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Street Sweeping – Report No. 1
State of the Practice

Ramsey-Washington Metro Watershed District

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Executive Summary

The Street Sweeping Project is organized into the following three reports:

1. Street Sweeping – Report No. 1, State of the Practice
2. Street Sweeping – Report No. 2, Survey Questionnaire, Results and Conclusions; and
3. Street Sweeping – Report No. 3, Policy Development and Future Implementation Options for Water Quality Improvement.

The reports are the information base for the Ramsey-Washington Metro Watershed District to advance efforts to improve water quality within its jurisdictional boundaries. In addition, the reports serve as an education tool for members of the Ramsey–Washington Public Works Forum and other public works staff within Minnesota and across the United States and Canada. The Ramsey-Washington Public Works Forum is a monthly discussion group focused on increasing communications and collaboration related to stormwater quality improvement concerns of the city and county governments within the Ramsey-Washington Metro Watershed District.

Street Sweeping – Report No. 1, State of the Practice summarizes and analyzes recent literature, WEB search reviews, personal communications with pertinent industry experts and yet-to-be-completed street sweeping research projects.

Street sweeping equipment has evolved significantly in the last 15 years and will continue to do so as two aspects relating to the practice move forward. First, Phase 1 and 2 storm water permits and associated Storm Water Pollution Prevention Plans (SWPPP) will likely become more comprehensive as regulatory agencies require further controls on non-point source pollution. With Total Maximum Daily Load (TMDL) studies being completed over the next ten years, these same permits will contain more stringent requirements. Street sweeping equipment and the associated practice will be looked at more favorably as a cost-effective non-point source control measure.

Second, additional research studies may shed information on street sweeping as a practice that improves water quality. Subsequently, this may result in equipment and operational upgrading that may produce more fuel-efficient sweepers, greater use of waterless sweepers or implementing new technology (e.g. captive hydrology). Regulatory requirements and research findings may drive street sweeper manufacturers to respond to an increasing market for newer technologies.

Mechanical brush sweepers are effective at removing coarse materials and gross pollutants. They are less effective removing fine materials often associated with various pollutants and may expose such materials to wash-off. High-efficiency street sweepers and associated operations may increase the percent of total solids removal from 30 – 70+%. Street sweeping frequencies approximately monthly to biweekly and varied depending upon land use and transportation features have been shown as being most effective for pollutant removal.

As a pollution control practice, street sweeping is cost-effective when compared to structural best management practices such as detention ponds, and settling or filtering devices and prolongs their operational efficiency and required maintenance. As a pollution prevention or source control measure when integrated with other structural and non-structural BMPs, high-efficiency street sweeping improves water quality and reduces ongoing habitat deterioration.

Report No. 1 has not identified definitive studies pointing to receiving water quality improvement as a direct result of street sweeping alone. However, as a pollution prevention or source control measure when integrated with other structural and non-structural BMPs, high-efficiency street sweeping improves water quality and reduces ongoing habitat deterioration.

A 2004 mathematical optimization study for BMPs provided information on which storm water management strategies are likely to be cost-effective in reducing non-point pollution and which are not. Sweeping of commercial areas will likely be a priority while residential areas will not. The optimization model study shows insensitivity to a reasonable range of street sweeping costs, but sensitivity to sediment removal effectiveness. This suggests it is more important to address sediment removal effectiveness for street sweeping rather than cost.

The following are suggested topic areas for further research as it relates to street sweeping:

- **High-efficiency sweeping and water quality improvement**;
- **Street sweeping as a component in subwatershed modeling**;
- **Disposal of street sweepings and recycling practices**;
- **Life cycle costing of street sweeping practices; and**
- **Integration of street sweeping practices into local government MS4 permits**.

Introduction

The Ramsey-Washington Metro Watershed District (RWMWD) is a regional government located in the northeastern portion of the Minneapolis – St. Paul Metropolitan Area. RWMWD covers approximately 52 square miles draining into the Mississippi River and includes 5 major creeks, 11 lakes and 750 wetlands. The RWMWD jurisdictional boundary includes all or part of 10 cities in Ramsey and Washington counties: St. Paul, Woodbury, Oakdale, Landfall, North St. Paul, Maplewood, Little Canada, White Bear Lake, Vadnais Heights and Gem Lake.

Resident complaints and inquiries are received by District staff regarding concern over the volume of street sand, leaves, grass clippings, dirt, fertilizer and their impact upon lakes, ponds, streams and wetlands. Local governments in the District face mandates from their governing bodies and the Minnesota Legislature to be more cost efficient ("do more with less"), but continue to assure public health, safety and welfare of its citizens.

During the 1990s and early 2000s, state and federal regulators began to regulate municipal storm water under the National Pollutant Discharge Elimination System (NPDES) permit program with the advent of Phase 1 and Phase 2. Looming on the horizon is the need for local governments to participate as stakeholders in the Total Maximum Daily Load (TMDL) program. The TMDL regulatory program is directed at improving water quality for impaired waters listed in a state after Section 303(d) of the Clean Water Act through reductions in point and non-point source discharges. The TMDL process may result in more stringent Phase 1 and Phase 2 - storm water discharge permits.

The RWMWD is a Phase 2, NPDES permit holder through ownership and operation of infrastructure constituting a **m**unicipal **s**eparate **s**torm **s**ewer **s**ystem (a.k.a. MS4). Over the years, the RWMWD has constructed a number of structural stormwater treatment projects. These expensive structural treatment systems, while successful have initiated an interest in street sweeping as a potentially less expensive non-structural "source control" Best Management Practice (BMP). By investigating this source control BMP, the District was hopeful for two long-term outcomes:

1. Source control of pollutants would positively affect structural treatment control efficiency; and

2. Receiving water quality would improve.

In addition, the RWMWD's 1997 *Watershed Management Plan* discusses street sweeping as a standard non-structural BMP for nonpoint source control.

Central Question

Through the review and evaluation of literature and existing street sweeping operations, it's hoped the information gathered would answer the central question for Report No. 1:

- What is the street sweeping state of the practice and is there a relationship between street sweeping as a BMP and improving lake, wetland or steam water quality?

The RWMWD in collaboration with the 10 municipalities and 2 counties comprising the District is interested in gaining knowledge to answer this query and formulate a District-wide street sweeping program with goal, policies, BMP implementation recommendations and budget. Completing a street sweeping - state of the practice lays the groundwork in formulating a District-wide street sweeping program.

Secondary Questions

There are also secondary questions explored supporting the central query:

- What is known about street sweeping?
  - Brief History
  - Equipment available
- What are the areas of controversy regarding street sweeping?
- What are the research needs?

Answering these questions is supported with a street sweeping annotated bibliography of street sweeping. The bibliography of 53 documents is not intended list all materials published or unpublished on the subject of street sweeping, rather it synthesizes and evaluates suitable information from the last five to eight years addressing the central question. A more complete list of 74 street sweeping documents follows in the References section.

What is known about street sweeping?

Streets are built and maintained for vehicle use. Safety is the primary concern for the traveling public with time of travel and accessibility concerns being secondary. Wildlife managers view streets as migration hazards. Urban storm water managers view streets and associated the storm water drainage systems as a collector and transmission system for runoff discharged to receiving waters. Streets are the chief collection and removal points for vehicle-related pollution, atmospheric pollutant deposition, vegetation accumulation, construction-related sedimentation, trash, chemicals and sand particles from winter snow and ice management and materials from normal street deterioration.

Brief History

Street sweeping either manual or mechanical has been a normal operation for most municipalities for hundreds of years. The earliest sweepers were manual efforts using a broom, shovel with either push or horse-drawn carts. Street sweeping materials consisted of trash, dirt, vegetation and horse droppings. Thus, aesthetics and sanitation were the two driving forces for municipalities to keep streets clean and protect the citizens. The first motorized sweeper was developed in the early 20th century. The mechanical broom sweeper remains today by far the most common piece of equipment in the majority of cities to keep streets clean of gross pollutants (Report No. 2). Today, street sweeping materials have changed, with gross pollutants including more plastics and paper products than would have been present even 50 years ago along with discarded items associated with cars and trucks using the roadway.

During the 1970's, regenerative-air street sweeping technology came upon the scene. Coincidentally, the 1968 Federal Water Pollution Control Act Amendments (current Federal statute is the Clean Water Act of 1987, as amended) were enacted and regulatory requirements included pollutants from point and non-point sources. Local government and industry needed to address these new regulatory terms as well as receiving water quality. During the period of the mid-1980's and early 1990's, the Clean Air Act had an increasing impact upon southern California with respect to fugitive dust emissions.

PM_{10} Issue

In the late twentieth century, the South Coast Air Basin (Orange County; parts of Los Angeles, Riverside and San Bernardino counties) in California exceeded state and federal air quality standards for PM_{10}. PM_{10} , is particulate matter with an aerodynamic diameter of 10 microns or less, in this case primarily derived from fugitive dust (any solid particulate matter that becomes airborne other than that emitted from an exhaust stack, directly or indirectly as a result of the activities of man). Because of the exceedances, U.S. Environmental Protection Agency (U.S. EPA) designated the South Coast Air Basin as a "serious non-attainment area" for PM_{10}. Under the federal Clean Air Act (CAA), the South Coast Air Quality Management District (SCAQMD) was required to implement best available control measures (BACM) for fugitive dust sources. Sources of fugitive dust were agriculture, development sites, industry and streets, all to some degree affected by the semi-arid climatic conditions of southern California.

Street sweeping was a management practice identified by SCAQMD that could reduce the amount of fugitive dust on streets re-entrained into the atmosphere by vehicular traffic. However, street sweeping could not allow the fugitive dust situation to worsen, in fact it had to improve it. Street sweeping had to remove from the road surface a certain percentage of particles and not cause a "dust cloud" from its operation (brooms or from sweeper air discharged from the unit). Staff from SCAQMD developed a routine street sweeping control measure based on a demonstration project conducted by the University of California – Riverside, College of Engineering - Center for Environmental Research and Technology (CE-CERT) for the Coachella Valley Association of Governments. The project evaluated four vacuum-based (PM_{10}-efficient) street sweepers outfitted with filtration systems and one mechanical broom sweeper. The sweeping tests occurred within an artificial tunnel to determine the amount of material removed from the road and the amount of material re-suspended or vented by the equipment itself. The study determined that vacuum sweepers and mechanical broom sweeper were similarly effective in removing material from the road. However, the study also determined that two of the PM_{10}-efficient street sweepers represented an eighty percent (80%) reduction in PM_{10} particles re-entrained or vented from the sweeper. On this basis and utilizing BACM guidance provided by the USEPA, staff incorporated street sweeping into Public Rule 1186 adopted by SCAQMD in 1997 (SCAQMD, 2004).

While the rule was enacted in 1997, it was effectively delayed for three years while a testing protocol to certify sweepers for PM_{10} emissions was developed by SCAQMD staff working with sweeper manufacturers. Local governments were required by the Rule to replace existing sweepers with PM_{10} efficient models. The testing protocol was adopted by SCAQMD in 1999 (SCAQMD, 1999) and is known as Appendix A to Rule 1186. The protocol purpose was to assure that PM_{10} efficiency included both the sweepers ability to remove typical urban street loadings and limit the amount of PM_{10} entrained during the sweeping process (Appendix A to Rule 1186, Section 1.1 Purpose). Following is a brief summary of the PM_{10} testing protocol.

> Sweeping is conducted within a 200-foot long test track tunnel. Air quality monitors located on each end of the tunnel conduct ambient particulate matter air monitoring as fans blow air through it. The test tunnel track is paved with about half having curb. Thirty-eight (38 lbs.) of test material (90% by weight of washed sand and 10% Georgia Paint Pigment as calcium carbonate)[1] at the rate of 1,000 lbs. per curb-mile is spread across the test track for pick-up. The sweeper makes three passes through the test track at a speed no slower than a minimum of 4 miles per hour. After the sweeper runs, any test material left on the track is removed by a modified carpet cleaner or industrial scrubber and weighed. The material picked up by the sweeper is also

[1] The protocol provides no additional information on the Georgia Paint Pigment as calcium carbonate. It may be technical grade *fine ground* limestone with a particle size of 3 – 9μm or similar (Mineral and Pigment Solutions, Inc. http://www.mp-solutionsinc.com). Presumably, the material is added to simulate PM_{10} particles.

> weighed. The sweeper must demonstrate a greater than or equal to 80% pick-up efficiency and a normalized mass of entrained PM_{10} that is less than or equal to 200 mg/m based upon the ambient particulate matter air monitoring.

Achieving the entrained PM_{10} materials requirement is provided by the filtering mechanism onboard each sweeper. Thus having PM_{10} certification means a sweeper has achieved the 80% pick-up efficiency on the test track and entrained PM_{10} particles are filtered adequately to not exceed the 200 mg/m requirement based upon the ambient particulate air monitors. As of July 9, 2004, 54 street sweepers have achieved PM_{10} certification. They are listed on the SCAQMD WEB site (www.aqmd.gov) and include essentially all makes and models of street sweepers generally in use today. Interestingly, PM_{10} standards go into effect in Sweden in 2005 due to road dust from winter sanding operations and the use of studded tires (Stidger, R.W. 2003).

Equipment Available

The number of street sweeper manufacturers is limited in the United States, numbering less than ten. In general, street sweepers are a significant capital expenditure ranging from nearly $100,000 for mechanical broom sweepers to over $250,000 for high-efficiency vacuum-assisted machines. When compared to other heavy equipment (vactors, backhoes, dump trucks, loaders, etc.) for maintenance operations by state, regional and local governments, capital cost of street sweepers is typical. Street sweeper types fall into three categories: mechanical broom, regenerative-air, and high-efficiency units. Appendix A to this report, lists sweeper manufacturers, available models and common specifications for such equipment.

1. **Mechanical broom sweeper**

A significant percentage of the sweepers used in the United States are traditional mechanical broom sweepers. With some variations, the process removes debris by sweeping material with gutter brooms rearward into the path of a pick-up broom. The pick-up broom sweeps the material moving it upward with a conveyor system into a hopper. Most new mechanical sweepers have been certified to clean to the PM_{10} standard (SCAQMD, 2004).

Advantages: Ability to pick-up gross pollutants (trash, road debris, vegetation). Good for picking up wet vegetation, gravel and coarse sand. Some models can conduct dry sweeping operations. These units are very good in roadways with heavy loads of materials, such as seal coating operations.

Disadvantages: Mechanical broom sweepers are generally used for gross pollutant pick-up, not chemicals (soluble) adsorbed onto fine sands and silt particles. Because the sweeping action removes coarse materials, fine sands and silts become exposed for easy wash-off into storm sewers (Versar, Inc. 2002;

Minton, G.H. et al., 1998; Smith, K.P. 2002). The performance of these units may diminish substantially on poor pavement with cracks and uneven sections.

2. **Regenerative-air sweeper**:

While the California air quality situation requiring PM_{10} controls and sweeper certification resulted in industry equipment changes, mechanical sweepers were slowly being replaced or augmented by regenerative-air technology. Regenerative-air technology attempts to increase the removal of both coarse and fine materials on typical pavement with cracks or uneven sections where sediment would become lodged. To capture sediments, these sweepers are equipped with gutter brooms and a pick-up head. The gutter brooms direct materials towards the pick-up head. The regenerative-air process blows air into one end of the horizontal pick-up head and onto the pavement dislodging materials entrained within cracks and uneven pavement. The other end of the pick-up head has a suction hose that immediately vacuums out the materials within the pick-up head into a hopper.

Advantages: Ability to pick-up most gross pollutants (trash, road debris, vegetation) and especially coarse as well as some fine grained materials entrained within cracks and uneven pavement sections that mechanical brooms cannot reach. Significantly greater pick-up of soluble pollutants and fine road surface materials than mechanical sweepers and some units can operate in a dry mode (Minton, G.H. et al., 1998).

Disadvantages: In general, these units have difficulty in picking up wet vegetation and large road debris. Models are certified to clean to the PM_{10} standard and are used for more intense sweeping operations. The sweeping action of the gutter brooms and the pick-up head may still expose fine silts for easy wash-off into storm sewers. Particles that may not get picked-up are spread across the street surface under the pick-up head, sometimes making the street look dirty or streaked (Selbig, W. 2005).

3. **Vacuum sweeper wet or dry (high-efficiency)**:

In the last 15 years, vacuum street sweepers (a.k.a. vacuum-assisted or vacuum filter) were developed in an attempt to remove the coarse and fine materials within typical pavement structure. Both the regenerative-air and vacuum sweepers may be the technology that succeeds at providing routine cost-effective and pollutant source control. These units will have gutter brooms and strong vacuum head(s) for picking-up both coarse and fine materials. While some models use water as a dust suppressor, others can operate in a dry mode.

Advantages: Ability to pick-up most gross pollutants (trash, road debris, and vegetation). These units are believed to be more effective than regenerative-air and mechanical sweepers for pollutant removal associated with fine particles and can operate in a dry mode (Curtis, M.C. 2002; Shoemaker, L. et al. 2000).

Disadvantages: In general, these units do not pick up wet vegetation or large road debris. Models are certified to clean to PM_{10} standard and are used for more intense sweeping operations. The sweeping action of the gutter brooms may still expose fine silts for easy wash-off into the catch basin and storm sewers.

4. **Scrubbers and Captive Hydrology (high-efficiency)**:

Now in the early part of the 21st century, there are new technologies known as street scrubbers/cleaners and the Captive Hydrology technique invented in Great Britain, both are the latest innovations in street surface management. These are relatively new proprietary technologies developed to clean airport pavement surfaces. In general, they may include brooms for coarse and fine materials directed into a one or more pick-up heads. The pick-up heads may include a high-pressure washer system followed by intensive vacuum pressure. Relatively small amounts of water are entrained leaving a nearly dry pavement surface. Water is recycled within the machine (therefore reducing downtime for water augmentation). The initial application of this technology was for airport runway resurfacing (rubber and paint removal) to increase skid resistance and industrial applications where very clean surfaces are required. Thus, experience with typical roadway surfaces has yet to be reported extensively.[2]

The City of Olympia, Washington has included a Captive Hydrology street cleaner in its 2005 budget (2004 Annual Report to the Community, Storm and Surface Water Utility, Public Works Department, City of Olympia). The technology is discussed further within the City of Olympia, Storm Water Manual, Volume V (January 2005), http://www.ci.olympia.wa.us/publicworks/waterresource/stormsurfaceplan.asp.

Advantages: Fine sands and silts picked up the unit along with other priority pollutants in small concentrations. Ultra clean and nearly dry surface is left.

[2] The following WEB sites and vendor address provides some manufacturer and supplier information relating to Scrubbers and Captive Hydrology: http://www.veegservice.nl/site%20engels/index.htm, http://pavedsurfacetreatments.com/index.htm Water revitalizes roads at http://www.ringway.co.uk , and Cyclone Surface Cleaning, Inc., Tempe, AR 85282.

Disadvantages: Not yet a proven technique for routine roadway surfaces, especially worn pavement with cracks and uneven sections. The units have a high capital cost. Operation and maintenance cost information lacking for roadway surfaces. Efficiencies may be realized in dealing with "hot spots" within high pollutant generating areas. A tandem operation may still be necessary for routine operations.

Sweeping Operation Scenarios

There are several sweeping operation scenarios involving equipment worth discussing in the state of the practice. While only two examples are shown, it goes without saying that individual public works agencies may have different or unique operational scenarios that "get the job done".

1. **Tandem Operation (heavy loads)**:

Two machines, either two mechanical broom sweepers in tandem or a mechanical broom followed by a regenerative-air sweeper. First machine travels at a higher ground speed to pick-up a majority of the heavy material whether organic or inorganic. The second machine travels at a slower rate, conducting final clean up. Theoretically, such an operation would increase mileage efficiency, volume and thus requiring less time in the field.

Advantages: May be more labor and equipment efficient. Can be an option for residential areas where sweeping frequency is not as critical, thus "freeing up" equipment and labor for target "hot spot" areas requiring greater frequency.

Disadvantages: By definition, more labor intensive, but could be cost-effective because of increased efficiency.

2. **Tandem Operation (high-efficiency)**:

A two-machine operation, first a mechanical broom or regenerative-air sweeper and is followed by a vacuum sweeper. This operation was employed in several projects with success (Curtis, 2002; Sutherland & Jelen, 2003; and Lake Barcroft Watershed Improvement District, 2005).

Advantages: Ability to pick-up gross pollutants (trash, road debris, vegetation). Wet vegetation, sand and gravel picked up by first unit. Fine sands and silts picked up by second unit. Can conduct dry sweeping operations. Efficiency could be realized for "hot spots" by removing larger materials quickly followed by equally quick removal of fine materials.

Disadvantages: By definition, more labor intensive.

Street sweeping equipment has evolved significantly in the last 15 years and will continue to do so as two issues relating to the practice continue to move forward in a more rapid pace.

1. It is likely that the Phase 1 and 2 storm water permits and their associated Storm Water Pollution Prevention Plans (SWPPP) will become more comprehensive as regulatory agencies begin to require additional non-point source pollution control measures. With completion of TMDL studies over the next ten years, stormwater permits will likely have more stringent requirements. Street sweeping equipment and the associated practice will be looked at more favorably as a cost-effective source control measure.

2. Notwithstanding the scarcity of research grant funds available for street sweeping evaluations, it's likely additional studies will shed more information upon street sweeping as a practice that may improve water quality (Horwatich, J. 2005 and Selbig, W.R. 2005). Changes in operations or equipment will be identified resulting in equipment that is both more fuel-efficient and waterless sweeping may become the norm in the future. Research findings as well as regulatory requirements will drive sweeper manufacturers to respond to a likely increasing market for this technology.

What are the areas of controversy regarding Street Sweeping?

A number of controversial issues continue to surround the street sweeping practice. The following are two important issues regarding street sweeping: Sweeping Effectiveness and Street Sweeping Cost. While these issues are not new, they are paramount to moving this practice ahead as both an effective and acceptable best management practice.

Sweeping Effectiveness

While sweeping for water quality improvement is on the forefront of RWMWD's interest in completing this study, street sweeping historically has been implemented for aesthetic (litter or trash control) and sanitary reasons. Aesthetics and sanitary issues while important are not directly related to water quality improvement. The mechanical broom sweeper has and will continue to function very effectively in providing an aesthetically pleasing roadway appearance. On the West Coast and in Australia, mechanical broom sweeping effectively removes "gross pollutants"(Walker, T. A. & Wong, T.H.F. 1999). "Gross pollutants" are defined as trash (paper, plastic, metals, etc.), vegetation (leaves, twigs, grass clippings, etc.) and miscellaneous road debris (e.g. vehicle parts). Street sweeping as a integral practice to remove trash is contained within the TMDL Plan for the Los Angeles River watershed issued by the Los Angeles

Regional Water Quality Board in early 2001 (Allison, S. & Mehta, S., 2001). This "zero discharge" requirement must be achieved by 2013 (CRWQB, 2001). Therefore, street sweeping in both frequency and efficiency has increased for southern California governments (County of Los Angeles, 2004).

"Fine pollutants" are essentially everything else, but may be considered materials whose size fraction are not suited for effective pick-up by the mechanical broom sweeper. The size fraction often seen as less than or equal to approximately 65 microns in diameter is a significant contributor to pollutant loading if routinely left behind. The advent and use of regenerative-air and vacuum street sweepers has seen the percent of total suspended solids removal increase from approximately 30 to 70%, respectively (Sutherland, R. & Jelen, S.L. 1996). High-efficiency street sweepers and operations may increase the percent removal to 70+% (Minton, G. R., et al 1998 and USEPA, 2000).

The trend towards the use of high-efficiency street sweeping equipment appears to be increasing along with their recommended usage as borne out in several studies (California Coastal Commission, 2002; California Stormwater Quality Association, 2003; Federal Highway Administration, 2005; City of Livonia, 2001; City of Olympia, 2005; Sutherland, R.C. & Jelen, S.L. 2002; U.S. Environmental Protection Agency, 2000; and Venner Consulting & Parsons Brinckerhoff, 2004). Local government purchase and use of high efficiency sweepers may focus more on the need for pollution control and water quality improvement rather than aesthetics. Thus, street sweeping effectiveness begins first with the choice of the right equipment.

Sweeping Frequency

Street sweeping equipment type and associated efficiencies will be an ongoing decision-making process for the consumer. Knowing how often or the frequency of street sweeping remains an equally critical issue. A program of 30 street sweepings per year was suggested to reduce wash-off of total suspended solids by approximately 60% (Bannerman, R. 2002). The City of Dana Point, California (2005) increased sweeping removal amounts by 100% going from biweekly to weekly, thus supporting higher frequencies. Other studies and reports (Allison, S. & Mehta, S. 2001; California Coastal Commission, 2002; City of Livonia, 2001; Ontario Ministry of Environment, 2004; and Sutherland, R.C. & Jelen., S.L. 2002;) have identified street sweeping frequencies on the order of monthly to biweekly as being most effective for pollutant removal. However, street sweeping frequencies should be varied depending upon land use and transportation features (California Coastal Commission, 2002; Federal Highway Administration, 2005; and Venner Consulting & Parsons Brinckerhoff, 2004). The effectiveness of street sweeping is a function of both equipment and the frequency implemented. Frequency is addressed in more detail within Reports 2 and 3.

Are the range in removal efficiency for street sweeping and suggested frequencies effective? Yes, if looked at from two perspectives.

1. As a pollution control practice, street sweeping has been shown to be quite cost-effective. When compared to structural best management practices such as detention ponds, and settling or filtering devices, street sweeping removes pollutants at a lower cost per pound (USEPA, 2005; StormwaterCenter, 2005 and FHWA, 2005). Land, capital and construction costs relating to detention ponds and settling devices per unit of pollutant removal are significant variables affecting their expense.

2. As a best management practice, street sweeping prolongs the operational efficiency or maintenance of structural BMPs. Pollutant source control is a more efficient practice than allowing materials to traverse further into the storm sewer system or receiving water where removal is often more costly and less efficient (Versar, Inc., 2002; Lake Barcroft WID, 2005; and USEPA, 2004).

Is street sweeping an effective practice that will improve water quality? This report has not identified definitive studies pointing to receiving water improvement as a direct result of street sweeping. However, as a pollution prevention or source control measure when integrated with other structural and non-structural BMPs, high-efficiency street sweeping improves water quality and reduces ongoing habitat deterioration (USEPA, 2005; Lake Barcroft WID, 2005).

BMP Integrated Approach

Street sweeping is a particularly good BMP within ultra-urban land uses (Central Business Districts, commercial centers and industrial parks) that are either older in age and/or do not have land available for structural BMPs (FHWA, 2005). In such situations, frequent high-efficiency sweeping will have the greatest benefits (FHWA, Fact Sheet – Street Sweepers). Integrating storm water management using both structural and non-structural approaches is considered more effective than a single approach (County of Los Angeles, 2004; Taylor, T. A. & Wong, T. 2002b; U.S.EPA 2004; and Walker, T. A. & Wong T.H.F. 1999). For example, the U.S. Environmental Protection Agency's Phase 1 and 2 storm water permit programs implicitly require both structural and non-structural BMPs within the six minimum measures.

1) Public education and outreach;
2) Public participation;

3) Illicit discharge detection and elimination;
4) Construction site storm water runoff control;
5) Post-construction storm water management in new development and redevelopment; and
6) Pollution prevention/good housekeeping for municipal operations.

Design and construction of detention ponds, settling devices, catch-basin inserts and other structural BMPs would likely be included within minimum measures 4 – 6. Street sweeping as a non-structural BMP falls within minimum measure 6. Other non-structural measures such as educating the public on fertilizer use, low impact development techniques and their impact upon the environment are most often included in minimum measures 1 and 2.

While individual pollutants seldom are the sole impact upon a wetland or stream, their control through implementing BMPs often involves more than one approach for the greatest benefit. Effective storm water management requires a suitable balance between both structural and non-structural BMPs (Taylor, T. A. & Wong, A. 2002b). The County of Los Angeles, Public Works Department (2004) in compliance with its TMDL requirements recommends emphasizing two priority levels of non-structural practices:

First Priority Level

- Hydraulic disconnection and replacement of impervious surfaces;
- Increased street sweeping; and
- Increased private and public parking lot sweeping.

Second Priority Level

- Adjusting of private street sweeping contracts;
- Stricter enforcement of no-parking regulations;
- Encouragement/sponsorship of more public clean-up events;
- Increased or focused public education; and
- A dedicated hot line and response.

For the Ramsey-Washington Metro Watershed District and associated local governments, street sweeping as a non-structural BMP can lessen pollutant loading to existing detention pond facilities. In turn, this reduces required long-term maintenance burden from minimum measure #6 of the Phase 2 permit.

Street Sweeping Costs

As discussed briefly above, street sweeping is a cost-effective practice. While the initial capital cost for sweeper purchase can be quite high, ranging from $100,000 to $250,000+, the long-term removal costs per pound of materials when compared to other methods is on the low end. Tables 1 and 2 present estimated costs of street sweeping based upon several sources (Finley, 1996; SWRPC, 1991; Satterfield, 1996; and USEPA, 1999). Cost information has been updated to 2005 based upon Consumer Price Index and Employment Cost Index adjustments[3].

Table 1 Street Sweeper Cost Data (2005 dollars)

Sweeper Type	Life (years)	Purchase Price($)	Operation and Maintenance Costs ($/curb-mile)
Mechanical	5 years	$100,000	$40
Vacuum	8 years	$200,000+	$20

Table 2 Sweeping Costs Based Upon Frequency ($/curb-mile/year) [2005 dollars]

Sweeper Type	Sweeping Frequency					
	Weekly	Bi-weekly	Monthly	Four times per year	Twice per year	Annual
Mechanical	$2,235	$1,120	$520	$170	$90	$45
Vacuum	$1,260	$630	$290	$100	$50	$25

How do the above costs compare to published costs? Most local government street sweeping costs are based upon the unit of "dollars per curb-mile". The City of Livonia, Michigan (2001) study reported a street sweeping cost per curb-mile of $76.90, based upon 1998-99 dollars, sweeping of 3 – 7 times per year using broom and regenerative-air sweepers. The City of Jackson, Michigan (Sutherland & Jelen, 2003) reported a cost of $140 per curb-mile, based upon 2000 dollars, mechanical sweepers and a frequency of four times per year. The City of Urbandale, Iowa spent $122 per curb-mile based upon a frequency of three times per year (2001-2002 dollars) and mechanical broom sweeper

[3] http://www1.jsc.nasa.gov/bu2/inflate.html. Inflation calculators were used to increase unit costs in the USEPA, 1999 study to 2003 using the mean from the sum of CPI and ECI indices from 1995 – 2003. A five-year running average for CPI and ECI indices was used to inflate the CPI and ECI to 2005.

(http://www.urbandale.org/streets_andRoads/street_Sweeping.htm. Adjusting for inflation, the above three cities and others reviewed but not included here suggest Table 2 is a reasonable summary of street sweeping costs per curb-mile.

A recent study by Volkening (2004) reported a range of street sweeping costs per curb-mile of $150 - $170. This BMP cost effectiveness study used $100 per curb-mile in the analysis. Of particular importance in the modeling study were the variables affecting *cost* versus *effectiveness* with respect to street sweeping and other storm water management strategies. Results indicate the model was insensitive to a reasonable range of street sweeping costs, but **was** sensitive to sediment removal effectiveness. This suggests that it is more important to address sediment removal effectiveness of street sweeping rather than cost.

Implementation of the voluntary requirements of the Chesapeake Bay 2000 Agreement, caused Curtis, M.C. (2002) to discuss street sweeping as a BMP:

> "Regardless of absolute cost-effectiveness, street sweeping is one of the few easily implemented practices for use in highly developed urban areas that will clearly reduce sediment, and any associated pollutants, and provide for improved water quality to often severely degraded urban streams."

What are research needs?

The following are suggested topic areas for further research as it relates to street sweeping. Following each topic area is a brief background description.

1) **High-efficiency sweeping and water quality improvement**. This issue requires further research, but particularly as it relates to various receiving water types (lakes, wetlands, streams and rivers). Existing U.S. Geological Survey studies (Selbig, W.R. 2005 and Horwatich, J. 2005) may provide answers regarding high-efficiency street sweeping and water quality improvement.

2) **Street sweeping as a component in subwatershed modeling**: With the eventual determination of optimal frequency and effectiveness of street sweeping, it would be very important to use such information within a watershed model (e.g. P8, SLAMM). Such research would allow watershed planners to conduct the "what if" scenarios to further improve water quality with BMPs retrofitting or other measures.

3) **Disposal of street sweepings and recycling practices**. While this is not a high priority item, it needs investigation to further document current practices. The issue lends itself to survey methods.

4) **Life cycle costing of street sweeping practices**. This is a very important and valuable issue for further research. Knowing the long-term costs associated with street sweeping from both a frequency and efficiency perspective is important, especially when compared with other BMPs. Such research is needed as regulatory pressure is increasing to retrofit structural BMPs in conjunction with roadway reconstruction.

5) **Integration of street sweeping practices into local government MS4 permits**. Individual pollutants seldom are the sole impact upon a wetland or stream, their control through BMP implementation involves more than one approach for the greatest benefit. Effective storm water management requires a suitable balance between both structural and non-structural BMPs. Therefore, how street sweeping for water quality improvement fits into an MS4 permit as part of an integrated effort with structural measures is important.

ANNOTATED BIBLIOGRAPHY

Published Documents

The forty-eight (48) documents reviewed and summarized below for Report No. 1 follow citation format of the Publication Manual for the American Psychological Association, 5th Edition.

Allison, S. & Mehta, S. (2001). *Street sweepers stage a comeback*. Los Angeles Times. September 24, 2001.

This is a summary article on street sweeping, but includes recent developments to meet increased regulatory requirements. The City of Seal Beach proposed to triple its street sweeping fee, from $0.50 to $1.46 per month for single family residences in order to increase street sweeping frequency from twice monthly to weekly. In a related action, the city increased the parking ticket fine from $16 to $34 for a failure to move their cars on sweeper day. A city councilman responded that they've experienced 18 (high bacteria warnings) and nine beach closures in the past year. Orange County began street sweeping 70 unincorporated areas monthly in July 2000 abandoning a policy of sweeping only arterials. A county supervisor was quoted: "The county was the one that was a laggard, and now we're catching up." Increased sweeping was in response to the January 2001 Los Angeles Regional Water Quality Control Board's adopted 12-year plan to eliminate trash from the Los Angeles River Watershed.

Bannerman, R., Legg, A, and Greb, S.R.. (1996). *Quality of Wisconsin Stormwater*. U.S. Geological Survey. Report 96-458.

Approximately 75% of the sediment mass resides in the >250 micron size fractions
Less than 5% of the mass was found iin the particle sizes < 63 microns.
About 80% of the total phosphorus mass resides in the leaf and >250 micron size fraction.

Bannerman, R. 1999. Sweeping water clean. *American Sweeper*, Vol. 7, No. 1.

There are proven, non-sweeping technologies removing up to 80 to 90% of stormwater pollutants., however, they are very expensive. New-technology sweeping may be more efficient and feasible than structural devices since retrofitting is often the case. We're facing two issues:

1. How do we make street sweepers more efficient at cleaning?, and
2. How do we determine street sweeping frequency, particularly in areas with frequent rainfall?

From our studies using traditional mechanical broom machines, you may achieve a 10 or 15% reduction in solids reaching streams with a very thorough sweeping in the spring and fall. A benefit of high-efficiency street sweeping is removal of some soluble pollutants before they reach a structural control measure, like a catch basin or filtration-type device. Streets and parking areas remain the greatest source of pollutants of concern. Street loads can be as high as 8,000 pounds per curb mile in the springtime in a residential area, and drop to 400 pounds per curb mile in summer months. What has changed is our ability to clean these surfaces. We need to put this new technology to more widespread use and verify water quality improvements it appears to offer.

Bannerman, R. (2002). Effectiveness of Enviro Whirl Technology. *Schwarze Technologies* Web site, Schwarze.com 1/28/02.

Reduction in street load may not translate directly into reductions in pollutant loading to water resources. Primary reasons are rains tend to selectively wash off small particles whereas many sweepers (especially mechanical types) tend to selectively pick up larger particles. Another factor is the timing of sweeping operations with respect to rainfall patterns: poorly timed sweeping leaves more material on the street available for washoff. Finally, proper machine maintenance and operation (road speed, curb access, etc) are critical. Assuming adequate operation and maintenance, the more frequent the sweeping pattern, and the greater the sweeper's ability to capture small particles, the more the water quality benefits will approach the ability of the machine to reduce street loads. Generally, for a sweeping program involving about 30 passes per year (a reasonable expectation for Wisconsin), the estimated reduction in washoff of total suspended solids was approximately 60%.

California Coastal Commission. (2002). Model Urban Runoff Program, A how-to guide for developing urban runoff programs for small municipalities. Prepared by the cities of Monterey & Santa Cruz, California Coastal Commission, Monterey Bay National Marine Sanctuary, Assoc. of Monterey Bay Area Governments, Woodward-Clyde Consultants and Central Coast Regional Water Quality Board. Web site: http://www.coastal.ca.gov/la/water_quality.html.

The Model Urban Runoff Program lists and presents recommended improvements to existing municipal activities or functions to reduce the potential for urban runoff pollution. The MURP is included within the California Nonpoint Source Plan as an integral tool. Appendix 4J Best Management Practices, Good Housekeeping Practices for Municipal Operations lists some of the following practices for Street Sweeping and Cleaning:

- Sweep weekly in high traffic downtown areas;
- Sweep twice per month for moderate traffic collector streets, and
- Sweep monthly in residential, low traffic areas.
- Avoid wet cleaning or flushing of street, and utilize dry methods where possible.
- Institute restrictive parking policy to allow sweepers better access to areas close to the curb and storm drain inlets.
- Use your most effective sweepers in the high sediment and trash areas (typically industrial/commercial)
- Replace old sweepers with new technologically advanced sweepers.

California Stormwater Quality Association. (2003). Road and street maintenance, SC-70. *California Stormwater BMP Handbook, Municipal.* Web site: http://www.cabmphandbooks.com.

Fact sheet on road and street maintenance. Suggested protocols:

- Provide minimum monthly sweeping of curbed streets.
- Avoid wet cleaning or flushing of street, utilize dry methods where possible.
- Increase the sweeping frequency for streets with high pollutant loading, especially in high traffic and industrial areas.
- Old sweepers should be replaced with new technologically advanced sweepers (preferably regenerative-air sweepers) that maximize pollutant removal.
- If available use vacuum or regenerative-air sweepers in high sediment and trash areas (typically industrial/commercial).

- No currently available conventional sweeper is effective at removing oil and grease. Mechanical sweepers are not effective at moving fine sediments.
- Municipalities should be aware that fine dust not captured by sweepers can become airborne and could lead to issues of worker or public safety, therefore sweeping efforts need to sweep up finer sediments (less than or equal to 10 microns in diameter, symbolized as PM10).

Claytor, R. (1999). New developments in street sweeper technology. *Watershed Protection Techniques*, Vol. 3, No. 1. Center for Watershed Protection, Ellicott, MD.

The article explores the effectiveness of three basic street sweeping technologies: traditional mechanical sweepers, vacuum-assisted sweepers, and regenerative-air sweepers. Using the SIMPTM computer model, results showed the latest street sweeper technology picks up more street dirt and finer-grained particles than NURP-era sweepers. The vacuum-assisted dry and regenerative-air sweepers appeared to have the best performance. Performance issues include the sweeping frequency and sediment "washon" to the street following a rainfall event. A Port of Seattle study using SIMPTM determined weekly high-efficiency sweeping provided removal rates comparable to wet vaults for a fraction of the cost of wet vaults. Regions with defined dry seasons would probably benefit from street-sweeping the most, while regions with frequent intense storms maybe less because of sediment washon.

County of Los Angeles. (2004). Technical report on trash best management practices. Department of Public Works, Watershed Management Division, August 5, 2004. 23 pp. http://www.ladpw.org/wmd/bmp/trash_technical.cfm.

Good technical paper relating to the compliance with the Los Angeles Regional Water Quality Control Board's TMDL requirements for "zero discharge" of trash. Information is presented on results of existing and new BMPs addressing the trash wasteload reductions. The Department of Public Works (DPW) discusses the advantages of disconnecting impervious areas as well as program integrating both structural and non-structural BMPs in the future. Two years of data on trash volume related to land use indicated that commercial land use was twice as great as other land uses in the Ballona Creek watershed. In the Los Angeles River watershed both industrial and commercial land uses were by far the worse generators of trash. Sweeping of streets and parking lots was identified as a moderately easy trash BMP to implement with moderate cost with a high benefit.

Crites, B. (2004). Air quality issues in Coachella Valley. Prepared Witness Testimony before House of Representatives, Committee on Energy and Commerce, Subcommittee on Energy and Air Quality, January 12, 2004 3pp.

Mr. Curtis is Chairman of Energy and Environmental Resources for the Coachella Valley Association of Governments (nine cities within and including Riverside County), California. The testimony relates to the Valley's designation as a non-attainment area for PM-10 particulates and measures being taken to achieve the required three consecutive years compliance. The Association and the South Coast Air Quality Management District have developed a Clean Streets Management Program that includes regional street sweeping of sand and PM-10 particulates from arterials in the Coachella Valley. Alternative fueled and PM-10 efficient street sweepers are used to perform this function.

Curtis, M. C. (2002). Street sweeping for pollutant removal. Watershed Management Division, Department of Environmental Protection, Montgomery County, MD 18pp.

This report was prepared for three purposes:

1. Document the current status of street sweeping in Montgomery County;
2. Evaluate pollutant removal from street sweeping based upon literature review; and
3. Make recommendations for the County's street sweeping program to maximize pollutant removal to the lowest possible cost.

The County's overall sweeping program comprises residential and arterial roads while Central Businesses Districts of Bethesda, Silver Spring and Wheaton are funded and implemented under a partnership arrangement between businesses. Montgomery County is an MS4 permittee and a partner committed to the Chesapeake Bay 2000 Agreement to reduce by 40% nitrogen and phosphorus loading. There are currently no feasible opportunities to build new or enhance existing storm water pollution control structures. Street sweeping is one of the few practices in highly developed areas that will clearly reduce sediment and associated pollutants. The County's plan is to conduct more careful tracking of street sweeping materials removed to identify "dirtiest" areas. These areas (most likely arterial roads rather than residential) would be targeted for more frequent sweeping than once per month. The use of high-efficiency vacuum street sweepers will be evaluated initially on vehicle storage lots and parking lots. Eventually, such sweepers would be used at least on non-residential roads.

Dana Point, California. (2005). Street sweeping will make a clean sweep to protect the ocean. Web site: http://secure.purposemedia.com/dpstreetcleaning/streetsearch.html.

Dana Point in Orange County, California is a city of 35,000 located halfway between Los Angeles and San Diego. Dana Point is a Phase II permittee and their website describes their street sweeping program. "One of the best ways to prevent pollutants from entering the ocean is to remove them from the streets before rain carries them into the storm drain and the watershed. In recent months, the City has stepped up street-sweeping efforts, and the results have been tremendous. Our experience in Dana Point shows that street sweeping is effective in moving pollution. When streets sweeping was conducted twice a month, the monthly debris intake was 23 tons. Since sweeping was increased to weekly basis, the monthly total increased to 46 tons of debris – more than 10 tons per week." Good discussion follows on parking restrictions and public education for compliance.

Federal Highway Administration. (2005). Stormwater best management practices in an ultra-urban setting: selection and monitoring. Web site: http://www.fhwa.dot.gov/environment/ultraurb.uubmpl.htm.

This report supplements other recent FHWA manuals in the 1996 era. The street sweeping portion of the document (Section 3.8) while useful material, appears to be primarily late 1990's information. Highlights from the accompanying street sweeping fact sheet: Street sweeping is well suited to ultra-urban environments where little land is available for installation of structural controls. It should be considered in commercial business districts, industrial sites, and intensely developed areas in close proximity to receiving waters. The benefits of street sweeping will be best realized by using the most sophisticated sweepers on a weekly or bimonthly frequency. Vacuum assisted and regenerative air sweepers are more effective at removing fine particles and associated heavy metals but tend to be ineffective at cleaning wet streets. Vacuum-assisted sweepers are capable of providing close to 100 percent of PM-10 particulates and better overall removal of sediment. Vacuum-assisted dry sweepers have significantly less down time than water-based sweepers (less than 10 percent of total operating time compared to about 50 percent for water-based sweepers) because they require no water loading and clean-up and dumping times are shorter.

Keating, Janis. (2002). Street sweepers: picking up speed and quieting down. *Stormwater*, July/August 2002, Vol. 3. No. 5. pp. 68-74. www.stormh2o.com.

Street sweeping can be an important "good housekeeping" measure for Phase II cities. This is a good general article examines street sweeping equipment, features and operations. Key characteristics are noted for those sweepers that are PM10 compliant. There is also a short discussion regarding noise impacts from street sweepers and current machine capabilities.

Livonia, City of. (2001). Storm Sewer Maintenance Study. Prepared for the City of Livonia, Michigan by Hubbell, Roth & Clark, Inc., Bloomfield, MI with R. Sutherland as subcontractor. Final Report December 2001.

Study evaluated the effectiveness of catch basin cleaning and street sweeping in reducing pollutant loading to the Rouge River. A calibrated Simplified Particulate Transport Model (SIMPTM) was utilized to evaluate the City's street practices for optimal Total Suspended Solids (TSS) removal on a cost-effective basis. The optimal cost-effective street sweeping frequency is 17 times per year for residential and commercial areas. A sweeping frequency every 15 days (March 15 through November) using a high-efficiency and regenerative air machines in tandem along with annual catch basin cleaning is estimated to reduce pollutant loading by 79 to 89% annually. Tandem sweeping at a monthly frequency (9x per year) with no catch basin cleaning is estimated to reduce pollutant loading by 49%. The City's cleaning costs are $44.25 per catch basin (1998 dollars) and $76.90 per curb mile (1999 dollars) for street sweeping.

Martinelli, T.J, Waschbusch, R, Bannerman, R. & Wisner, A. (2002). Pollutant loading to stormwater runoff from highways: the impact of a freeway sweeping program. Final Report No. WI-11-01, WISDOT Highway Research Study #97-01. Wisconsin Department of Transportation, Madison, WI.

Study evaluated the effectiveness of an improved highway sweeping program using a high efficiency sweeper to reduce both dirt levels and runoff pollutants on an urban freeway (I-894) pavement in Milwaukee, Wisconsin. This partnership study (WISDOT, WDNR, and U.S. Geological Survey) included study test and control sections over the March 1999 and September 2000 timeframe. Results indicated that a once per week freeway sweeping program using a high-efficiency sweeper can be an effective stormwater BMP for an urban freeway section.

Metropolitan Council Environmental Services. (2001). Minnesota urban small sites BMP manual – stormwater best management practices for cold climates. Prepared by Barr Engineering Company for Metropolitan Council, St. Paul, MN 55101. Chapter 3, Housekeeping – Pavement Management, pp. 3-35 to 3-37.

At minimum, pavement should be swept twice yearly: early spring (sand and winter debris) and fall (leaves and debris). Additional sweeping in June after trees drop seeds and flowers will prevent a fair amount of phosphorus-laden runoff. Mechanical broom sweepers are effective on large particles and wet street surfaces, however they generally operations create airborne dust increasing atmospheric loading. Vacuum sweepers are more effective for fine particles associated with pollutants, but are ineffective on wet surfaces. For heavy loads, tandem

operations with mechanical broom sweeper for large particles followed by regenerative-air sweeper.

Minnesota Pollution Control Agency. (2000). Protecting water quality in urban areas – best management practices for dealing with storm water runoff from urban, suburban and developing areas of Minnesota. Web site: http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html. Chapter 7, General Practices: STREET SWEEPING, pp. 7-27-1 to 7-27-2. Minnesota Pollution Control Agency, St. Paul, MN 55155.

Prime reason for street sweeping is for aesthetics and urban housekeeping rather than for water-quality benefits. Routine street sweeping is recommended as a BMP in Minnesota at only two times during the year – immediately following spring snowmelt to remove sand and other debris, and in the fall to remove accumulated debris, such as leaves. Vacuum sweepers are more effective for removing fine particles with pollutant adsorption properties, but have a disadvantage of being ineffective at cleaning wet surfaces. Broom sweepers are effective for large particles and wet surfaces, but create airborne dust during operations adding to atmospheric loading.

Minton, G.R., Lief, B. & Sutherland, R. (November 1998). High efficiency sweeping or clean a street, save a Salmon! *Stormwater Treatment Northwest*, Vol. 4, No. 4.

A high efficiency sweeper utilizes strong vacuum coupled with mechanical main and gutter brooms using a dry, no water system combined with an air filtration system (down to 2.9 microns) that only returns clean air to the atmosphere. Pickup performance of a high efficiency sweeper compared to a traditional sweeper? High efficiency sweeper: 70% for < 63 micron range to 96% for the > 6370 micron particle size range. Regenerative air sweeper: 32% for < 63 micron range to 94% for the > 6370 micron range. Mechanical sweepers performed poorly: actual removals ranged only from 44-79% during the U.S. EPA NURP 1983 studies. Broom sweeper of this era were effective at picking up litter and large dirt particles, but exposed smaller particles that were then available to washoff in the next rain. The SIMPTM model has been used to simulate potential pollutant loading reductions (primarily the particulate phases) by high efficiency sweeping. If TSS annual modeled removal is 60%, total metals annual reduction is 45-55%, nutrient annual reduction (such as TP) is 25-35%, and oxygen demand annual reduction is 35-45%.

Oberts, G. (April 1994, revised). *Best practices: street sweeping*. Metropolitan Council, St. Paul, Minnesota 55101. Publication No. 71-94-020A.

A 1994 Metropolitan Council survey of city street management practices determined cost reduction opportunities. Cities vary in how they provide street sweeping, but many contract with private firms. Street sweeping in Minnesota is done to reclaim the winter road sand. On the average, 75 % of the sand is reclaimed with Disposal becoming a growing issue with environmental concerns. It costs $2 to $4 per ton to buy sand and $6 to $11 per ton for landfill disposal, not including hauling costs. Some cities recycle spring sweepings, which may become more cost-effective in the future. Street sweeping costs vary widely throughout the region—in some cases, more than 10 to1. Cost of street cleaning was estimated to be $100 per mile. Findings from a small demonstration project identified 66 “best practices” in street sweeping by public works departments. The region could save nearly $1 million a year if these practices were implemented based upon reports from 102 communities in the region, who altogether spend approximately $7 million per year on street sweeping, a conservative estimate. Water quality

problems caused by particles smaller than sand were not promoted as resolvable through street sweeping technology; further research was advised.

Olympia, City of. (2005). Stormwater manual. Volume IV, Permanent Source Control (Pollution Prevention) BMPs, 156 pp. and Volume V, Stormwater Treatment BMPs, 233 pp.

This newly issued manual consists of five volumes. Volume IV contains a discussion on Operational Source Control BMPs which are non-structural. Street sweeping is a good housekeeping practice (Section 1.4). Pollutant Control Approach (Page 2-64): Conduct efficient street sweeping where and when appropriate to minimize the contamination of stormwater. The recommended BMPs for street sweeping are divided into three categories: maximum, moderate and minimal stormwater pollutant reductions. For maximum pollutant reduction, high-efficiency vacuum sweepers are recommended. For moderate pollutant reduction, regenerative air sweepers or tandem sweeping operation (mechanical sweeper followed by a vacuum or regenerative air sweeper). For minimal pollutant reduction, mechanical sweepers are recommended. Volume V (page 12-10 and 12-11) contains a summary discussion on high efficiency street sweepers and captive hydrology street cleaners.

Ontario Ministry of Environment. (2004). Street cleaning - MO4 Fact Sheet. *Stormwater Pollution Prevention Handbook*, Three pages. Web Site: http://www.ene.gov.on.ca/envision/gp/4224e_2.htm.

The fact sheet is a summary of previous studies. Highlights:

- Prioritize cleaning to use the most technically advanced sweepers, at the greatest possible frequency in areas with the highest pollutant loading.
- Optimize cleaning frequency based upon interevent times (the dry period between storms). To achieve 30% removal of street dirt, the sweeping interval must be no more than 2 times the average interval between storms. To reach 50% removal, sweeping must occur 1 or 2 times during the average interval between storms.

Partland, J.P. (2001). A clean sweep to swipe pollutants. *Stormwater*, May/June 2001, pp. 52-56. www.stormh2o.com.

This is an overview article on street sweeping using discussions from a consultant (Roger Sutherland), and local government staff (Don Waye, Northern Virginia Regional Commission; Pat Collins, Venice FL; Hossain Kazemi, San Francisco Reg. Water Quality Control Board; Nancy Breward, San Antonio, TX; and Mark Bosser, Olympia, WA). Good general discussion on equipment, sweeping frequency and performance issues. Not a technical article.

Pitt, R. (2002). Emerging stormwater controls for critical source areas. In: *Management of Wet-Weather Flow in the Watershed*. Sullivan, D. & Field R. (Eds). Street cleaning (pp. 14-16), CRC Press, Boca Raton, FL.

This is a good brief summary of the state of the practice in 2002. Highlights with references: Few data have shown street cleaning to be effective because of the different sized particles that street cleaners remove compared to the particles that are most removed by rains. Conventional street cleaning for aesthetics and traffic safety does not have a very positive effect on stormwater quality because large particles are preferentially removed and the smaller particles are effectively removed during rains. For high street loading, a tandem sweeper operation (mechanical followed by regenerative-air) may be best for large and fine particles. New high-efficiency sweepers may reduce suspended solids discharges by 50% versus the 15% from mechanical sweepers. High-efficiency sweeping of heavily paved areas (freeways, large parking lots, paved storage areas) should result in significant runoff improvements. Unless street cleaning operations can remove fine particles, pollutant removal effectiveness will be limited. More research is needed for the newer pavement cleaning operations especially in industrial storage areas and commercial parking areas.

Scholl, J.E. (2000). Development of a nonpoint source BMP control strategy for a watershed TMDL. Watershed Management 2000 Conference. July 9 –12, 2000, Vancouver, British Columbia, Canada.

Method optimizing the combination of BMPs and level of effort to achieve phosphorus removal using marginal cost analysis for this 1,800-acre lake in a 175-square mile watershed as part of a Total Maximum Daily Load (TMDL) study. Marginal analysis determined whether an action such as street sweeping resulted in a sufficient added benefit to justify the cost. As street sweeping is performed more often or on more streets, less load is available for removal, thus marginal costs increase to the point where other options become more competitive. The key benefit of the defensible approach was to select the lowest combination of BMPs for reducing the nonpoint source phosphorus load.

Smith, K.P. (2002). Effectiveness of three best management practices for highway-runoff quality along the Southeast Expressway, Boston, Massachusetts. Water-Resources Investigations Report 02-4059. U.S. Geological Survey, Northborough, MA.

The greatest benefit of annual street sweeping was the removal of particles greater than 8 mm in diameter that were not routinely mobilized during storm flows. Mechanical broom sweepers were used during the study. Sweeping provided little water-quality benefit for the Southeast Expressway. The equipment did not remove the dominant particles less than 0.062 mm in diameter efficiently.

South Coast Air Quality Management District, California. (2004). Rule 1186. PM_{10} emissions from paved and unpaved roads, and livestock operations. Adopted February 14, 1997, latest amendment: April 2, 2004.

The South Coast Air Quality Management District comprises the non-desert portions of Los Angeles, Riverside, and San Bernardino counties and all of Orange County, California. The Rule's purpose is to reduce particulate matter entrained in ambient air resulting from vehicular traffic on paved and unpaved public roads and at livestock operations. Routine sweeping by local governments is defined as every three months. PM_{10} is particulate matter with an aerodynamic diameter smaller than or equal to 10 microns. Local governments can only use PM_{10} – efficient sweepers certified by the SCAQMD.

Southeast Wisconsin Regional Planning Commission. (1991). Costs of urban nonpoint source water pollution control measures. Technical Report 31. 109 pp. Waukesha, WI.

Sweeping of commercial areas every two weeks could be expected to remove about 35% of the suspended sediment load from runoff. However, sweeping of residential areas every four weeks only removes about 2% of the sediment load from runoff. Average cost (capital and operations) per curb-mile swept is $21.20 (1989 dollars).

Stidger, R. (2003). The pros and cons of municipal street sweeping. *Better Roads*. April issue. Web site: http://www.betterroads.com/articles/apr03b.htm**.**

Relatively short summary article on various street sweeping practices. In Sweden, the National Road and Transport Research Institute sent a questionnaire to 103 cities and seven regional road authorities, as well as contacting Norway, Denmark, Finland and the State of California. Study results showed dust was considered the main problem solved by sweeping, especially in the spring. Wet sweeping was the most commonly used method, yet they were not designed to control PM10 particulates, except in California. In Sweden, PM10 requirements will go into effect in 2005. Much of the road dust is blamed on winter sanding and studded tire usage.

Stormwatercenter. (2005). Pollution Prevention Fact Sheet: Parking Lot and Street Cleaning. 4 pp. WEB site: http://www.stormwatercenter.net**.**

This is a short summary article on street sweeping referencing about ten articles. No new information is presented since 1999. Argues that the most essential factor in using street sweeping as a pollutant control practice is to use the most sophisticated sweepers available. Emphasizes the benefit of using high-efficiency sweepers that capture pollutants before they are made soluble from rainwater and may reduce the need for other storm water treatment practices. It suggests that further research is needed to establish the optimal sweeping frequency for pollutant removal and the type of streets appropriate for a sweeping program.

Sutherland, R.C. & Jelen, S.L. (1996). Sophisticated stormwater quality modeling is worth the effort. In James, W (Ed.), *Advances in modeling the management of stormwater impacts*. Lewis Publishers, Guelph, Canada.

Annual runoff and pollutant loads for six homogeneous stormwater sites in Portland, Oregon, were continuously simulated using SIMPTM, the Simplified Particulate Transport Model, calibrated to local runoff quality data from sites representing residential, commercial, industrial and transportation land uses. Event mean sample concentrations and continuous flow monitoring were combined with hourly local rainfall and street sediment data. Results clearly showed that current linear or exponential sediment accumulation models fail to represent the seasonal variation rates that depend upon the results they would compute. Calibrated model results suggest that simplified annual pollutant load calculations using concentration times volume may overestimate expected load by up to seven times. In addition, results of a street sweeping testing showed that tandem street sweeping (i.e. mechanical followed by vacuum) was much more effective than previously concluded by the Nationwide Urban Runoff Program (NURP).

Sutherland, R.C. & Jelen, S. L. (1997). Contrary to conventional wisdom, street sweeping can be an effective BMP. <u>In</u> James, W (Ed.), *Advances in modeling the management of stormwater impacts*. Vol. 5. Lewis Publishers.

Several different sweeping technologies were evaluated on their ability to pick up accumulated sediment of various sizes. Expected reductions in average annual washoff loads were evaluated using a calibrated SIMPTM model for two stormwater sites in Portland, Oregon. Results suggested reductions of up to 80% in annual TSS and associated pollutant washoffs may be achieved using bimonthly to weekly sweepings. This stands in sharp contrast to USEPA NURP program of 1983 indicating street sweeping to be generally ineffective as a technique for improving the quality of urban runoff quality. This study demonstrates street sweeping can be an effective BMP depending upon land use characteristics, precipitation and the accumulation dynamics of contaminated sediments. Pollutant reduction benefits possible from a cost-effective street sweeping program must be re-evaluated.

Sutherland, R.C., Jelen, S.L. & Minton, G. (1998). High Efficiency sweeping as an alternative to the use of wet vaults for stormwater treatment. <u>In</u> James, W. (Ed.), *Advances in modeling the management of stormwater impacts*. Vol. 6 Lewis Publishers.

The Port of Seattle conducted a 1996 evaluation of selected stormwater treatment BMPs for a new 400-acre marine cargo container yard. Study objective was to evaluate the stormwater pollutant removal effectiveness of new high efficiency sweeper combined with catch basins versus pollutant removal efficiencies of wet vaults. Wet vaults were the only technically feasible and approved (Washington Department of Ecology) technology for new marine facilities. Wet vaults with an estimated life-cycle cost of $18 million for a 250-acre yard expansion project were equivalent in pollutant removals compared to weekly high efficiency sweeping and annual catch basin cleaning with a $2 million life-cycle cost for the same project area. Weekly sweeping may be significantly more effective than biweekly, while twice weekly creates little incremental benefit.

Sutherland, R.C. (1998). How do we judge the equivalency of new treatment BMPs? High-efficiency sweeping or clean a street, save a salmon! *Stormwater Treatment Northwest* Vol. 4, No. 4.

Useful discussion on the pick-up efficiencies of mechanical broom, regenerative-air and high-efficiency street sweepers with respect to particle size. Article explains in some detail why the NURP study concluded street sweeping was ineffective and may have been misleading. Discussion concludes regarding the advantages and disadvantages of high-efficiency sweepers at this time.

Sutherland, R. C. 2001. A proposed method for performance testing. *American Sweeper*. Vol. 6, No. 1.

Good preliminary discussion regarding minimum protocols for conducting street sweeping evaluation. ‘Stormwater sweeping’ can be an effective BMP, but will take a different way of looking at it. It can no longer be done just for cosmetic reasons. A realistic testing procedure must take into consideration variables which can dramatically affect sweeper performance: pavement condition, gutter design, pitches, etc. A testing procedure uses ample area for collecting material before and after sweeping. A hand broom is used with a vacuum attached to assure dust capture. The “before sweeping plot” needs to be at least 400 – 500 square feet with the "after sweeping plot" 3 – 4 times larger to assure adequate area for material collection. Sanctioning of standards for testing and evaluation by an organization (e.g. APWA) is necessary to provide directors of public works, smaller communities and manufacturers with information to evaluate this technology.

Sutherland, R. C. & Jelen, S. L. 2002. A technique for accurate urban runoff load estimation. Water Environment Federation. National TMDL Science and Policy 2002 Specialty Conference, November 13 –16, 2002. Phoenix, AZ.

Reexamination of previous results from cities of Livonia and Jackson, Michigan studies. Street sweeping and catch basin cleaning at frequencies of 15 to 30 days could provide significant TSS load reductions. Most cost-effective maintenance involves high-efficiency sweepers. Reexamination of the stormwater benefits associated with these maintenance practices is needed.

Sutherland, R. C. & Jelen, S. L. 2003. SIMPTM diagnosis. A technique for accurate urban runoff load estimation. *Water Environment & Technology*. Vol. 15, No. 9, pp 59 – 66. September 2003.

This paper is a more detailed presentation of the City of Livonia, Michigan and the City of Jackson and Jackson County, Michigan studies addressing pollutant loading assessment using the SIMPTM model. Data summaries for size fractions and pollutant concentrations are presented on the sediment data gathered for the model calibration. Results show that annual catch-basin cleaning and street sweeping every 15 to 30 days could reduce annual total suspended solids loading by up to 80%. Costs are presented for catch-basin cleaning and sweeping. In Livonia (1999), catch-basin cleaning was $44.25 each with sweeping at $76.90 per curb mile. In Jackson (2000), catch-basin cleaning was $28.75 each with sweeping at $140 per curb mile. The most cost-effective sweeping practice seems to be high-efficiency or regenerative-air sweeping. The authors suggest that a serious re-examination of storm water quality benefits associated with these maintenance practices is needed.

Taylor, A.C & Wong, T. (2002). Non-structural stormwater quality best management practices – an overview of their use, value, cost and evaluation. Cooperative Research Centre for Catchment Hydrology. II. Victoria. Environment Protection Authority. 40 pp. Series Report 02/11.

This paper deals with the broader context of non-structural BMPs and their application. It is valuable in the discussion of the integration of non-structural BMPs (i.e. city-wide maintenance operations) along with other structural BMPs. It points out that a review of approximately 200 references relating to non-structural BMP evaluations was of lower quality than normally associated with structural BMPs of storm water improvement. The finding may reflect the maturity of the two areas and the difficulty in designing and executing a sound monitoring and evaluation program for many non-structural BMPs. An evaluation framework is presented (Appendix A) that provides a very good overview of the "top – down" process necessary to evaluate and monitor non-structural BMP implementation.

Taylor, A.C & Wong, T. (2002). Non-structural stormwater quality best management practices – a literature review of their value and life-cycle costs. Cooperative Research Centre for Catchment Hydrology. II. Victoria. Environment Protection Authority. 111 pp. Series Report 02/13.

This is repeat of the Walker and Wong, 1999 report. Little addition information is provided. The report concludes: "automated sweeping is however still considered a potentially valuable BMP in *specific circumstances*, such as the use of newer sweeping technologies (that can capture a high percentage of fine particles) on commercial and industrial sites , where limitations in terms of sweeping frequency, sweeping timing and gaining access to pollutants can be overcome."

Terrene Institute. (July/August 1998). A clean sweep is now possible. *Runoff Report*, Vol. 6, No. 4. Terrene Institute, Alexandria, VA. WEB site access, http://www.epa.gov/NewsNotes/issue56/techncl56.html#street

The article covers current technology and sweeping methods for a number of sweeping models and sweeping situations, and draws upon both their own experience as well as previous studies. Cities use one or more of five basic kinds of sweepers:
<u>Mechanical:</u> 90% of the street sweepers used in this country are traditional broom sweepers.
<u>Vacuum-assisted wet:</u> These machines create a vacuum at the surface but use water to suppress dust from its gutter broom.
<u>Regenerative air:</u> this sweeper blows air onto the pavement and immediately vacuums it back capturing the sediments.
<u>Tandem:</u> a two-machine operation: a first pass by a mechanical sweeper, followed by a vacuum-assisted sweeper.
<u>Vacuum-assisted dry:</u> a *high efficiency* sweeper combining essential elements of tandem sweeping into a single unit without using water.
A sixth type, scrubbers, has more limited application. Scrubbers saturate the pavement with enough water to suspend the fine particles, then vacuum up the solution.
The overall conclusion is that vacuum-assisted dry sweepers are the top technology available for addressing stormwater runoff pollution.
Studies by Sutherland show that conventional mechanical broom and vacuum-assisted wet sweepers reduce nonpoint pollution by 5 to 30%; its nutrient content by 0 to 15%. Dry vacuum sweepers reduce nonpoint pollution by 35 to 80%; nutrients by 15 to 40%.

Tilton, Joseph Lynn. 2003. Keeping it clean. *Stormwater*, March/April 2003, pp. 58-64. www.stormh2o.com.

Street sweepers help meet municipalities meet federal and state regulations. This is a brief sweeper technology overview.

U.S. Environmental Protection Agency. (1999). Preliminary data summary of urban storm water best management practices. EPA-821-R-99-012, Office of Water, Washington D.C.

There is short summary of land use of runoff volume and pollution generation percentages (adapted from Bannerman et al, 1993) in Chapter 5 (pp. 5-34 and 5-35). The basic conclusion: streets and parking lots can contribute significant pollutant loadings to urban runoff, therefore sweeping programs that remove a portion of these materials may significantly reduce pollutant load contributions. A short cost data discussion is presented in Chapter 6 (pp. 6-21 and 6-22) dealing with the capital, operational and maintenance costs of street sweeping based upon several studies (Finley, 1996; SWRPC, 1991 and Satterfield, 1996). It concludes that the capital cost of a vacuum sweeper is significantly higher than mechanical, the operation and maintenance costs per curb mile are reversed for the two types.

U.S. Environmental Protection Agency. (2000). National menu of best management practices. Parking lot and street cleaning. Pollution prevention and good housekeeping. 4 pp. October 27, 2000. http://www.epa.gov/npdes/menuofbmps/BMP_files.htm**.**

Very good summary of the current state of the practice. Provides indications of the limitations of street sweeping along with expected pollutant removal efficiencies for the new technologies. Street sweepers that can show a significant level of sediment removal efficiency (vacuum-assisted dry) may prove to be more cost-effective that certain structural controls, especially in urbanized areas with greater areas of pavement.

U.S. Environmental Protection Agency. (2004). The use of best management practices (BMPs) in urban watersheds. Muthukrishnan, S., Madge, B., Selvakumar, A., Field, R. & Sullivan, D. EPA-600/R-04/184, Office of Research and Development, Washington D.C. 20460.

Good overall document covering the state of the art for street sweeping. Recognizes that this is a non-structural BMP that has limited studies showing direct water quality benefits and removal efficiencies. Street sweeping is considered to be an ultra-urban best management practice for reducing total suspended solids and associated pollutant washoff from urban streets. Chapter 5 has a good discussion on the in value of the integrated approach to storm water management that may involve structural and non-structural BMPs. Stresses that an effective storm water management program requires the optimum balance between both structural and non-structural BMP types. Costs associated with non-structural BMPs are not included in Chapter 6 as they were generally not as easily quantified as structural BMPs due to their indirect and highly variable implementation levels.

Venner Consulting & Parsons Brinckerhoff. (2004). Environmental stewardship practices, procedures, and policies for highway construction and maintenance. Prepared for Transportation Research Board of the National Research Council. National Cooperative Highway Research Program (NCHRP) Project 25-25(04). 850 pp.

The following is summarized from Chapter 10: Roadside Management and Maintenance: Beyond Vegetation – *Cleaning/Sweeping of Shoulders.* Care should be taken to minimize dust as much as possible. Water applied during sweeping operations should be controlled to prevent unpermitted non-stormwater discharges. Avoid wet cleaning or flushing of street, utilize dry methods where possible. Consider increasing sweeping based on factors such as traffic volume, land use, field observations of sediment and trash accumulation, proximity to watercourses, etc. For example:

- Increase the sweeping frequency for streets with high pollutant loadings, especially in high traffic and industrial areas.
- Increase the sweeping frequency just before the wet season to remove accumulated sediments.
- Increase the sweeping frequency for streets in special problem areas such as special events, litter or erosion zones.

Old sweepers should be replaced with new technologically advanced sweepers (regenerative air sweepers) that maximize pollutant removal. If available use vacuum or regenerative air sweepers in the high sediment and trash areas (typically industrial/commercial). Keep accurate logs of the number of curb-miles swept and the amount of waste collected.

Versar, Inc. (2002). An assessment of road maintenance activities in Frederick County and their effect on storm water runoff quality. Prepared for the Division of Public Works, Frederick County, Maryland by Versar, Inc. Columbia, MD.

This is a brief sweeper technology overview used to recommend to the County additional and alternative procedures to implement and minimize the level of pollutants in road runoff from maintenance activities. Street sweeping is one of the most cost-effective BMPs primarily because it reduces pollutant levels at the source. Critical discussion of mechanical broom sweepers making water quality worse by removing surface dirt with adsorbed pollutants, thus preventing them from being entrained in runoff and breaking down pollutants into smaller sizes and more subject to runoff. Suggests integrating a sweeping program that includes 'hot spots' for pollutants (high traffic areas, downtown streets, light industrial).

Volkening, A. (2004). Use of mathematical optimization to select cost-effective best management practices. Watershed 2004 Conference, July 11-14th, Dearborn, Michigan. Water Environment Federation.

Paper presents a mathematical optimization model of stormwater management strategies to meet water quality requirements at the least cost. BMPs incorporated were wet ponds, street sweeping and settling vortex devices (SVDs). Street sweeping had strong benefit because no land cost is incorporated for wet ponds along with the capital cost and installation for SVDs. For 20 – 60% sediment removal efficiency, maximum sweeping of commercial areas was incorporated with SVDs added to achieve water quality goal. Results show the optimization model is not sensitive to reasonable ranges in street sweeping costs. The model is sensitive to the effectiveness of street sweeping, suggesting that it is more important to analyze the sediment removal of street sweeping, rather than its exact cost. It would be important to thoroughly investigate the probable performance of street sweeping for specific applications of this model. Using multiple BMPs or the "treatment train" approach would be very useful incorporating updated cost and efficiency data.

Walker, T. A. & Wong, T.H.F. (1999). Effectiveness of street sweeping for stormwater pollution control. Technical Report 99/8 Cooperative Research Centre for Catchment Hydrology. Dept. of Civil Engineering, Monash University, VIC 3800.

Australian street sweeping practices (mechanical and regenerative-air) are generally ineffective stormwater pollution control measures. Street sweeping should be accompanied by structural pollution control measures to effectively reduce gross and sediment associated pollutants in stormwater. Gross pollutant materials are comprised of 10-30% litter (plastic, paper and some metal) and 70 – 90% organic matter (leaves, twigs, etc.). The regenerative-air sweeper exhibits a substantially better performance than a mechanical sweeper. Commercial land uses contribute larger loads of gross pollutants despite more intensive street sweeping frequencies.

Waschbusch, R. J. (2003). Data and methods of a 1999-2000 street sweeping study on an urban freeway in Milwaukee County Wisconsin. USGS Open File Report 03-93 (prepared in cooperation with Wisconsin Dept. of Transportation). U.S. Geological Survey, Madison, WI.

This is a technical report providing results of the data collection inconjunction with the WISDOT Highway Research Study #97-01 (Final Report No. WI-11-01).Highlights related to particle-size data from the control and test sites indicated that the freeway generated much larger size fractions than other USGS sites. This characteristic caused significant variability in the two analytical parameters: suspended solids and suspended sediment. Direct observation of the high-efficiency sweeper performance raised questions regarding operational problems. The sweeper's operational ground speed reduced the freeway area effectively swept. The freeway median appeared to contribute disproportionately to suspended solids loads from the study sites. Because of these issues, it may be difficult to show the benefit of the sweeping program in improving water quality from highway runoff.

Unpublished Documents

The five documents reviewed and summarized below for Report No. 1 follow citation format of the Publication Manual for the American Psychological Association, 5th Edition.

Bannerman, R. (January 29, 2002). Wisconsin Department of Natural Resources, Madison, WI. Personal communication: Watson, L. Ramsey-Washington Metro Watershed District(RWMWD). RE: EV Sweeper study request and some questions.

We did finish the study, but I am not sure when the DOT is going to release the final report. Bottom line is we observed about a 40% reduction in suspended sediment concentrations when we operated the high efficiency sweeper. Unfortunately, the variability in the data is very high, so we only have an 80% confidence in the reduction value. This is the first time however we have been able to document any water quality benefits of a street sweeper. So I think the vacuum assisted sweepers will do a better job than just broom sweepers. In fact, a tandem operation is still probably the best for a heavy spring street load.

Eagan, City of. (2001). Analysis of street sweeping to improve water quality. Personal communication: Schilling, J. with E. Macbeth, Water Resources Coordinator (10/21/04).

Grant project was to study effectiveness of three street sweepers: mechanical broom, regenerative air, and vacuum-based on water quality. Specific objectives:

1. Determine effectiveness of each sweeper to collect nonpoint source pollutants;
2. Determine the extent each sweeper contributes to water quality improvement; and
3. Determine the economic and environmental feasibility of street sweeping to improve water quality.

Results show the cost per ton and cost per hour are less for the regenerative air sweeper versus mechanical broom sweeper. Mechanical sweeper picks-up heavy concentrations of sand at a faster rate, but do not remove the fine materials. Costs per curb mile: mechanical - $84 and regenerative air - $64 (2001 dollars). Entire project results incomplete.

Horwatich, J. (2005). DOT street sweeping Phase II. U.S. Geological Survey, Madison, WI. URL: http://wi.water.usgs.gov/projects/nonpoint/bqy26.htm.

Both the Wisconsin departments of transportation and natural resources are cooperators on this project slated to run from October 2004 – September 2006 addressing a possible method to control stormwater runoff pollutants on urban freeways using high efficiency street sweepers.

Project objectives:

1. determine the effectiveness of street sweeping in removing pollutants from highways by alternating the technique and frequency throughout the project,
2. compare the measured removal efficiencies with manufacturers' estimates,
3. characterize the variability in freeway runoff quality, and
4. characterize pollutant loading in freeway runoff

A control site will be swept once per week with a broom sweeper. Storm discharge and water quality samples will be collected for at least 15 storms. Event Mean Concentrations (EMC) will be calculated at one water quality monitoring site. The test-site evaluation will compare changes in the dirt load on the roadway to predict the benefits of three sweeping formats. The sweeping formats will include: (1) sweeping at different speeds, (2) using tandem sweepers, and (3) sweeping twice per week instead of once. Roadway vacuuming at both the test and control sites will be done to determine particulate matter accumulation rates on the highway and street-sweeping efficiency. Vacuuming will initially need to occur immediately before and after a sweeper makes a pass.

Results from the water-quality sampling will be used to develop plots describing the amount of pollutants removed from the road surface for different rainfall amounts and intensities. A relation will be developed between the efficiency of each format and the amount of pollutants washed off the road surface. This relation will quantify the water-quality benefits of each street-sweeping format.

Selbig, W.R. (March 2005). Evaluation of street sweeping as a water-quality management tool in residential basins in Madison, WI. U.S. Geological Survey. URL: http://wi.water.usgs.gov/projects /nonpoint/bqy19.htm. Personal communication: Telephone conversation with Schilling, J., March 7th.

This project is going into the last year of evaluating reduction of dirt load on residential streets by various street-sweeping scenarios. Three residential subwatershed basins are being monitored:

1. Street sweeping every 19 days or essentially monthly, same street sweeping equipment;
2. Street sweeping on a weekly basis, same street sweeping equipment used; and
3. No street sweeping.

Initial two years involved the evaluation of both mechanical and regenerative-air sweepers. Neither sweeper did a good job at picking up fine to very fine materials (< 63 microns). There were no water quality changes in the stormwater runoff. Problems were encountered with respect to the parameter total suspended solids. An alternative parameter, suspended sediment will be further evaluated.

In 2004 – 2005, the project will continue with an evaluation of a high-efficiency vacuum street sweeper. Initial results from 2004 indicate the high-efficiency sweeper is very good at removal of fine sediments. Stormwater runoff sampling results in 2004 is yet to be evaluated. In 2005, the high-efficiency sweeper will be evaluated for removal of coarse sand and fine sand/silt.

An additional USGS study was initiated in 2004 within the City of Madison to further evaluate the operation of the high-efficiency street sweeper.

Watson, L. (2003). *Draft* street management literature review, analysis and BMP recommendations report. In preparation for the development of a District-wide street management for water quality program plan. Ramsey-Washington Metro Watershed District, North St. Paul, MN 55109.

This *draft* 51 page report consists of the following sections:
Section One – Introduction:
General Overview, Current Practices and Published Overview, Street Sweeping: A Quick Overview by Metropolitan Council;
Section Two – Literature Reviewed and Listed by Date: Abstracts or Content Summary;
Section Three – Literature Reviewed Listed by Date: Findings and Conclusions; and
Section Four - Findings Grouped by Subject Area.

Conclusions

1. Streets need to be clean of sediment, trash and dissolvable pollutants. With emerging new technologies, cities and watershed management organizations may shift water quality improvement efforts from structural Best Management Practices to implementing non-structural practices directed at pollutant source control on street surfaces. Street sweeping equipment technology and practices have reached a level of sophistication that is it now possible to come close to accomplishing a goal of significantly cleaner street surfaces before major rain or snowmelt events.
2. Mechanical brush sweepers are effective at removing coarse materials and gross pollutants. They are less effective removing fine materials often associated with various pollutants and may expose such materials to wash-off. High-efficiency street sweepers and associated operations may increase the percent of total solids removal from 30 – 70+%.
3. Street sweeping frequencies approximately monthly to biweekly and varied depending upon land use and transportation features have been shown as being most effective for pollutant removal.
4. Street sweeping equipment has evolved significantly in the last 15 years and will continue to do so as two aspects relating to the practice move forward. First, Phase 1 and 2 storm water permits and associated Storm Water Pollution Prevention Plans (SWPPP) will likely become more comprehensive as regulatory agencies require further controls on non-point source pollution. With TMDL studies being completed over the next ten years, these same permits will contain more stringent requirements. Street sweeping equipment and the associated practice will be looked at more favorably as a cost-effective non-point source control measure.
5. Second, additional research studies may shed more information upon street sweeping as a practice that alone improves water quality. Subsequently, this may result in equipment and operational upgrading that may produce more fuel-efficient sweepers, greater use of waterless sweepers or implement new technology (e.g. captive hydrology). Regulatory requirements and research findings may drive street sweeper manufacturers to respond to an increasing market for newer technologies.
6. As a pollution control practice, street sweeping is cost-effective when compared to structural best management practices such as detention ponds, and settling or filtering devices and prolongs their operational efficiency and required maintenance.
7. As a pollution prevention or source control measure when integrated with other structural and non-structural BMPs, high-efficiency street sweeping improves water quality and reduces ongoing habitat deterioration.
8. Report No. 1 has not identified definitive studies pointing to receiving water quality improvement as a direct result of street sweeping alone. However, as a pollution prevention or source control measure when integrated with other structural and non-structural BMPs, high-efficiency street sweeping improves water quality and reduces ongoing habitat deterioration.

9. A 2004 mathematical optimization study for BMPs provided information on which storm water management strategies are likely to be cost-effective in reducing non-point pollution and which are not. Sweeping of commercial areas will likely be a priority while residential areas will not. The optimization model study shows insensitivity to a reasonable range of street sweeping costs, but sensitivity to sediment removal effectiveness. This suggests it is more important to address sediment removal effectiveness for street sweeping rather than cost.
10. The following are suggested topic areas for further research as it relates to street sweeping.

- **High-efficiency sweeping and water quality improvement**;
- **Street sweeping as a component in subwatershed modeling**;
- **Disposal of street sweepings and recycling practices**;
- **Life cycle costing of street sweeping practices; and**
- **Integration of street sweeping practices among local governments**.

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Appendix A-Street Sweeping Equipment

Mechanical Broom Sweepers		
Make	**Model**	**Highlights**
Elgin	Broom Bear	4.5 CY, 4-wheel, wet operation, diesel
	Eagle	3.3 CY, 4-wheel, dry or wet operation, CNG, LNG, & diesel fuels,
	Pelican	3.2 CY, 3-wheel, dry or wet operation, diesel
	Road Wizard	3.8 CY, wet operation, diesel, free-floating gutter brooms
Johnston	MS/MT350	4.4 CY, wet operation, diesel, single or twin engines
	MX450	5.6 CY, 3-wheel, front wheel steering, wet operation
	3000	5.6 CY, 4-wheel, diesel, shorter wheel-base, commercial applications
	4000	5.6 CY, 4-wheel, diesel, longer wheel-base, wet operation
Schwarze	M5000	5.0 CY, wet operation, auxiliary engine
	M6000	5.0 CY, wet operation, high dump, auxiliary engine
Sweeprite	Husky	4.0 CY, wet operation, water saver system, diesel auxiliary engine
	Husky II	6.0 CY, wet operation, water saver system, diesel auxiliary engine
Sweepster/FFC	Various models	Quick attach (skid steers & loaders) enclosed broom & hopper sweeper
Tennant	Centurion	6.0 CY, dry or wet operation, with vacuum mode capability
Regenerative-air Sweepers		
Elgin	Air Cub	4.4 CY, shorter wheelbase, commercial applications (parking lots, etc.)
	Crosswind J	8 CY, 90” pick-up head, optional CB hose
	Crosswind Fury	4.4 CY, smaller wheelbase
	Crosswind FSX	8 CY, fast sweeper for flat, smooth surfaces such as airports
TYMCO	210	2.4 CY, wet operation, diesel or gas auxiliary engines, commercial appl.
	435	4.0 CY, wet operation, high dump, auxiliary engine
	DST-4	4.0 CY, wet or dry operation, auxiliary engine
	600	6.0 CY, wet operation, diesel auxiliary engine
	DST-6	6.0 CY, wet or dry operation, diesel auxiliary engine
	600-HSP	6.0 CY, dry operation, high speed operation, airports
	FHD	4.5 CY, forward high dump, auxiliary engine
Johnston	770	7.4 CY, wet or dry operation, water re-circulation system
Schwarze	A4000	4.3 CY, shorter wheel-base, wet operation
	A7000	8.4 CY, conventional wheel-base, wet operation
	A8000	5.0 CY, conventional wheel-base, wet operation, high dump
	A9000	9.6 CY, larger version of A7000
	S333	3.0 CY, single engine, wet operation
	S343	3.0 CY, diesel or gas, conventional chassis, auxiliary engine
	S347-I	3.0 CY, diesel, cabover mounted chassis, auxiliary engine
	S347-LITE	3.0 CY, diesel, cabover mounted chassis, light duty, high dump
	S348-LE	3.7 CY, high dump, diesel, auxiliary engine
	S348-I	3.0 CY, high dump, diesel, auxiliary engine

Regenerative-air Sweepers (cont'd)		
Sweeprite	Raven 25	2.5 CY, high dump, wet operation, gasoline auxiliary engine
Sweeprite	Raven 45	4.5 CY, regenerative-air or vacuum modes, diesel auxiliary engine
Vacuum Sweepers		
Elgin	GeoVac	8 CY, wet operation, std. wheel-base
	Whirlwind	8 CY, wet operation, optional leaf suction hoses
	Air Cub	4.4 CY, shorter wheel-base, commercial applications
	GRV	Glycol Recovery Vehicle - airports
Johnston	VT605/VT650	8.5 CY, CB hose std., water re-circulation system
Schwarze	EV1	6.5 CY, dry operation, rear wheel steering
	EV2	4.2 CY, dry operation, small version of EV1, 4-wheel
Sweeprite	Raven 45	4.5 CY, regenerative-air or vacuum modes, diesel auxiliary engine
Tennant	Centurion	6.0 CY, dry or wet operation, with regenerative-air mode capability