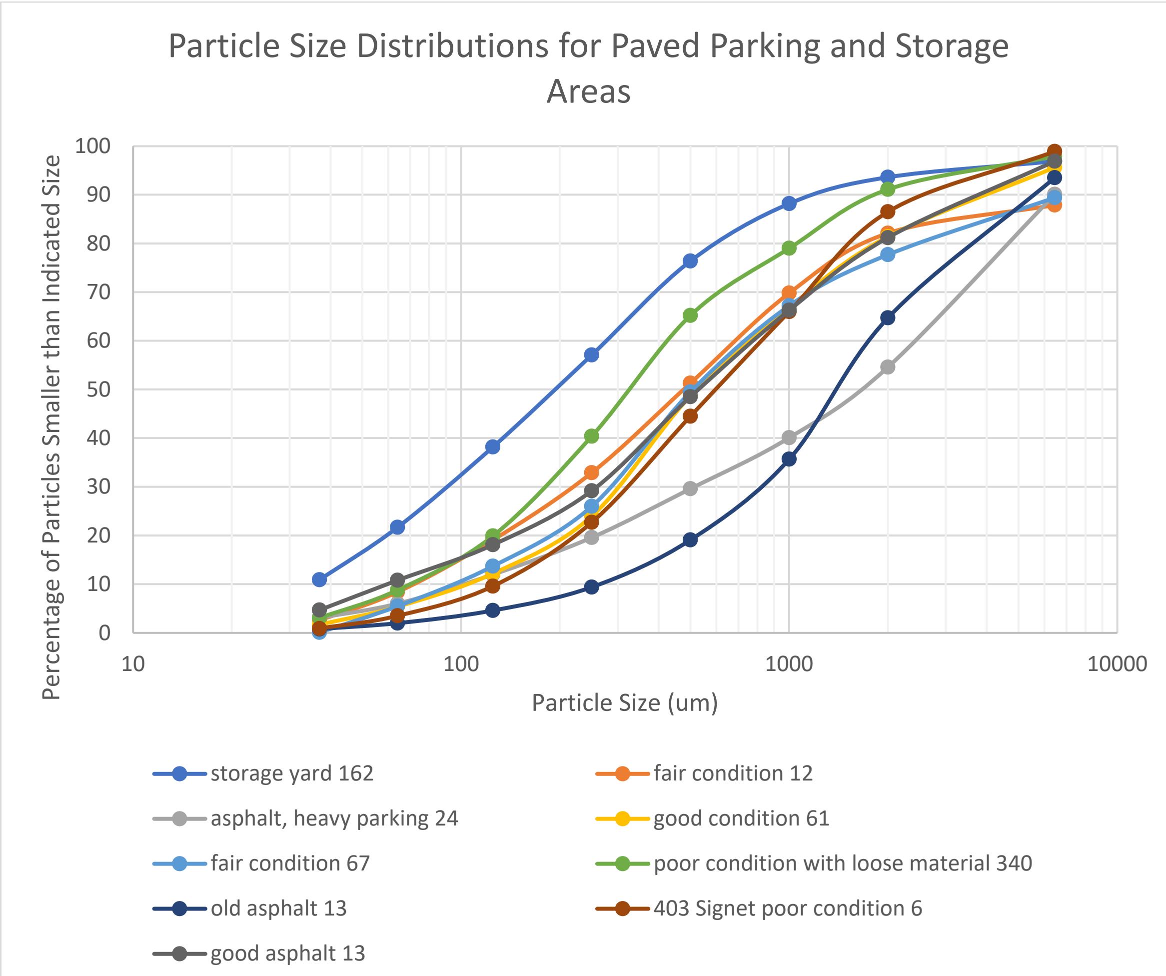
Paved Surface Particulate Sampling (Pitt and McLean 1986)

| | | | | total load ($g/m^2$, unless otherwise noted) | Percentage of Solids in Each Size Range (µm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | <37 | 37-64 | 64-125 | 125-250 | 250-500 | 500-1000 | 1000-2000 | 2000-6450 | >6450 |
| Rooftops | | | | | | | | | | | | | |
| | T43 | 51 Alhart | flat tar and gravel roof | 7840 | 0.2 | 0.3 | 1 | 1.1 | 1.3 | 2.2 | 3.1 | 26.1 | 64.7 |
| Roof Gutters | | | | | | | | | | | | | |
| | T42 | 51 Alhart | Al gutter on composition roof | 160 g/m of gutter | 2.2 | 3.7 | 3 | 2 | 2.8 | 34.2 | 49.5 | 1.5 | 1.1 |
| | T63 | 60 Thistledowns | Galv. steel on composition roof | 82 g/m of gutter | 10.5 | 7.9 | 3.1 | 1.2 | 2.3 | 28.6 | 44.6 | 0.3 | 1.5 |
| Footpath | E4 | B&E Furniture | good asphalt | 28 | 3.3 | 5.4 | 14.1 | 21.4 | 23.4 | 13.9 | 7.8 | 6.5 | 4.2 |
| Paved Parking/Storage Areas | | | | | | | | | | | | | |
| | E1 | North York yard | | 162 | 10.9 | 10.8 | 16.5 | 18.9 | 19.3 | 11.8 | 5.4 | 3.3 | 3.1 |
| | E5 | B&E Furniture | good asphalt | 13 | 4.7 | 5.8 | 10.7 | 13.8 | 18.4 | 18.5 | 12.3 | 5.8 | 10 |
| | E6 | Lumber King | poor condition with loose material | 340 | 3.1 | 2.9 | 6 | 7.6 | 10 | 10.5 | 14.5 | 35.5 | 9.9 |
| | E8 | Food processing composite | good condition | 61 | 1.7 | 3.7 | 6.8 | 11.8 | 24.7 | 18.2 | 14.5 | 14.2 | 4.4 |
| | E9 | Continental Can | fair condition | 67 | 0.1 | 5.4 | 8.2 | 12.3 | 23.5 | 17.7 | 10.5 | 11.7 | 10.6 |
| | T19 | Shopping center | asphalt, heavy parking | 24 | 3.1 | 5.7 | 11.1 | 20.5 | 24.8 | 13.8 | 12.1 | 6.8 | 2.1 |
| | T45 | Church | old asphalt | 13 | 0.8 | 1.2 | 2.6 | 4.8 | 9.7 | 16.6 | 29 | 28.8 | 6.5 |
| | E56 | General manufacturing | 403 Signet poor condition | 6 | 0.9 | 2.6 | 6.1 | 13.1 | 21.8 | 21.5 | 20.5 | 12.4 | 1.1 |
| | E61 | Commercial | fair condition | 12 | 2.6 | 6.1 | 7.3 | 11.1 | 19.3 | 17.8 | 14.9 | 15.7 | 5.2 |
| | | | | | | | | | | | | | |
| Driveway | | | | | | | | | | | | | |
| | T28 | Thistledown composite | good asphalt | 3 | 0.5 | 1.1 | 2.2 | 9.9 | 34.4 | 20.3 | 8 | 9.9 | 13.7 |
| Sidewalks | | | | | | | | | | | | | |
| | T46 | 258 Thistledown | good concrete | 13 | 1.8 | 4 | 9.2 | 14.8 | 20 | 15.5 | 8.6 | 17.5 | 8.6 |

Paved Surface Particulate Sampling (Pitt and McLean 1986) (cont.)

| | | | | total load (g/curb-meter for roads) | Percentage of Solids in Each Size Range (µm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | <37 | 37-64 | 64-125 | 125-250 | 250-500 | 500-1000 | 1000-2000 | 2000-6450 | >6450 |
| Roads | | | | | | | | | | | | | |
| | E11 | Toryork | old | 107 g/curb-meter | 0.8 | 1.3 | 3.7 | 9.4 | 23.8 | 24.3 | 16.9 | 13.1 | 6.7 |
| | E12 | Emery composite | | 40 g/curb-meter | 1.6 | 2.9 | 11.7 | 20 | 21.4 | 14.9 | 11.1 | 10.7 | 5.7 |
| | T47 | Thistledown Blvd | poor cracked | 2190 g/curb-meter | 0.5 | 1.1 | 2.9 | 6.5 | 13.3 | 15 | 15.9 | 37.2 | 7.6 |
| | T48 | 82 Alhart | good and smooth | 67 g/curb-meter | 2.7 | 5.8 | 11.7 | 20 | 26 | 18.1 | 7.4 | 5.8 | 2.5 |
| | T49 | Humberland Ct | rough, good condition | 100 g/curb-m | 3.9 | 7 | 13.4 | 21.2 | 25 | 15.1 | 8.1 | 5.2 | 1.1 |
| | T50 | Edgebrook | old asphalt, very poor condition | 103 g/curb-meter | 1 | 1.9 | 4.2 | 6.9 | 8.6 | 8.1 | 12.2 | 42 | 15.1 |
| | T51 | Bondhead Ct | newly sealed, very good | 99 g/curb-meter | 0.8 | 1.1 | 1.5 | 2.9 | 7.6 | 17.3 | 18.4 | 41.3 | 9.1 |
| | T52 | Bondhed road and shoulder | newly sealed, very good | 329 g/curb-meter | <0.1 | 0.2 | 0.1 | 0.1 | 0.3 | 1 | 2.9 | 70.1 | 25.3 |
| | T53 | Church at Thistledown Blvd | w/o shoulder | 156 g/curb-meter | 0.9 | 1.8 | 4 | 7.7 | 13.6 | 20.6 | 23 | 25.8 | 2.6 |
| | T55 | 20 Norelco | cracked asphalt | 140 g/curb-meter | 2.5 | 4.7 | 9.7 | 17.2 | 24.1 | 19.7 | 13.5 | 7.7 | 0.9 |
| | E58 | Marta | poor, cracked | 485 g/curb-meter | 1.7 | 3.6 | 8.3 | 15.5 | 23.8 | 21.5 | 13.9 | 8.7 | 3 |
| | E59 | composite | very good condition, clean | 43 g/curb-meter | 1.6 | 3.3 | 6.7 | 10.8 | 17.7 | 18.7 | 17.1 | 19.4 | 4.7 |
| | T40 | Alhart at Thistledown | intermediate condition | 37 g/curb-meter | 2 | 3.4 | 7 | 10.7 | 12.3 | 9.6 | 8.7 | 30 | 16.3 |

The paved parking and storage area particle size data were plotted to obtain the median sizes and to determine groupings of the data, as shown on the following plot.




Particle size distribution for paved parking and storage areas (values in key are the SSC loadings in g/m2) (data from Pitt and McLean 1986)

There are four apparent groupings of these PSD data. The lowest median size sample has a median size of 195 um, followed by the next sample at 320 µm. Most of the data are in the middle group having median sizes ranging from 480 to 590 µm, while the largest median size group has median sizes of 1250 and 1400 µm. The median sizes did not correlate with the particulate loading values or the condition of the pavement. The median sizes were therefore likely associated with adjacent areas and parking/traffic conditions, plus cleaning activities.

The following table compares the observed sheetflow SSC concentrations from these areas (plus some of the unpaved areas not shown above), for comparison. The roof runoff SSC concentrations were very low, as were the residential sidewalk. The paved parking and storage area SSC concentrations generally overlap with the road SSC concentrations, but do vary greatly.

Sheetflow Sample SSC Concentrations from Toronto Source Area Sampling (Pitt and McLean 1986)

| | | | SSC concentration medians and ranges (mg/L) |
|---|---|---|---|
| Bare ground | Emery* (median and range), mg/L | | 248 (103 to 392 |
| | Thistledowns (median and range), mg/L | | 807 |
| | | | |
| Unpaved driveways and storage areas | | | |
| | Emery (median and range), mg/L | | 805 (309 to 4670) |
| | Thistledowns (median and range), mg/L | | n/a |
| | | | |
| Roof runoff: | | | |
| | Emery (median and range), mg/L | | 6 (3 to 8.8) |
| | Thistledowns (median and range), mg/L | | 4 (1 to 40) |
| | | | |
| Sidewalks: | | | |
| | Emery (median and range), mg/L | | 435 (86 to 783) |
| | Thistledowns (median and range), mg/L | | 20 |
| | | | |
| Paved parking/storage areas: | | | |
| | Emery (median and range), mg/L | | 202 (14 to 1210) |
| | Thistledowns (median and range), mg/L | | 687 (170 to 7880) |
| | | | |
| Paved roads: | | | |
| | Emery (median and range), mg/L | | 871 (170 to 4430) |
| | Thistledowns (median and range), mg/L | | 137 (43 to 870) |

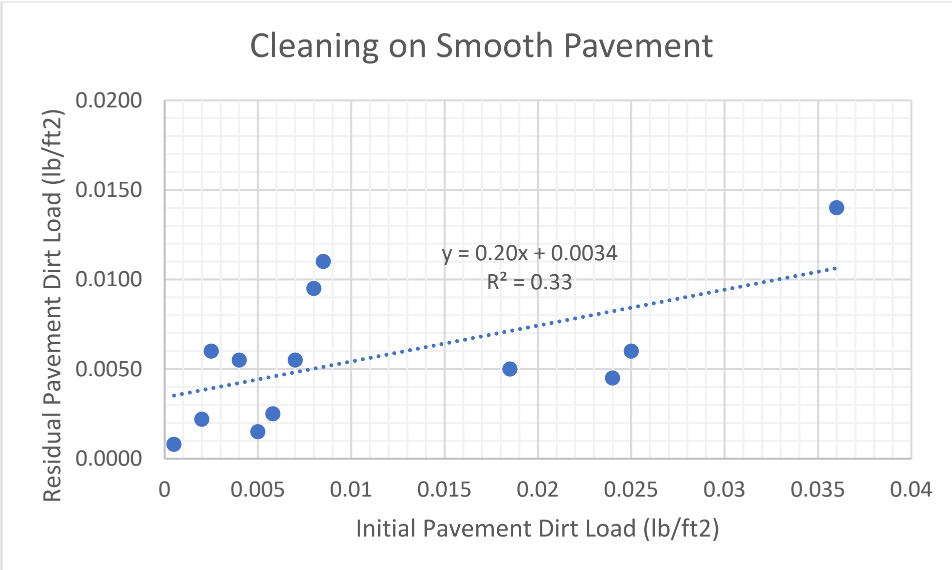
* Emery is an industrial area while Thistledowns is a mixed residential (mostly) and commercial area

Based on the above data, an approximation of pavement cleaning benefits of un-curbed paved parking and storage areas may relate to the unit area street cleaning tests that were used to measure the distribution of street dirt across the street, described previously. The following table summarizes the unit area initial and residual street dirt loading values from several tests conducted in San Jose (Pitt 1979) and Bellevue (Pitt 1983). These data are separated into smooth asphalt tests. These loading values are for several strips along the curbs and out into the streets. Data shown below are up to about 6 to 8 ft from the curbs and are within the width of the street cleaners. Further strips outside of the cleaned area are not shown here as they represented increased loadings associated with material blown away from the cleaned strips by the street cleaning equipment brooms. Those loading in the driving lanes were very low.

| Street cleaning strips across the street (San Jose, Pitt 1979) | | | |
|---|---|---|---|
| strips out 6 or 8 ft (very low loads further out with negative removals) | | | |
| | smooth asphalt | | |
| | initial lbs/ft$^2$ | residual lbs/ft$^2$ | |
| | 0.024 | 0.0045 | |
| | 0.004 | 0.0055 | |
| | 0.0005 | 0.0008 | |
| | | | |
| | 0.025 | 0.0060 | |
| | 0.0058 | 0.0025 | |
| | 0.0085 | 0.0110 | |

| Street cleaning strips across the street (Bellevue, Pitt 1983) | | |
|---|---|---|
| strips out 6 or 8 ft (very low loads further out with negative removals) | | |
| | smooth asphalt | |
| | initial lbs/ft$^2$ | residual lbs/ft$^2$ |
| | 0.005 | 0.0015 |
| | 0.036 | 0.0140 |
| | 0.0025 | 0.0060 |
| | | |
| | 0.0185 | 0.0050 |
| | 0.008 | 0.0095 |
| | 0.007 | 0.0055 |
| | 0.002 | 0.0022 |

These initial and residual unit area loading values were plotted and simple regression equations were fitted to the data for these two street roughness categories.




(negative removals for initial loads <0.004 lb/ft$^2$)

The Toronto paved parking and storage area loading values were divided into two categories: good to fair pavement condition with very low particulate loadings, and good to fair pavement condition with typical particulate loadings. The site with poor condition pavement with high particulate loadings is not shown as the poor pavement condition precludes effec. The following table summarizes these loadings (converted from g/m$^2$ to lb/ft$^2$) and the residual loadings after cleaning are calculated using the regression equation.

Calculated Pavement Cleaning Benefits for Paved Parking and Storage Areas

| good and fair condition very clean | | | total load (g/m$^2$) | initial load (lb/ft$^2$) | residual load (lb/ft$^2$) | % reduction |
|---|---|---|---|---|---|---|
| T45 | General manufacturing | 403 Signet poor condition | 6 | 0.0012 | 0.0036 | -196.8 |
| T19 | Commercial | fair condition | 12 | 0.0025 | 0.0039 | -58.4 |
| E56 | Church | old asphalt | 13 | 0.0027 | 0.0039 | -47.8 |
| E6 | B&E Furniture | good asphalt | 13 | 0.0027 | 0.0039 | -47.8 |
| | | | | | average: | -87.7 |
| | assume zero removal in absence of redistribution | | | | | |
| good and fair condition typical loading | | | total load (g/m$^2$) | initial load (lb/ft$^2$) | residual load (lb/ft$^2$) | % reduction |
| E5 | Shopping center | asphalt, heavy parking | 24 | 0.0049 | 0.0044 | 10.8 |
| E9 | Food processing composite | good condition | 61 | 0.012 | 0.0059 | 52.8 |
| E8 | Continental Can | fair condition | 67 | 0.014 | 0.0061 | 55.2 |
| E1 | North York yard | storage yard | 162 | 0.033 | 0.010 | 69.7 |
| | | | | | average: | 47.1 |

The clean areas all have very low loadings (0.0012 to 0.0027 lb/ft$^2$) which are below the effective cutoff for mechanical street cleaners (0.004 lb/ft$^2$) and therefore reflect increases in particulate loadings after cleaning. The increased loadings during the street cleaning tests are do the redistribution of material from the dirtier street areas being blown out into the street. If a street cleaner was operating in these areas of low loadings, no redistribution would occur, so these increased loads should not be considered for paved parking and storage areas. These areas are expected to correspond to the driving lanes of the parking or storage areas where the vehicle turbulence is assumed to keep the loadings low. Therefore, pavement cleaning is not recommended in those areas, as it would result in nil benefit.

The typical particulate loading areas having reasonably smooth pavement have particulate loads (0.0049 to 0.033 lb/ft$^2$) above the critical cutoff value (0.004 lb/ft$^2$), resulting in an average removal rate of 47%. These areas would correspond to any non-curbed edges of the pavement or in areas normally used for parking of vehicles (assuming the vehicles are removed for cleaning). If not removed, then cleaning benefits would be nil.

These comparisons indicate similar unit area particulate loads characteristics between paved parking and storage area unit areas and streets. However, no accumulation information is available for paved parking and storage areas, so the detailed accumulation and washoff calculations are not possible for these other paved areas. It is suggested that the street accumulation and washoff relationships used in WinSLAMM for streets can be used to calculate the percentage SSC concentration reductions for these other paved areas. Therefore, the street cleaning calculations in WinSLAMM can be modified to calculate the cleaning benefits in those areas, as described in the following sections of this memo.

## Pavement Cleaning along Curbs

Paved parking and storage areas should be subdivided into about three subareas, such as:

1. edge areas with curbs which normally may be under parked vehicles but moved before cleaning. This may also be a driving area with a curb on one side and no parked cars. If cars are not removed, then high obstructions are present with much less efficient cleaning.
2. interior parking areas, with or without curbs, which normally may be under parked vehicles, but moved before cleaning.
3. roadways/traffic lanes that are much cleaner than the other areas (and only effectively cleaned with vacuum pavement cleaners due to lack of curbs).

Cleaning analyses are conducted for each subarea separately. The results are then area-weighted for the calculated percentage SSC concentration percentage reduction benefit for the whole area, which is then applied to reduce the WinSLAMM calculated sheetflow concentrations for the whole area.

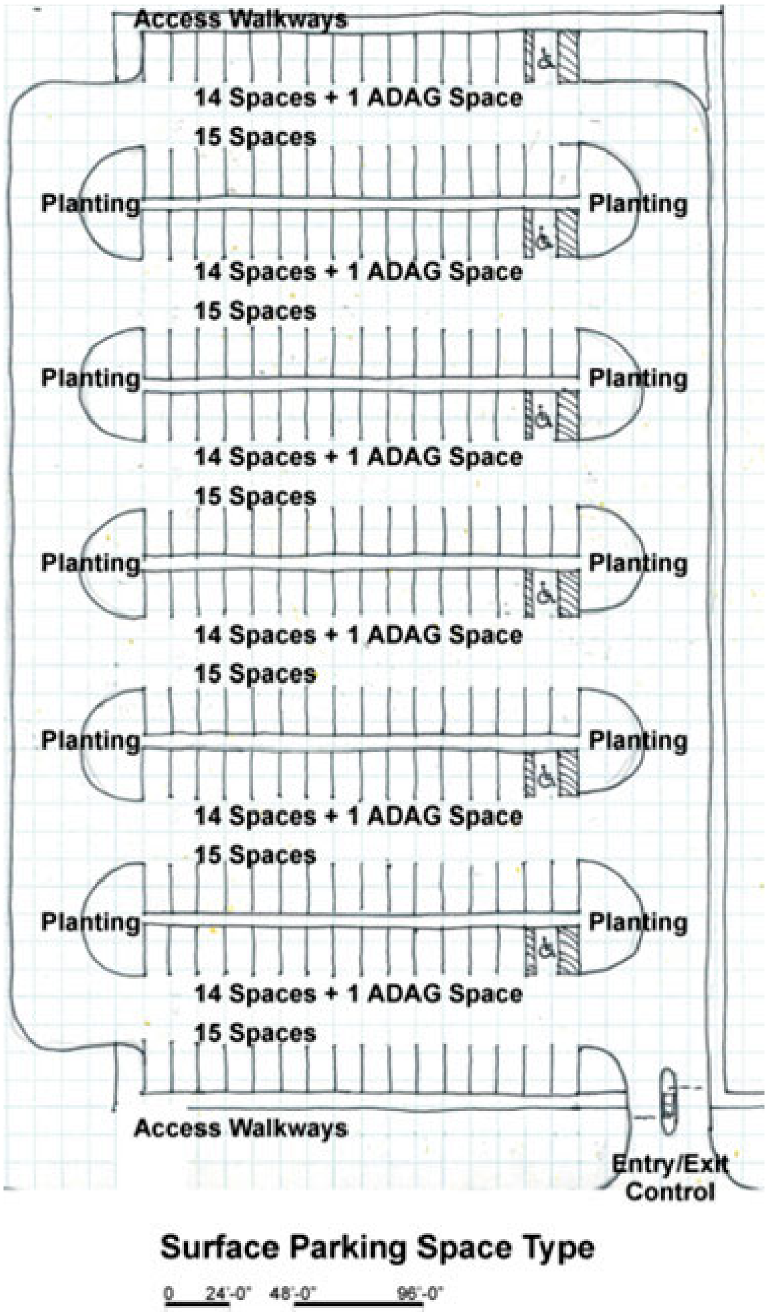
The following is a typical parking lot layout, but obviously they can vary greatly. In this example, the dividers are 61 ft apart and it accommodates 186 parking spaces in 2.44 acres (76 spaces per acre). The figure has a typo showing 15 spaces in the rows without the ADAG space, while 16 spaces are actually present. The curb length along the outer edges is about 1,100 ft and the internal curb length is about 1,700 ft. The total curb length is therefore about 0.22 curb-miles per acre. A typical residential street that is 33 ft wide has about 0.25 curb-miles per acre. This example also has planting areas at the ends of each parking row that total about 0.17 ac, or 7.1% of the total parking lot. Interestingly, this is likely more than sufficient for parking lot biofilters that could control most of the runoff (and pollutants) from the parking lot. However, these planting areas result in obstructions that may hinder the pavement cleaners from reaching the paved inside corners, while smaller pavement cleaners having gutter brooms in front of the vehicles may be able to reach into these corners.

A new pavement cleaner input form would therefore be a simplified version of the street cleaning form, containing the following information requests for the curbed areas:

- Type of Cleaner: mechanical broom cleaner or vacuum assisted cleaner
- Cleaning Dates or Cleaning Frequency (and final cleaning period ending date)
- Pavement obstructions or parking densities: none, low, moderate, or extensive (based on parking densities during cleaning or other obstructions), and if parked cars are removed for cleaning
- Total curb length in paved area (direct entry)
- Pavement texture (from parking area source area form)

No cleaner productivity options, as use texture and obstructions, and no accumulation equation options would be necessary.

WinSLAMM will calculate a curb-mile loading based on the land use and texture, and accumulation period (for streets in the same land use). Pavement cleaning will then be based on the curb-mile length actually cleaned. If the paved area only has perimeter curbs, that would be the only areas cleaned using the traditional street cleaning model guts. The area-weighted particulate solids concentration percentage reduction for the street equations (compared to no cleaning) would then be applied to the particulate solids concentration values from the paved area.




**Surface Parking Space Type**

https://www.bing.com/images/search?view=detailV2&ccid=5kuMQbOq&id=D6F8ED8271E0D47DCF8B57778629132C02DC7808&thid=OIP.5kuMQbOqp4jly1ttTFAYogHaM2&mediaurl=http%3A%2F%2Fwbdg.org%2Fimages%2Fparking_surface_1.jpg&exph=651&expw=375&q=parking+lot+layout+standards&simid=608011075258614100&ck=AC6DED7A8165E17EC095BAA4B62E970E&selectedindex=12&ajaxhist=0&vt=0&sim=11 (got that?)

## Numeric Example for Pavement Cleaning in WinSLAMM

In the above parking lot diagram, curbs are around the perimeter and as dividers, totaling 0.53 curb-miles in length (divided into the edge and interior areas). WinSLAMM was used to calculate comparable street cleaning effectiveness as summarized in the following tables, using the standard WI parameter files, for a commercial parking lot cleaned with a vacuum or mechanical pavement cleaner. Since there were planters at the end of each internal parking row, a medium level of obstructions was assumed (represented by medium parking with no parking controls). The effects of obstructions (parked cars during street cleaning) can be significant, as street cleaners must maneuver around parked cars, leaving curb side heavy loadings uncleaned. Similar issues are likely in parking or storage areas. In the example presented above, the end of row planters requires the cleaner to turn before the full curb can be cleaned. As shown above, modern small pavement cleaners may be able to maneuver much closer to the inside corners, with less effective obstructions.

The following table illustrates the effects of obstructions with street cleaning in WinSLAMM, for weekly vacuum cleaning. The two columns show the effect of parked cars moved before street cleaning. Obviously, obstructions that are not moveable would reflect the “no” parking control condition.

Annual flow-weighted SSC concentration reductions, all once a week, vacuum cleaning in a commercial area

| parking conditions | % SSC conc reduction, no parking controls | % SSC conc reduction, with parking controls |
|---|---|---|
| none | 43.8 | 43.8 |
| light | 32.6 | 43.8 |
| medium | 14.4 | 36.1 |
| extensive (short term) | 19.7 | 32.6 |
| extensive (long term) | 19.7 | 13.2 |

Obstructions cause substantial reductions in the removal effectiveness, with additional benefits associated with removal of the obstructions (except for the extensive long-term parking condition where most of the street dirt is displaced away from the curb due to the cars blocking the blowing of debris towards the curb). Therefore, it is critical to divide the paved area into separate subareas reflecting the presence of curbs, the presence of obstructions, and the driving/traffic lanes.

The following tables are examples showing the calculations for determining the pavement cleaning benefits for three scenarios for the above described commercial parking lot, with cleaning frequencies of 2/year, 1/month. 1/week, and 3/week: 1) Inner and outer areas are curbed, but inner obstructed by planters and cleaned by mechanical or vacuum cleaners, 2) same as above, but without end or parking row obstructions, and 3) outer curbs cleaned with low obstructions, and internal area without curbs and no obstructions cleaned by vacuum but not cleaned by mechanical pavement cleaners. The driving lanes are not cleaned for any of these scenarios.

Commercial areas both inner and outer curbs cleaned with obstructions at both

| subareas | cleaning frequency | obstructions | area | area weighting factor | edge length | flow-weighted SSC conc (mg/L) before cleaning | flow-weighted SSC conc (mg/L) after vacuum cleaning | flow-weighted SSC conc (mg/L) after mechanical cleaning | % SSC concentration reduction after vacuum cleaning | % SSC concentration reduction after mechanical cleaning | pvd area SSC conc (mg/L) before cleaning | pvd area SSC conc (mg/L) after vacuum cleaning | pvd area SSC conc (mg/L) after mechanical cleaning |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| interior curbs | 2/year | medium | 1.09 ac | 0.45 | 0.32 mi (1 edge) | 110.6 | 104.2 | 103.0 | 5.8 | 6.9 | | | |
| outer curbs | 2/year | low | 0.21 ac | 0.33 | 0.21 mi (1 edge) | 146.1 | 129.4 | 127.3 | 11.4 | 12.9 | | | |
| traffic lane | none | n/a | 0.54 ac | 0.22 | 0 | 130.0 | 130.0 | 130.0 | 0.0 | 0.0 | | | |
| weighted total area | | | | | | 126.6 | 118.2 | 117.0 | 6.4 | 7.3 | 130 | 122 | 120 |
| | cleaning frequency | obstructions | area | area weighting factor | edge length | flow-weighted SSC conc (mg/L) before cleaning | flow-weighted SSC conc (mg/L) after vacuum cleaning | flow-weighted SSC conc (mg/L) after mechanical cleaning | % SSC concentration reduction after vacuum cleaning | % SSC concentration reduction after mechanical cleaning | pvd area SSC conc (mg/L) before cleaning | pvd area SSC conc (mg/L) after vacuum cleaning | pvd area SSC conc (mg/L) after mechanical cleaning |
| interior area | 1/month | medium | 1.09 ac | 0.45 | 0.32 mi (1 edge) | 110.6 | 102.9 | 102.9 | 7.0 | 6.9 | | | |
| outer area | 1/month | low | 0.21 ac | 0.33 | 0.21 mi (1 edge) | 146.1 | 122.5 | 127.2 | 16.1 | 12.9 | | | |
| traffic lane | none | n/a | 0.54 ac | 0.22 | 0 | 130.0 | 130.0 | 130.0 | 0.0 | 0.0 | | | |
| weighted total area | | | | | | 126.6 | 115.3 | 116.9 | 8.5 | 7.4 | 130 | 119 | 120 |
| | cleaning frequency | obstructions | area | area weighting factor | edge length | flow-weighted SSC conc (mg/L) before cleaning | flow-weighted SSC conc (mg/L) after vacuum cleaning | flow-weighted SSC conc (mg/L) after mechanical cleaning | % SSC concentration reduction after vacuum cleaning | % SSC concentration reduction after mechanical cleaning | pvd area SSC conc (mg/L) before cleaning | pvd area SSC conc (mg/L) after vacuum cleaning | pvd area SSC conc (mg/L) after mechanical cleaning |
| interior area | 1/week | medium | 1.09 ac | 0.45 | 0.32 mi (1 edge) | 110.6 | 94.6 | 98.0 | 14.4 | 11.4 | | | |
| outer area | 1/week | low | 0.21 ac | 0.33 | 0.21 mi (1 edge) | 146.1 | 98.5 | 116.7 | 32.6 | 20.1 | | | |
| traffic lane | none | n/a | 0.54 ac | 0.22 | 0 | 130.0 | 130.0 | 130.0 | 0.0 | 0.0 | | | |
| weighted total area | | | | | | 126.6 | 103.7 | 111.2 | 17.2 | 11.8 | 130 | 108 | 115 |
| | cleaning frequency | obstructions | area | area weighting factor | edge length | flow-weighted SSC conc (mg/L) before cleaning | flow-weighted SSC conc (mg/L) after vacuum cleaning | flow-weighted SSC conc (mg/L) after mechanical cleaning | % SSC concentration reduction after vacuum cleaning | % SSC concentration reduction after mechanical cleaning | pvd area SSC conc (mg/L) before cleaning | pvd area SSC conc (mg/L) after vacuum cleaning | pvd area SSC conc (mg/L) after mechanical cleaning |
| interior area | 3/week | medium | 1.09 ac | 0.45 | 0.32 mi (1 edge) | 110.6 | 81.2 | 89.7 | 26.6 | 18.9 | | | |
| outer area | 3/week | low | 0.21 ac | 0.33 | 0.21 mi (1 edge) | 146.1 | 74.3 | 108.4 | 49.2 | 25.8 | | | |
| traffic lane | none | n/a | 0.54 ac | 0.22 | 0 | 130.0 | 130.0 | 130.0 | 0.0 | 0.0 | | | |
| weighted total area | | | | | | 126.6 | 89.6 | 104.7 | 28.2 | 17.0 | 130 | 93 | 108 |

Commercial areas both inner and outer curbs cleaned with obstructions only at outer edges (no planters at end of rows)

| | cleaning frequency | obstructions | area | area weighting factor | edge length | flow-weighted SSC conc (mg/L) before cleaning | flow-weighted SSC conc (mg/L) after vacuum cleaning | flow-weighted SSC conc (mg/L) after mechanical cleaning | % SSC concentration reduction after vacuum cleaning | % SSC concentration reduction after mechanical cleaning | pvd area SSC conc (mg/L) before cleaning | pvd area SSC conc (mg/L) after vacuum cleaning | pvd area SSC conc (mg/L) after mechanical cleaning |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| interior area | 2/year | none | 1.09 ac | 0.45 | 0.32 mi (1 edge) | 110.6 | 94.0 | 92.5 | 15.0 | 16.3 | | | |
| outer area | 2/year | low | 0.21 ac | 0.33 | 0.21 mi (1 edge) | 146.1 | 129.4 | 127.3 | 11.4 | 12.9 | | | |
| traffic lane | none | n/a | 0.54 ac | 0.22 | 0 | 130.0 | 130.0 | 130.0 | 0.0 | 0.0 | | | |
| weighted total area | | | | | | 126.6 | 113.6 | 112.2 | 10.5 | 11.6 | 130 | 116 | 115 |

| | cleaning frequency | obstructions | area | area weighting factor | edge length | flow-weighted SSC conc (mg/L) before cleaning | flow-weighted SSC conc (mg/L) after vacuum cleaning | flow-weighted SSC conc (mg/L) after mechanical cleaning | % SSC concentration reduction after vacuum cleaning | % SSC concentration reduction after mechanical cleaning | pvd area SSC conc (mg/L) before cleaning | pvd area SSC conc (mg/L) after vacuum cleaning | pvd area SSC conc (mg/L) after mechanical cleaning |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| interior area | 1/month | none | 1.09 ac | 0.45 | 0.32 mi (1 edge) | 110.6 | 85.7 | 92.5 | 22.5 | 16.4 | | | |
| outer area | 1/month | low | 0.21 ac | 0.33 | 0.21 mi (1 edge) | 146.1 | 122.5 | 127.2 | 16.1 | 12.9 | | | |
| traffic lane | none | n/a | 0.54 ac | 0.22 | 0 | 130.0 | 130.0 | 130.0 | 0.0 | 0.0 | | | |
| weighted total area | | | | | | 126.6 | 107.6 | 112.2 | 15.4 | 11.6 | 130 | 110 | 115 |

| | cleaning frequency | obstructions | area | area weighting factor | edge length | flow-weighted SSC conc (mg/L) before cleaning | flow-weighted SSC conc (mg/L) after vacuum cleaning | flow-weighted SSC conc (mg/L) after mechanical cleaning | % SSC concentration reduction after vacuum cleaning | % SSC concentration reduction after mechanical cleaning | pvd area SSC conc (mg/L) before cleaning | pvd area SSC conc (mg/L) after vacuum cleaning | pvd area SSC conc (mg/L) after mechanical cleaning |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| interior area | 1/week | none | 1.09 ac | 0.45 | 0.32 mi (1 edge) | 110.6 | 62.2 | 84.1 | 43.8 | 23.9 | | | |
| outer area | 1/week | low | 0.21 ac | 0.33 | 0.21 mi (1 edge) | 146.1 | 98.5 | 116.7 | 32.6 | 20.1 | | | |
| traffic lane | none | n/a | 0.54 ac | 0.22 | 0 | 130.0 | 130.0 | 130.0 | 0.0 | 0.0 | | | |
| weighted total area | | | | | | 126.6 | 89.1 | 105.0 | 30.5 | 17.4 | 130 | 90 | 107 |

| | cleaning frequency | obstructions | area | area weighting factor | edge length | flow-weighted SSC conc (mg/L) before cleaning | flow-weighted SSC conc (mg/L) after vacuum cleaning | flow-weighted SSC conc (mg/L) after mechanical cleaning | % SSC concentration reduction after vacuum cleaning | % SSC concentration reduction after mechanical cleaning | pvd area SSC conc (mg/L) before cleaning | pvd area SSC conc (mg/L) after vacuum cleaning | pvd area SSC conc (mg/L) after mechanical cleaning |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| interior area | 3/week | none | 1.09 ac | 0.45 | 0.32 mi (1 edge) | 110.6 | 44.0 | 80.1 | 60.2 | 27.6 | | | |
| outer area | 3/week | low | 0.21 ac | 0.33 | 0.21 mi (1 edge) | 146.1 | 74.3 | 108.4 | 49.2 | 25.8 | | | |
| traffic lane | none | n/a | 0.54 ac | 0.22 | 0 | 130.0 | 130.0 | 130.0 | 0.0 | 0.0 | | | |
| weighted total area | | | | | | 126.6 | 72.9 | 100.4 | 43.3 | 20.9 | 130 | 74 | 103 |

Commercial areas outer curbs cleaned with low obstructions, and internal area having no curbs and no obstructions cleaned by vacuum but not cleaned by mechanical

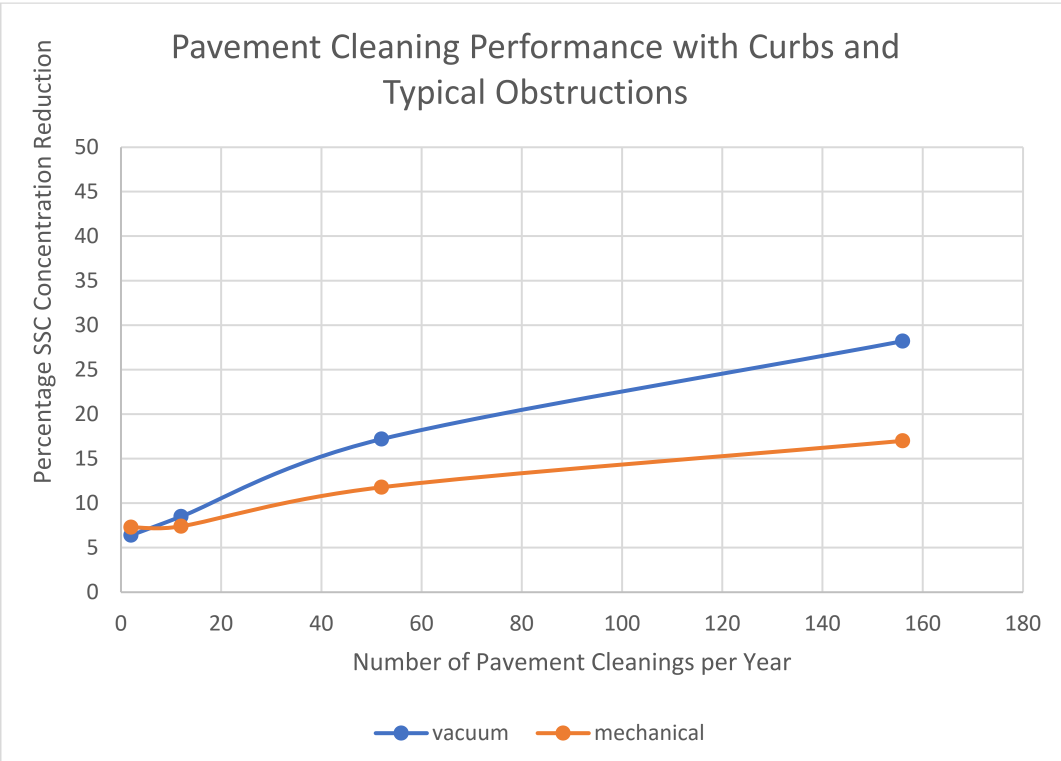
| | cleaning frequency | obstructions | area | area weighting factor | edge length | flow-weighted SSC conc (mg/L) before cleaning | flow-weighted SSC conc (mg/L) after vacuum cleaning | flow-weighted SSC conc (mg/L) after mechanical cleaning | % SSC concentration reduction after vacuum cleaning | % SSC concentration reduction after mechanical cleaning | pvd area SSC conc (mg/L) before cleaning | pvd area SSC conc (mg/L) after vacuum cleaning | pvd area SSC conc (mg/L) after mechanical cleaning |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| interior area | 2/yr vacuum only | none | 1.09 ac | 0.45 | 0.32 mi (1 edge) | 110.6 | 94.0 | 110.6 | 15.0 | 0.0 | | | |
| outer area | 2/year | low | 0.21 ac | 0.33 | 0.21 mi (1 edge) | 146.1 | 129.4 | 127.3 | 11.4 | 12.9 | | | |
| traffic lane | none | n/a | 0.54 ac | 0.22 | 0 | 130.0 | 130.0 | 130.0 | 0.0 | 0.0 | | | |
| weighted total area | | | | | | 126.6 | 113.6 | 120.4 | 10.5 | 4.2 | 130 | 116 | 124 |

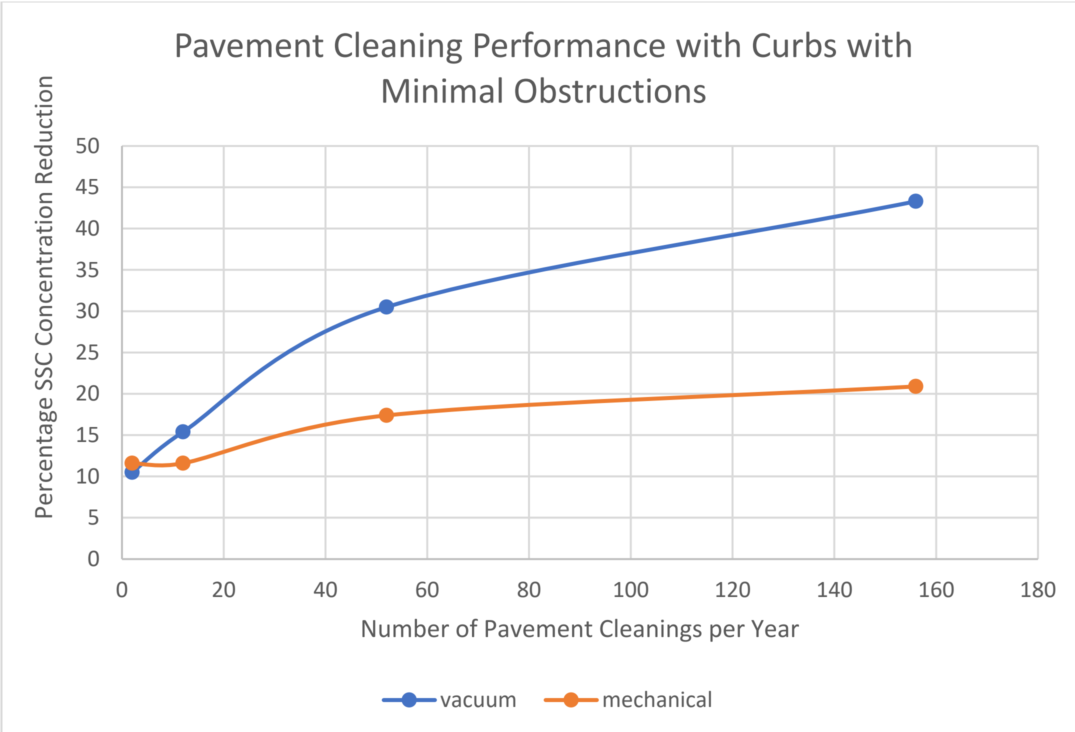
| | cleaning frequency | obstructions | area | area weighting factor | edge length | flow-weighted SSC conc (mg/L) before cleaning | flow-weighted SSC conc (mg/L) after vacuum cleaning | flow-weighted SSC conc (mg/L) after mechanical cleaning | % SSC concentration reduction after vacuum cleaning | % SSC concentration reduction after mechanical cleaning | pvd area SSC conc (mg/L) before cleaning | pvd area SSC conc (mg/L) after vacuum cleaning | pvd area SSC conc (mg/L) after mechanical cleaning |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| interior area | 1/month vacuum only | none | 1.09 ac | 0.45 | 0.32 mi (1 edge) | 110.6 | 85.7 | 110.6 | 22.5 | 0.0 | | | |
| outer area | 1/month | low | 0.21 ac | 0.33 | 0.21 mi (1 edge) | 146.1 | 122.5 | 127.2 | 16.1 | 12.9 | | | |
| traffic lane | none | n/a | 0.54 ac | 0.22 | 0 | 130.0 | 130.0 | 130.0 | 0.0 | 0.0 | | | |
| weighted total area | | | | | | 126.6 | 107.6 | 120.3 | 15.4 | 4.3 | 130 | 110 | 124 |

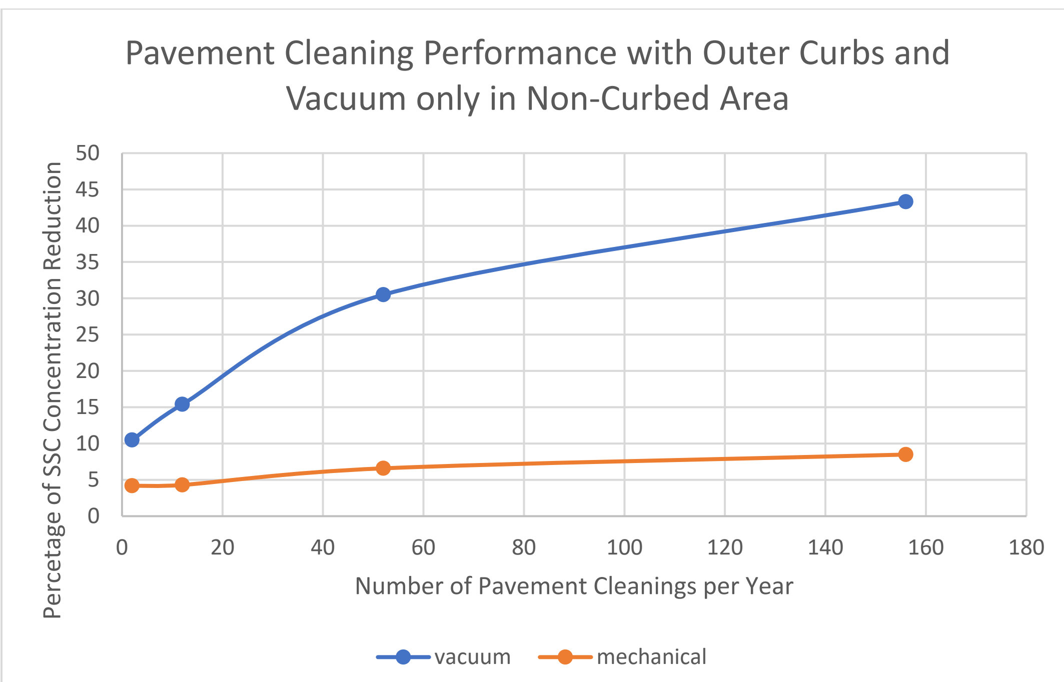
| | cleaning frequency | obstructions | area | area weighting factor | edge length | flow-weighted SSC conc (mg/L) before cleaning | flow-weighted SSC conc (mg/L) after vacuum cleaning | flow-weighted SSC conc (mg/L) after mechanical cleaning | % SSC concentration reduction after vacuum cleaning | % SSC concentration reduction after mechanical cleaning | pvd area SSC conc (mg/L) before cleaning | pvd area SSC conc (mg/L) after vacuum cleaning | pvd area SSC conc (mg/L) after mechanical cleaning |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| interior area | 1/week vacuum only | none | 1.09 ac | 0.45 | 0.32 mi (1 edge) | 110.6 | 62.2 | 110.6 | 43.8 | 0.0 | | | |
| outer area | 1/week | low | 0.21 ac | 0.33 | 0.21 mi (1 edge) | 146.1 | 98.5 | 116.7 | 32.6 | 20.1 | | | |
| traffic lane | none | n/a | 0.54 ac | 0.22 | 0 | 130.0 | 130.0 | 130.0 | 0.0 | 0.0 | | | |
| weighted total area | | | | | | 126.6 | 89.1 | 116.9 | 30.5 | 6.6 | 130 | 90 | 121 |

| | cleaning frequency | obstructions | area | area weighting factor | edge length | flow-weighted SSC conc (mg/L) before cleaning | flow-weighted SSC conc (mg/L) after vacuum cleaning | flow-weighted SSC conc (mg/L) after mechanical cleaning | % SSC concentration reduction after vacuum cleaning | % SSC concentration reduction after mechanical cleaning | pvd area SSC conc (mg/L) before cleaning | pvd area SSC conc (mg/L) after vacuum cleaning | pvd area SSC conc (mg/L) after mechanical cleaning |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| interior area | 3/week vacuum only | none | 1.09 ac | 0.45 | 0.32 mi (1 edge) | 110.6 | 44.0 | 110.6 | 60.2 | 0.0 | | | |
| outer area | 3/week | low | 0.21 ac | 0.33 | 0.21 mi (1 edge) | 146.1 | 74.3 | 108.4 | 49.2 | 25.8 | | | |
| traffic lane | none | n/a | 0.54 ac | 0.22 | 0 | 130.0 | 130.0 | 130.0 | 0.0 | 0.0 | | | |
| weighted total area | | | | | | 126.6 | 72.9 | 114.1 | 43.3 | 8.5 | 130 | 74 | 119 |

The following figures show the pavement cleaning performance for different conditions, vs. the cleaning effort, contrasting mechanical and vacuum pavement cleaners. The first two plots show the effects of the obstructions due to the planter areas at the end of the interior parking rows, while the third plot indicates the effects of the mechanical cleaner only operating along the outer curb edge, compared to the vacuum being able to operate along the outer edge and the inner area.




Pavement Cleaning Performance with Curbs with Minimal Obstructions
Percentage SSC Concentration Reduction
50
45
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
180
Number of Pavement Cleanings per Year
vacuum
mechanical


Pavement Cleaning Performance with Outer Curbs and Vacuum only in Non-Curbed Area
Percetage of SSC Concentration Reduction
50
45
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
180
Number of Pavement Cleanings per Year
vacuum
mechanical

The following are the important aspects of pavement cleaning:

- Paved areas need to be divided into subareas, such as corresponding to outer edges with curbs, internal areas with or without curbs and obstructions, and driving lanes, with each subarea's cleaning benefits calculated separately and the total area cleaning benefit determined by area-weighting. If parking is only along the outside edge, then only two subareas would be used: the outer area (with curbs normally) and the central driving lane.
- The long-term cleaning performance is based on the WinSLAMM street dirt accumulation, washoff, and street cleaning procedures for the same land use and pavement texture conditions as the paved parking and storage areas. The percentage SSC concentration reduction for this equivalent street is then used to modify the paved area SSC concentration. Obviously, this is a continuous calculation that is performed for each rain separately.
- Vacuum cleaners can operate in the absence of curbs, while mechanical cleaners should not as they re-distribute substantial material out of the cleaning area.
- Obstructions need to be considered for equipment having large turning radiuses, while smaller pavement cleaners are more maneuverable with less obstruction problems. Obstructions also increase with the presence of parked vehicles or materials that need to be avoided and not cleaned.
- Driving lanes in parking areas are assumed not to be cleaned as the vehicle turbulence keeps these areas below the particulate loadings for removal. However, if the model user considers these areas unusually dirty, they can be cleaned by vacuum pavement cleaners (but not by mechanical cleaners, unless they have curbs).
- Very rough pavement should not be cleaned as the residual loads remain very high with little water quality benefit.

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