Real World Street Cleaner Pickup Performance Testing

by Roger Sutherland, P.E.
Principal Water Resources Engineer, AMEC Earth & Environmental, Inc.

A great deal of controversy surrounds the question of how much of the pollution found in urban stormwater runoff can street cleaning remove? For an accurate assessment of cleaning effectiveness, pickup performance data is needed for the various street cleaner models currently available.

Since the early 1980's, the author has conducted numerous pickup performance tests for a wide range of sweeper types and models. A major challenge for any test design is the ability to recreate real world conditions in a controlled and measurable manner. These real world conditions relate to the amount, location and physical characteristics of accumulated test material, the characteristics of the test track like pavement type and condition and whether it is curbed, and the characteristics of the sweeping operation itself such as the forward speed of the sweeper and the use of water for dust suppression.

In July 2008, Pacific Water Resources, Inc. (PWR) (now merged with AMEC Earth & Environmental, Inc.) conducted a series of street dirt pickup performance tests for four different sweeper models that included two different regenerative air machines, along with a vacuum and a mechanical machine. The purpose of these tests was to measure the street dirt pickup efficiency for these various machines operating under conditions that are typically found throughout the country. The purpose of this paper is to describe the important characteristics that can affect street sweeper pickup performance and document the test protocols that were used along with the results that were obtained.

The paper will also briefly review the history of street sweeper performance testing dating back to the early 1970's. The discussion will address the different sampling and testing protocols that have been used and the pros and cons of each. Finally, the paper will discuss why street cleaner pickup performance testing is an important practice that should be implemented on nationwide basis by a consumer organization or federal agency.

HISTORY OF STREET CLEANER TESTING

Dr. Robert Pitt was first to conduct street cleaner pickup performance tests for stormwater quality improvement in the late 1970's as part of his EPA funded San Jose CA study (Pitt, 1979). The street dirt sampling protocol used was developed in several previous studies (Sartor and Boyd, 1972; Pitt and Amy, 1973). This protocol is has been predominately used in subsequent street sweeper testing efforts (Pitt and Shawley, 1981; Pitt and Sutherland, 1982; Pitt and Bissonnette, 1984) as well as more recent studies (CWP, 2008; Selbig and Bannerman, 2007; City of Seattle, unpublished).

With this protocol street dirt collection occurs throughout a study area randomly at a number of locations. Collection is done with an industrial vacuum cleaner (shop-Vac) having a stainless steel canister powered by an electric generator, using a wand attachment that is referred to as a gobbler. The sample collector randomly selects a location along the curb and slowly pulls the gobbler in a straight line extending from the curb to the centerline of the street.

Any material accumulated along this randomly chosen six inch wide path is vacuumed up. By keeping tract of the number of these gobbler pulls obtained before the vacuum canister is emptied, the length of curb sampled can be computed and the street dirt loading usually expressed as pounds per curbed mile is computed. Depending on when this sampling occurs, it will either establish a "before sweeping" or "after sweeping" sample.

The pros for this random sampling protocol are that it is easy to implement and does not require much time. Nor does it require any direct coordination with the street sweeper operator outside of knowing that you sampled the day before or the day after a sweeping occurred. Many people like it because its random nature seems to fit the random nature of stormwater itself. This protocol works well if the objective is to establish average street dirt loading throughout a study area. However as a protocol for measuring the pickup performance of a street cleaner it has some serious drawbacks.

PROBLEMS WITH THE TYPICAL STREET CLEANER TESTING PROTOCOL

The testing protocol usually requires that the "before sweeping" sampling be conducted a day or two before the actual street sweeping occurs. To determine the amount of material left behind an "after sweeping" sampling is usually conducted a day or two after the street sweeping occurs. To compute the pickup performance of the sweeper, the before and after street dirt loadings are calculated along with a pickup percentage.

The obvious problem is that many hours and even days lapse between these two samplings. Research on street dirt accumulation has shown that the highest rate of accumulation seems to occur immediately following a cleaning or a significant wash off of material. So with this protocol you really don't know the exact street dirt loadings immediately before and after the actual sweeping. Second, nothing is known about the cleaning operation conducted.

For example, forward sweeping speed has been shown to be a very important variable in the effectiveness of street cleaner particulate pick up (Sartor and Boyd, 1972). If the speed of the sweeper is not known because it was not specifically measured or observed, then the pickup results are of very limited value since operational changes can't be implemented to help improve pickup performance.

Parked cars are another obvious problem. If parking restrictions have not been imposed or imposed but not effectively enforced, then random sampling will randomly sample areas that have not been swept. How representative is that when making an estimate of sweeper pickup? The few times that the author used this type of sampling protocol, he has always instructed the sample collectors to not purposely sample a location that they can see or suspect was not swept.

That works if your technicians are diligent and seek to do a good job. But what happens when the before sweeping loadings are very low so it becomes difficult to determine what section of the curb was or was not swept. This kind of uncontrolled variability has led to very poor pickup performance results that are inappropriately attributed to the machine that was used or its operation.

The preferred street cleaning testing protocol involves the establishment of a specific test area of a known length and a known initial loading. The street cleaning operation is observed and photographed with forward sweeping speeds timed. Immediately following the cleaning a sampling that essentially vacuums up everything left behind on the test track. The protocol requires considerably more time but it provide the most accurate measurement of street cleaner pickup performance.

The author pioneered this type of performance testing back in the mid 1990's. This preferred protocol was developed as a way of obtaining particle size specific pickup performance parameters needed for the accurate simulation of street cleaning pickup (Sutherland and Jelen, 1997). This work was done as part of various municipal stormwater planning projects that included the estimation of stormwater pollutant loadings and the pollutant removals from various street cleaning operations using the SIMPTM program (Sutherland and Jelen, 1998).

PROBLEMS WITH THE TYPICAL STREET CLEANER PICKUP DEMONSTRATION

The concept of the preferred test protocol described previously originated from the desire to correct the obvious mistakes that were being made during the various demonstrations of new street cleaner pickup performance observed by the author. Typically a very large amount of material including assorted debris like hubcaps, for example, is laid down on a parking lot or paved public works yard. While municipal officials and invited guests watch, each competitive sweeper takes a few passes at the pile. The winner is often the machine which most of the observers subjectively agree left the least amount on the ground. The problems with this type of test are many.

First, a curbed street which is the typical street being swept in their sweeping programs was never used. Second, the officials running the test generally allow multiple passes but the street sweeping operations they manage rarely involve multiple passes since funding usually limits the number of area wide sweepings that can be performed each year. Third, the forward speed of the sweeper is never specified nor measured.

As a result the sweeper operator (who is generally an employee of the manufacturer or dealer and really wants to do a good job showing the new machine) will usually operate the machine at a very slow speed of only 1 or 2 mph. Typical forward operating speeds in a sweeping operation are around 4 to 6 mph. Fourth, the magnitude of the material and debris placed is never measured or weigh and it usually is much greater than what a sweeper would typically encounter during its operation.

And, finally, the particle size distribution (PSD) of the particulate material used is never known. The ability of a street cleaner to pickup fine particulate material under typical loading and operational conditions should be the most important consideration when trying to maximize the pollutant reduction benefits of a municipal sweeping program.

Real world conditions mean curbed streets with at least fair pavement conditions an a single pass of the cleaner operating at a reasonable forward sweeping speed with typical street dirt loadings and particle size distributions and representative (PSD). The final testing protocol reported herein was further improved from recent experiences with two separate testing efforts. The first involved pickup performance testing for nine different models of street cleaners conducted for the City of Seattle Public Utilities.

The results of these tests were used by the City of Seattle's Department of Transportation to determine the manufacturer and model of a new street cleaner that was acquired for a street cleaning pilot study. These test results were presented at STORMCON 2006 and published in the proceedings (Sutherland and Martin, 2006). The second effort was a 2007 pickup performance testing of two different types of three-wheeled mechanical sweeper models that the District of Columbia Department of Public Works was considering for acquisition.

FINAL TESTING PROTOCOL

Since the testing was expected to occur over a number of days it was important that the test could be repeated under similar dry weather and low wind conditions at the same location on any given day. Dry weather conditions are needed since the test involves the use of a street dirt stimulant whose remaining amount after the sweeping operation is removed using the vacuum cleaner (i.e., shop-vac). It was also important to select a site that had essentially had no traffic or could be closed to traffic. Most importantly, the test site needed to have a curb with at least fair pavement conditions similar to the conditions generally encountered by the street sweepers on their route. Given these requirements, it was decided to conduct the tests at a parking lot under a large tent.

The test protocol is simple. A known quantity of the street dirt simulant is spread evenly along the test track curb line using a fertilizer spreader whose spreading width is approximately two feet. A street sweeper then performs a single pass at a specified forward speed. This is checked with a stop watch. Digital photographs are taken before during and after the sweeping operation.

Before the test material is actually applied, the sweeper operator practices several sweeping passes that are timed. This ensures that the operator will successfully execute the desired sweeping speed when the actual test is performed. Also, these practices runs ensure the track is very clean before the stimulant is applied.

Following the sweeping, the stimulant remaining on the pavement is removed with the shop-vac previously described. After the hand cleaning the vacuum hose is elevated and shaken several times to ensure that all of the pebbles have traveled to the canister, the vacuum is turned off and the canister is carefully opened in a working area protected from any wind. The small micron Dacron filter cloth (that is covering the canister to separate the machine's built in air filter from the captured material) is tapped several times by a clean, brand new paintbrush before it is very carefully removed and brushed to dislodge material trapped on the canister side of the filter cloth which is then carefully transferred to the canister. A new Dacron filter was used after each test and a new paper filter was used for each day of testing.

The captured material is transferred from the vacuum canister to a plastic zip lock bag using a paintbrush. This delicate operation requires two people to ensure that none of the captured material is spilled. Some loss of dust will occur and should be expected but its mass weight is generally very small and not significant enough to meaningfully influence the results. The bag is sealed and labeled. The bag is weighed in the field. The material is taken to a soils lab where it is weighed, dried, weighed again and sieved into eight pre-selected particle size groups. A single representative sample of the simulant is also sieved to determine its PSD.

Before the application of the test material for the first test, the test track and its approach section is swept several times by the sweeper waiting to be tested as noted earlier and then hand vacuumed as described earlier. However this sample is not retained but discarded instead. Between tests, the test track and approach section are only swept several times and not hand cleaned again. If water is used in these pre-test sweepings able time is needed for the track to completely dry before the next test material is applied. If water is used during a test, as was the case for one of these tests, then able time is needed for the track to completely dry before the sample collection using the vacuum starts.

LOGIC ASSOCIATED WITH THE TESTING PROTOCOL

Pavement conditions are known to significantly affect the pickup performance of street cleaners (Sartor and Boyd, 1972). Street sweepers have considerable difficulty effectively picking up particulate material from streets whose pavements are classified as poor since this usually means numerous surface cracks and deep depressions where dirt accumulates. The uneven surfaces that accompany poor pavement conditions also make it more difficult for the sweepers to operate effectively.

Research has shown that when sweeping streets with poor pavement a large portion of the material removed may be the street pavement itself. The selected test track should be representative of the average pavement conditions that are likely found within a given city or county which would most likely be classified as fair to good. The test track selected for the testing reported herein had fair pavement conditions with numerous pavement cracks that where sealed which is a common practice used throughout the country and especially in areas that experience a lot of freeze and thaw.

Barriers such as street curbs or New Jersey barriers are known to have a significant effect on both the accumulation of street dirt and the ability of street cleaners to effectively pick up the accumulated material. The San Jose study found that residential asphalt streets in fair to good conditions with medium to light parking density had approximately 58 to 73% of the street dirt accumulation located within 2 feet of the curb (Pitt, 1979).

Street dirt monitoring throughout six cities at bus stops where no parking was allowed found that 90% of the solids were located within one foot of the curb (Sartor and Boyd, 1972). The test track selected herein included a curb and the street dirt simultant was applied within two feet of the curb which matches the across the street distribution observed throughout the country.

The length of the test track is also very important. The longer the length of the test track the longer it takes to prepare the test and hand vacuum the remaining amount. If the test track is too short, the mass of the remaining material could be too little to effectively measure its particle size distribution. The 50-foot test track length used herein provided plenty of length needed to balance these competing factors.

As mentioned previously, the forward speed of a street cleaner will affect its ability to pickup particulate material. The pickup effectiveness increases as the forward speed decreases (Sartor and Boyd, 1972). The machine operator was instructed to clean at approximately 5 miles per hour which is generally considered the optimum operating speed given the trade off between pickup performance effectiveness and the need to sweep a certain number of miles a day. Operating at 5 miles per hour, it only takes about 7 seconds to sweep the 50-foot long test track. Since the testing protocol called for measuring the actual time it took the cleaner to clean the test track the actual sweeping speed for each test was known.

Fugitive dust losses were not measured. This means that dust from the simulant entrained during the testing that settled behind the curb could not be vacuumed up. It is assumed to be captured by the sweeper instead. This is an obvious source of error. Measurement errors due to fugitive dust losses that are generally considered to be quite small and will only effect the pickup performance calculations for the two smallest particle sizes fraction of less than 125 microns.

Because of dust concerns, mild wind conditions are desired during testing hence the use of a tented test track. In addition, each of the sweepers where photographed during testing. Fugitive dust losses where then qualitatively assessed using these photographs. It should be noted that two of the sweepers tested were equipped with fugitive dust collection technologies, the Elgin Crosswind (NX) and the Eagle (FW).

STREET DIRT SIMULANT

One of the most important aspects of a street cleaner pickup performance test is the amount and particle size distribution of the street dirt that is used. The magnitude and PSD of accumulated street dirt has been investigated in the United States starting in 1969 when the historic APWA Chicago study of urban runoff pollution sources was conducted (APWA, 1969). The author is unaware of any significant street dirt accumulation or particle size data set for the Chicago metropolitan area where the test was conducted.

The test quantities used for these tests were based on the range of street dirt accumulations that had been observed in Winston-Salem, North Carolina (North Carolina DNR, 1983) as part of the Nationwide Urban Runoff Program (NURP) conducted in the early 1980's (USEPA, 1983). That study found that street dirt accumulations generally ranged from 300 to 1000 pounds per curb mile. The test for each machine used 7.5 lbs (3405 grams) of simultant applied along the 50-foot test track that is equivalent to 792 lbs per curb mile (225 grams per curb meter). Thus, the initial accumulation used in these tests is well within the range observed in the Winston-Salem data set and very typical of what has been observed throughout the country.

One of the largest street dirt data sets was collected in Bellevue Washington in the early 1980's also as part of the NURP (Pitt and Bissonnette, 1984). Street dirt was monitored throughout five small urban watersheds and approximately 600 samples were collected over a two-year period. Each of these 600 street surface samples was separated into eight different particle sizes. Figure 1 (Pitt and Bissonnette, 1984) shows the PSD for each of these five areas observed during the two dry seasons that were monitored.

These size distributions show that the smallest particle sizes account for a relatively small fraction of the total particulate material. This was especially true during the wet season when the rains were most effective in removing the smallest particles. The larger particle sizes also accounted for relatively small fractions of the total sediment weight. Most of the street surface particulates were associated with particles in the size range of 125 to 1000 microns.

The underlying objective was to create a street dirt simulant that was as close as possible to the overall particle size distributions found in Bellevue during dry season conditions. The materials needed to create the simulant mixture had to: (1) be available in relatively small quantities; (2) have a known PSD so the proper recipe could be designed; and (3) have the same specific gravity of real street dirt, which is approximately 2.6.

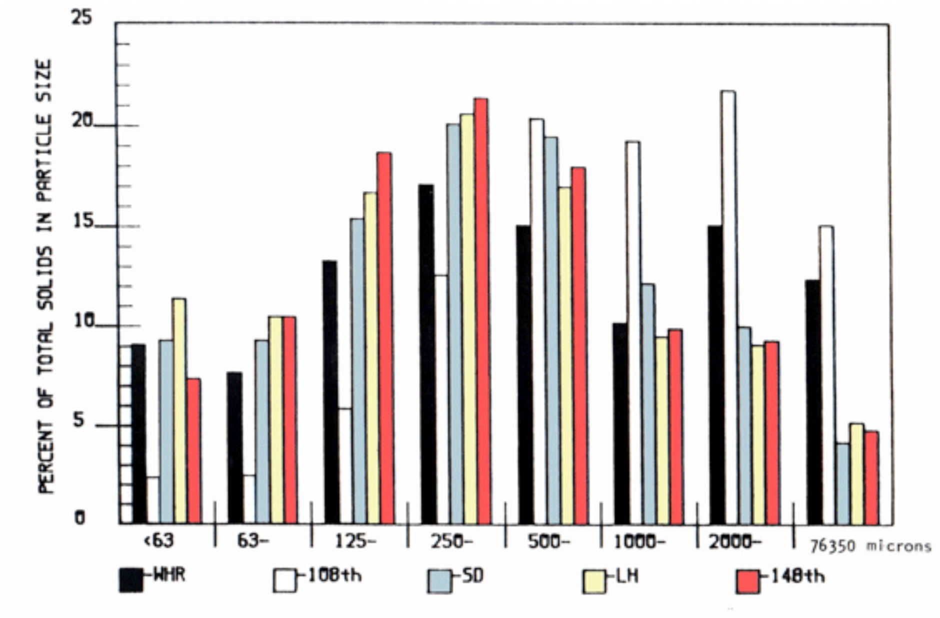

Figure 1 - Dry Season Particle Size Distributions in Bellevue, Washington

The PSD of the resulting street dirt simulant that was used is presented below in Table 1 along with a comparison to the average PSD from the Bellevue NURP data.

A comparison of the PSD's presented earlier in Figure 1 to that of the simulant clearly shows that the simulant was somewhat finer than the average street dirt observed in Bellevue. For example, approximately 57% of the simulant was in the 125 to 1000 micron range compared to only 51% in the actual Bellevue street dirt. Only 17% of the simulant was greater than 2000 microns compared to approximately 21% for the Bellevue street dirt.

However, the amount of material in the finest two fractions matched very well with 16.9% of the simulant was less than 125 microns and the average observed in the Bellevue street dirt was essentially the same at 16.7%. Even though the PSD of the simulant didn't match exactly as planned, the use of a simulant is still preferred since the initial quantities and PSD are known. As a result, both total pickup performance and pickup performance by particle size (PS) group can be computed.

Table 1 – Particle Size Distribution (PSD) of Street Dirt Simulant

PS No.	Sieve No.	Size Range (microns)	Bellevue NURP Average Incremental Mass (%)	Simulant Incremental Mass (%)	Percent Retained	Percent Passing
8	1/4	>6370	8.2	0.0	0.0	100.0
7	10	2000-6370	13.0	16.9	16.9	83.1
6	18	1000-2000	11.8	10.8	27.7	72.3
5	30	600-1000	17.8	7.1	34.8	65.2
4	60	250-600	19.1	19.4	54.2	45.8
3	120	125-250	14.2	30.1	84.3	15.7
2	230	63-125	8.0	7.1	91.4	8.6
1	Pan	<63	7.9	8.6	100	0.0

The Bellevue street dirt data also showed that the average dry season accumulations ranged from 160 to 920 lbs per curb mile (i.e. 45 to 259 grams per curb meter), depending on several factors like land use and traffic (Pitt, 1985). As stated previously, the tests were designed to simulate initial accumulations of 792 1bs per curb mile (225 grams per curb meter) that is well within the range of the average accumulations observed in Bellevue.

SWEEPER MODELS TESTED

Five controlled pickup performance tests on four different Elgin sweeper models were conducted over a three-day period at a curbed test track under a tent that was erected on a parking lot located in University Park, Illinois. Two different regenerative air based Crosswind models where tested. The standard Crosswind and a prototype Crosswind NX high performance with dust control.

The new waterless Elgin Eagle (FW), designed with shrouded gutter brooms and vacuum assist that transports dust to the hopper, was tested both without and with water. The Eagle is a mechanical machine with main broom action and a conveyor used to entrain and transport sweepings to its hopper. The truck-mounted vacuum based Whirlwind (MV) was also tested.

TESTING RESULTS

The overall pickup performance results from the five tests are presented in Table 2. And, the remaining material in each particle size (PS) range that was measured through the use of sieve analyses is presented below in Table 3. The pickup efficiencies computed for each of the particle size ranges is presented in Table 4.

As noted previously fugitive dust losses where not measured. And would only affect the remaining material measured in the two smallest PS ranges (i.e. less than 125 microns). Some fugitive dust losses occur in the process of transferring the collected material from the stainless steel vacuum canister to the plastic container bags.

It is largely believed that these losses are small in comparison to those from the sweeping operation. Qualitative analysis of the photographs taken during sweeping indicated that no visible fugitive dust losses occurred during the Crosswind (NX) test since it was equipped with fugitive dust control The fugitive dust losses observed when the Eagle (FW) was being tested (both with and without the use of the water spray) were very low. This is due to the shrouded gutter broom design with the vacuum assist that transport fugitive dust generated by the gutter brooms directly to the hopper.

Table 2 – Overall Pickup Performance Test Results

Model	Type	Remaining Mass (gms)	Initial Mass (gms)	Pickup Mass (gms)	Pickup %	Forward Sweeping Speed (mph)
Crosswind (NX)	Regenerative	85.6	3405	3319.4	97.5	4.7
Crosswind	Regenerative	121.1	3405	3283.9	96.4	4.9
Whirlwind (MV)	Vacuum	221.1	3405	3183.9	93.5	5.1
Eagle (FW)	Mechanical	288.3	3405	3116.7	91.5	4.9
Eagle (FW) with water	Mechanical	646.0	3405	2759.0	81.0	4.7

Table 3 – Remaining Material by Particle Size Range (grams)

PS No.	Size Range (microns)	Crosswind (NX)	Crosswind	Eagle (FW)	Eagle (FW) with water	Whirlwind (MV)
7	2000-6370	3.8	3.5	23.6	24.6	4.4
6	1000-2000	5.6	4.6	24.6	32.3	6.8
5	600-1000	5.2	4.7	16.7	28.4	8.9
4	250-600	13.6	15.9	43.5	104.7	43.1
3	125-250	23.4	44.3	91.4	287.3	106.1
2	63-125	7.2	17.0	24.5	75.6	32.7
1	<63	26.8	31.1	64.0	93.1	19.1

Table 4 – Pickup Performance Efficiencies by Particle Size Range (Percent of Initial Mass)

PS No.	Size Range (microns)	Crosswind (NX)	Crosswind	Eagle (FW)	Eagle (FW) with water	Whirlwind (MV)
7	2000-6370	99.4	99.4	95.9	95.8	99.3
6	1000-2000	98.5	98.7	93.3	91.2	98.2
5	600-1000	97.8	98.1	93.1	88.3	96.3
4	250-600	97.9	97.6	93.4	84.2	93.5
3	125-250	97.7	95.7	91.1	72.0	89.6
2	63-125	97.0	93.0	89.9	68.7	86.5
1	<63	90.8	89.4	78.1	68.2	93.5

DISCUSSION OF THE RESULTS

The pickup results were excellent and order of the machine performance conformed to preconceived expectations. The regenerative air based Crosswind (NX) model with dust control performed the best as expected with an impressive overall pickup efficiency of 97.5%. The second best performer was the standard regenerative air Crosswind at 96.4% overall.

Regenerative air machines are generally considered the best overall performers in particulate pickup. The standard Whirlwind (MV) vacuum machine was third with an overall pickup efficiency of 93.5%. Vacuums are classified as air machines but are generally though to provide less pickup when compared to regenerative air machines.

The waterless Eagle (FW), which is a mechanical machine, finished in fourth place overall with a pickup efficiency measured at 91.5%. Mechanical machines are the most popular in the country but are known to provide lower particulate pickup when compared to air machines. The pickup performance of the Eagle (FW) was very good though with numbers that qualify it to be classified as a high efficiency cleaner just like the air machines that were tested.

The fifth place finisher was the mechanical Eagle (FW), operating with a water spray. This machine had an overall pickup efficiency measured at 81.0%. This was also expected, since researchers have known for some time that the use of water spray to control fugitive dust reduces a machine's ability to pickup particulate material. In fact, the Eagle test that used water spray was some 10.5 % lower than the measured pickup of the Eagle without water. The particle size (PS) data shows the use of water results in a significant amount of additional material remaining on the street for particles less than 1000 microns.

The use of water resulted in a 121% increase in the remaining mass for particles 250 to 1000 microns in size and a 153% increase in remaining material for particles less than 250 microns. So the take home message for communities throughout the country is that if the removal of pollutants from stormwater is an important objective of your cleaning program then the use of water to suppress dust doesn't help. Programs like these should consider switching to high efficiency sweepers like those tested here. And if fugitive dust losses are a concern then sweeper models that provide effective fugitive dust capture like the Crosswind (NX) and the waterless Eagle should be used.

There is a heightened amount of concern for the pickup performance of the finest particles (i.e., less than 63 microns). As expected, all of the regenerative air and vacuum machines outperformed the mechanical one in this regard although the waterless Eagle (FW) was impressive with a 78.1% removal of these fine particles. It is interesting to note that the vacuum machine's fine particle pickup percentage of 93.5 was slightly better than those observed for both regenerative air machines of 89.4 and 90.8. However, these pickup percentages are very competitive and this alone should not be the deciding factor when selecting a sweeper model.

NEED FOR UNIVERSAL TESTING OF STREET CLEANER PICKUP PERFORMANCE

Over a decade ago the author called for universal testing of street cleaner pickup performance (Sutherland, 1997). With the increased regulation of stormwater runoff through the NPDES program, the need for street cleaner particulate pickup performance data on available municipal sweeper models is greater today than ever before.

If this were undertaken, public works personnel concerned about the quality of their community's stormwater could make informed buying decisions on the type and specific models of street cleaners they acquire. Testing of this magnitude would need to be conducted by a Federal agency, a consumer organization or perhaps a power sweeping industry trade association that currently doesn't exist.

The author would love to be involved in the establishment of the testing protocols and the overseeing of the initial tests. The work reported herein has achieved the underlying goal of real world conditions for street cleaner pickup performance testing and represents a model protocol that could be used for these universal tests

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The author of this article is Roger C. Sutherland, P.E.
Principal Water Resources Engineer
AMEC Earth & Environmental, Inc.

You may reach him via email sent to: Roger.Sutherland@amec.com
Telephone: (503) 639-3400. Website: www.amec.com/divisions/earth_and_environmental/overview/introduction.htm

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