Recommended street sweeping practices for water quality purposes

Water quality considerations for street sweeping

Practices to consider

- Identify watersheds with phosphorus or sediment impairments and target streets in these areas for sweeping.
- Identify and prioritize sweeping in areas of high tree canopy cover.
- In areas with significant tree canopy, time spring and fall sweeping events to occur during and after blossoms, fruit and leaves drop and consider multiple passes to capture materials, as these will continue to drop over a period of weeks.
- Time sweeping to capture organics prior to significant rainfall events to avoid wash-off and leaching to stormwater.
- Consider sweeping during the summer, and winter (as practical) to capture other sediment and debris and lingering vegetative matter.

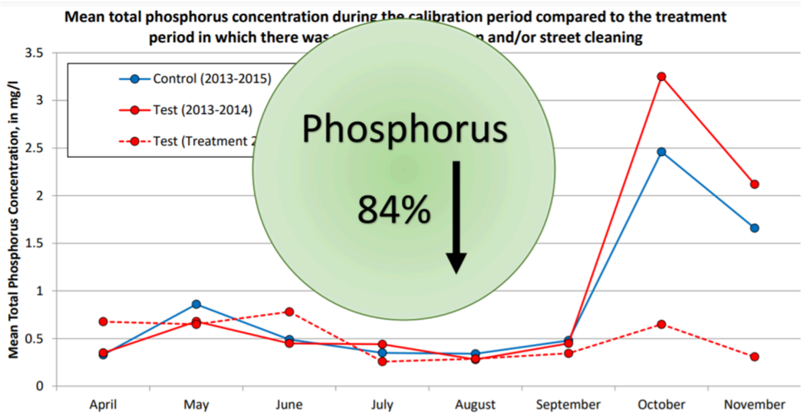
Water quality considerations for street sweeping

- Consider investing in a high efficiency sweeper to capture more of the smaller street dirt particles, which have been shown to have higher phosphorus concentrations.
- Use high efficiency and broom sweepers in tandem, with broom sweepers picking up the bulk of the material followed by a high efficiency sweeper to remove smaller particles.

Other considerations

- Conduct a tree inventory
- Collect and store data related to sweeping practices and material collected.
- Utilize **Geographic Information System (GIS)** and **Global Positioning System (GPS)** technology to track and record information.

Many cities have ordinances against placing leaves in the street. Consider implementing a mechanism to address leaves and organic material adjacent to streets (e.g. on boulevards). Research shows that phosphorus loads in late winter and early spring are significant and it seems likely leaves and other organic material adjacent to streets contributes to this loading, though there is insufficient research to establish this relationship. Leaf collection programs or incentives to place leaves in streets just prior to sweeping may reduce this phosphorus load.



Research conducted by Bill Selbig (USGS) shows that streets, when cleaned of leaf litter prior to a storm, can significantly decrease phosphorus loads in stormwater runoff (Link to study)

This page provides guidance to instruct users on best practices associated with street sweeping and provide the user with key information and resources to successfully develop and execute a street sweeping program. There is a wide breadth of data, research, and resources available related to street sweeping. This guidance is intended to aid in the understanding of street sweeping, its benefits, and links to a variety of helpful resources for a municipality seeking to review or develop its own street sweeping program. Note that the most common street sweeping practices, equipment, and technologies vary by location, but the focus of this document is on the United States, with specific relevance to the State of Minnesota to the extent possible.

Topics covered include the following.

1. Street sweeping overview
2. Street sweeping equipment
3. Benefits of street sweeping
4. Effectiveness of street sweeping (locations, timing, frequency)
5. Managing street sweeping waste
6. Cost considerations
7. Training for street sweeping professionals

Contents

Street sweeping overview

Street sweeping (also called street cleaning) refers to removal of sediment, litter, or other accumulated substances on roadways, particularly in urban and suburban areas. Street sweeping does not include removal of large quantities of leaves brought to the street/verge for removal, large debris or bulky items; removal of these items is typically handled by large vacuum leaf collectors or dump trucks, respectively.

Historically, street sweeping was conducted manually by a sanitation worker with a broom or shovel to remove animal waste from horse-drawn vehicles and other detritus on roadways. Mechanical sweepers such as broom systems attached to horse carts came about in the mid-1800s, and in the early 1900s street cleaning wagons sprayed water onto roadways to wash away debris. Motor-driven street sweeping vehicles were patented in the US in 1917.

Modern street sweeping has improved efficiency of debris removal from roadways dramatically. The focus of street sweeping was simple large “cosmetic” debris removal until the 1970s when concerns about water quality arose. In the decades following, improvements in street sweeping technology focused more on the removal and collection of coarse **sand** particle-sized street dirt, and smaller particles which contribute to instream sediment and nutrient pollution when swept off of or washed into waterways. Even when a street was cleaned of large refuse, the amount of tiny particulate matter that could not be effectively removed manually remained to wash-off into waterways following precipitation. Pollutants in stormwater runoff have long been recognized as contributors to **aquatic habitat** degradation, nuisance algal growth, low **dissolved oxygen** and toxicity in receiving water bodies . More recently, there has been a focus on street sweeping to remove the **organic matter** produced by street trees (leaves, seeds, flowers, etc), which can contribute significant amounts of phosphorus to runoff, especially in the fall during leaf drop. **Particulate matter (air)** also poses significant air-quality concerns when entrained in the air due to wind.

Street sweeping equipment

The focus of this guidance is on modern mechanized advanced street sweeping technologies. These types of mechanized street sweepers for roadways fall into four categories.

- **Mechanical Broom**: Rotating cylindrical brooms flick dirt and debris onto a conveyor moving into a **hopper** for collection. These perform well in picking up heavy material like coarse sand, gravel, and trash, but are less effective in picking up **fine particles**. These sweepers are abrasive which can lead to the breakdown of larger particles into smaller particles, and they are less effective at penetrating cracks and potholes in pavement. Sometimes these sweepers have onboard water spraying systems to help control dust, although sometimes a separate flush truck is used in tandem with mechanical sweepers.

- **Vacuum**: An engine-powered fan creates suction to remove dirt and debris up into a hopper. A windrow broom directs detritus into the path of the vacuum nozzle. While the vacuum is better at picking up fine material than mechanical broom sweepers, there is still some difficulty in penetrating cracks and potholes with the windrow broom. Vacuum exhaust can emit dust into the atmosphere.
- **Regenerative Air**: An engine-powered blower pushes a blast of air across the width of the sweeper truck which penetrates cracks and potholes, then similar to a vacuum sweeper, debris is sucked into a hopper. A windrow broom directs **detritus** into the path of the air blaster and vacuum. To avoid dust emission problems associated with vacuum sweepers, regenerative air sweepers employ a closed loop cycle of blast air and suction air.
- **High-Efficiency / New Technology**: These trucks represent new technology that includes a combination of technologies from other sweeper types, incorporating both mechanical and vacuum aspects. New technology includes both electric/hybrid sweepers, as well as high-powered electric, autonomous street sweeper vehicles. Vehicles are smaller in size than traditional street sweeping trucks and use **LiDAR**-based machine vision technology to operate under all weather conditions.

Effectiveness and costs associated with different mechanized street sweeper types varies and are summarized in other sections of this guidance.

When selecting the type of street sweeper that is best for a given municipality, the factors to consider are listed below and discussed in the adjacent table.

1. Understanding where and how frequently sweeping will occur (e.g. urban roadways, parking lots, permeable pavement; quarterly, monthly, seasonally).
2. Characterizing the type of sweeping waste most prevalent (e.g. loose or compacted materials, fine or coarse sediment, level of trash debris)

3. Taking stock of whether it makes sense to conduct street sweeping in-house with trained municipal staff or contract the work to a private street sweeping company.
4. Consider the cost, user-friendliness, and efficiency ratings of equipment.

Key functionality, limitations, and examples of street sweeping equipment. Modified from Kuehl et al, 2008

Link to this table

Sweeper type	Sub-type	Functionality	Limitations	Hopper capacity (cubic yards)	D st
Mechanical	Chain-and-paddle	Effective for wet/matted leaves and digging/ sweeping packed dirt; Able to sweep millings and coarse sand better than belt sweepers (no “inside” areas of buildup); Compared to belt	Paddles limit debris size to 6” diameter or smaller; Compared to the belt, chain-and paddle needs to be replaced more often; Does not pick up fine materials as well as other sweepers; Particles that do not get	4.5-7.5	Si M Le R M Le

Sweeper type	Sub-type	Functionality	Limitations	Hopper capacity (cubic yards)	D st
		sweepers, less daily build up; Requires less power than regenerative air and vacuum sweepers	picked up are spread across the street surface sometimes making the street look dirty or streaked		
	Belt	Able to pick up large debris (plastic bottles, cans, branches); Able to pick up wet/matted and large amount of leaves better than other sweepers; Effective at “digging into” and	Conveyor must be cleaned daily to prevent buildup of debris; Chip seal aggregate and winter abrasive (sand) can build up inside belt; Does not pick up fine materials as well as other	3.5-4.5	Si M Le R M Le

Sweeper type	Sub-type	Functionality	Limitations	Hopper capacity (cubic yards)	D st
		removing packed dirt from roadway; Requires less power than regenerative air and vacuum sweepers	sweepers; Particles that do not get picked up spread across the street surface sometimes making the street look dirty or streaked		
Vacuum	NA	Removes fine sand and silt, but surface must be dry; Best for situations with most debris in gutter; Will vacuum material directly from gutter; Ability to	Difficulty picking up wet/matted leaves; Cannot pick up tree brush; Water must be used in the hopper for dust suppression (prevents dust from being blown	8.0-8.5	R ti

Sweeper type	Sub-type	Functionality	Limitations	Hopper capacity (cubic yards)	D st
		pick up entrained material within cracks under vacuum head; Can have vacuum hose attachment (i.e. for catch basins)	out via the fan exhaust); Debris is limited to 3-inch diameter or smaller; Requires more power than mechanical broom sweepers; noise may be a consideration; Water should be used or excessive fan wear will occur; More efficient operation on flat pavement surface; Should be used in above freezing		

Sweeper type	Sub-type	Functionality	Limitations	Hopper capacity (cubic yards)	D st
			temperatures only		
Regenerative air	NA	Can remove fine sand and silt, but surface must be dry; Ability to pick-up materials entrained within cracks; Can have a larger than average hopper; Can have vacuum hose attachment (i.e. for catch basins); Regenerative head reaches up to eight feet in width	Debris is limited to diameter of air out hose; Difficulty in picking up wet/matted leaves; Particles that do not get picked-up are spread across the street surface sometimes making the street look dirty or streaked; Requires more power than mechanical broom	4.0-9.6	R ti

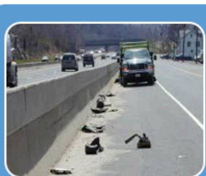
Sweeper type	Sub-type	Functionality	Limitations	Hopper capacity (cubic yards)	D st
			sweepers; noise may be a consideration; Should be used in above freezing temperatures only; More efficient operation on flat pavement surface		
High Efficiency / Newer Technology	Mechanical/ Vacuum	Removes fine sand and silt; Able to pick up wet, matted vegetation; Able to pick up large debris (plastic bottles, cans, small branches);	Broom skirting limits ingestion of large amounts of leaves in the fall; More skirting parts that are prone to wear	3.5-4.5	Fr M Le Si M Le

Sweeper type	Sub-type	Functionality	Limitations	Hopper capacity (cubic yards)	D st
		Wet operation with skirts removed; Can use dry vacuum or water to suppress dust; Year round operation			
	Regenerative air	Removes fine sand and silt; Year round operation	Should be used on flat surface to seal sweeper head; Debris is limited to diameter of vacuum hose; Difficulty in picking up wet, matted vegetation	4.5-7.3	R ti

Benefits of street sweeping

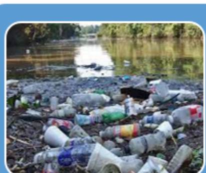
Improved Aesthetics

- Debris removed from roadways and curblines
- Reduced debris wash-off into BMPs, ditches, and waterways



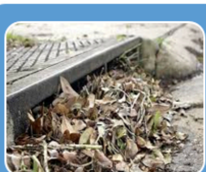
Improved Roadway Safety

- Reduced roadway hazards from trash and sediment for drivers, cyclists, pedestrians
- Improved pavement and marking visibility



Improved Environmental Quality

- Improved stormwater runoff quality due to removal of sediment, organic matter, nutrients, particulate metal, trash
- Improved air quality due to removal removal of fine particulate matter
- Improved removal of sand, silt, and cinders associated with snow and ice accumulation



Other Benefits

- "Free" waste material for re-use (e.g. landfill cover)
- Potential or periodic decreased inlet clogging and/or outlet deposition of debris (sediment, vegetation, trash) for both the stormwater pipe system, ditches, sumps, ponds, and dedicated stormwater BMP features.
- Crediting opportunity with removal of sediment and phosphorus for permit compliance

Benefits of street sweeping

Roadways accumulate debris and material such as sediment, vegetation, vehicle debris/waste, industrial emission particle deposition, and litter. Harmful pollutants which accumulate on roadways, parking lots, and pavement include metals, organics, nutrients, and particulate matter, which street sweeping helps remove. There are a number of benefits associated with street sweeping, the most cited being improved appearances, improved roadway safety, and improved environmental quality through both reducing air pollution and water quality pollution. Many key benefits associated with street sweeping have cumulative impacts as well. For example, increased removal of fine particulate matter can reduce the sediment load to downstream BMPs, extending the life of these practices which provide improved water quality further downstream. As the old adage goes, “an ounce of prevention is worth a pound of cure” when it comes to source removal before sediment enters the stormwater system.

For more information on stormwater and pollutants in stormwater, link here.

Effectiveness of street sweeping

Street sweeping effectiveness is determined by several factors including the type of street sweeper, **particle size distribution**, land use, tree cover, timing and frequency of sweeping, and whether there is a curb and gutter and parking restrictions. Effectiveness is generally defined as the efficiency of the sweeper. Efficiency can be represented in a few ways, which tends to vary across studies. Most commonly, the efficiency is represented as the portion of particles/pollutants/debris removed by the sweeper on a mass basis. Note that this measure of efficiency is different from an evaluation of the changes in runoff water quality as a result of sweeping. For more information on pollutants, see the pages on phosphorus and total suspended solids in runoff.

There are two main categories of materials removed by street sweepers – sediments and coarse organics. Sediments include dirt, rocks, and other inorganic components and are typically categorized by size ranging from the smallest particles in the silt and clay category (<0.063 mm) up to gravel (>2 mm). Coarse organics are larger particles of vegetative matter, including leaves, sticks, grass, blossoms, fruits, seeds, etc.

Sweeper type and particle sizes

Regenerative air street sweeper removal efficiency by particle size in Cambridge, Massachusetts (Sorenson 2013)

Land use	Removal efficiency (%)

	Total	Coarse (> 2mm)	Medium (0.125 - <2mm)	Fine <(< 0.125mm)
Multi-family residential	83.3	89.5	82.6	49.8
Commercial	78.2	92.4	79.4	48.6

Total Median percent reduction in street solid pollutant yields by season and land u (Sorenson 2013)

Land use	Phosphorus	Arsenic	Barium	Cadmium	Chromium	C
Residential - spring	82	70	85	78	55	7
Residential - summer	99	77	80	84	80	9
Residential - fall	94	90	93	94	98	9
Commercial - spring	62	72	54	69	59	3
Residential - summer	97	79	84	79	66	3
Residential - fall	83	79	84	88	93	9

Approximate phosphorus concentrations in sweeper solids by particle size (adapted from Chittenden County RPC et al. 2018).

Particle size	TP (mg-P/kg-dry)
> 2mm	950
0.125-2mm	390
0.063-0.125mm	450
< 0.063mm	1400
Total composite	480

Selbig and Bannerman (2007) found that in weekly sweeping of residential areas in Madison, Wisconsin with a regenerative air sweeper, the mean street dirt yield reduction (mass per unit length) was 25%. Similarly, a vacuum assist sweeper removed 30%. In contrast, weekly sweeping with a broom sweeper only removed 5% of street dirt and added to the street dirt yield over a third of the time. These efficiency values represent street dirt removal from April through September and do not account for fall leaf drop. Several other studies found regenerative air or vacuum assisted sweeper technology efficiencies to range from 35 to over 90%, but these studies were in controlled settings with pre-applied dirt mixes on a test surface. Selbig and Bannerman (2007) point out that their Madison study represents typical use conditions.

In another sweeping efficiency study, also in Madison, Wisconsin, Horwatich and Bannerman (2009) evaluated changes in street dirt yields as a result of sweeping. Using a vacuum assist sweeper, the median reduction rate was 32%, while the mechanical broom sweeper only reduced street dirt yields by 7%. Horwatich and

Bannerman (2009) also found that efficiencies were higher (60-80%) when street dirt yields were higher, and efficiencies were reduced (20-30%) in low yield situations. Weekly and monthly sweeping with the vacuum-assist sweeper resulted in relatively similar median efficiencies of 29 and 32%, respectively. A meta-analysis evaluating sediment and street dirt removal efficiencies of varying land uses and sweeper frequencies showed that overall efficiencies were 47% for mechanical broom sweepers, 63% for vacuum assisted sweepers and 74% for regenerative air sweepers (Tetra Tech 2020).

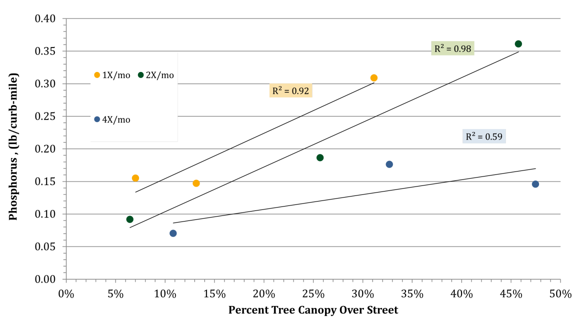
Sorenson (2013) evaluated regenerative air sweeper efficiencies in Cambridge, Massachusetts. They measured street solid mass before and after sweeping with the change in mass representing the sweeper efficiency. While total efficiency was quite high, efficiency decreased with decreasing particle size as summarized in the adjacent table. A similar pattern is shown in the pollutant reductions. In some instances, the change due to sweeping was an increase in pollutants associated with the smallest particles (<0.125mm, very fine sand, silt, and clay) but an overall reduction in the pollutant. Generally speaking, street sweepers of all types are more effective at removing larger particles and less effective at removing smaller particles, but regenerative air and vacuum assisted sweepers are consistently more effective than mechanical broom sweepers.

Breault et al. (2005) evaluated the removal efficiencies of a mechanical broom sweeper and a vacuum sweeper using a mix of street dirt with a known particle size distribution. They found that mechanical sweepers, in addition to being overall less effective at removing street dirt (20-31% efficiency), they were particularly ineffective at small particle removal (9-13% removal efficiency of particles less than 0.250 mm). In contrast, vacuum sweepers were able to remove 60-92% of street dirt overall and were able to maintain 31-75% efficiency in removal of particles less than 0.250 mm.

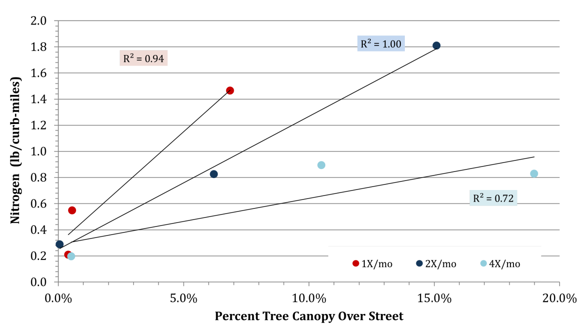
It is important to remove the larger particles, including coarse organics, like leaves, for successful sediment and phosphorus removal. Waschbusch et al. (1999) showed that approximately 50% of the total phosphorus and 70%of the sediment in street dirt is in particles greater than 0.25 mm and leaf litter contributes another 30% of the total phosphorus load.

However, when sweeping for water quality improvements, it is important to consider the smaller particles, which often have the highest phosphorus concentrations on a mass basis. Preliminary data from the Chittenden County Regional Planning Commission showed that street sweeper solids in the smallest particle fraction (<0.063 mm) had TP concentrations almost three times as high as the larger particles (0.063-2 mm) and nearly twice as high as the largest particles (>2mm).

Land use and tree cover



Average phosphorus recovered per sweep vs. street canopy cover by sweeping frequency (Kalinosky et al. 2014).



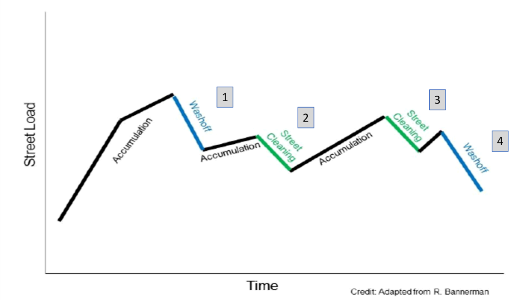
Average nitrogen recovered per sweep vs. street canopy cover by sweeping frequency (Kalinosky et al. 2014).

Land use can affect the amount of street dirt and organics generated; however, there is little evidence that land use type alone significantly impacts the amount of dirt and debris removal on a given street. SPU and HEC (2009) found a similar amount of material collected from both residential and industrial areas, and there was high within-site variability of removal efficiencies during repeated sweeping events. Sorenson (2013) found that sweeping residential and commercial land uses resulted in similar removal efficiencies. The specific activities occurring on a given street may be more relevant than the general land use. Janke et al. (2017) noted that factors such as traffic volume, population density, and vegetation are important land use variables controlling stormwater runoff nutrients. When evaluating a street sweeping program, consider specific characteristics of the surrounding landscape. For example, a roadway in an area classified as industrial may have a relatively low level of street dirt accumulation if the area is primarily storage warehouses; however, if the adjacent area is a gravel and sand supplier, higher street dirt is likely, due to spillage from trucks passing through and generally dustier conditions. Within residential areas, the age of development, level of urbanization, and tree canopy cover can influence street dirt and organics accumulation. Waickowski (2015) found that the total phosphorus load from low-density older residential neighborhoods and downtowns was about twice as high as from high-density residential neighborhoods and recently developed low-density neighborhoods. The lower rates from the new development and high-density development were attributed to the lack of tree canopy.

Tree cover is an important consideration in determining how effective sweeping can be. Janke et al. (2017) monitored 19 watersheds in the Minneapolis-Saint Paul metropolitan area to evaluate the influences of trees, vegetation and impervious cover on nutrient concentrations and loading in stormwater runoff. The presence of street trees within five feet of the curb was found to be highly correlated to the total phosphorus event mean concentrations in runoff, highlighting the importance of prioritizing leaf litter removal either through street sweeping or dedicated leaf litter collection.

Kalinosky (2015) conducted a two-year study of street sweeping in Prior Lake, Minnesota to evaluate the impacts of street tree canopy cover on the characteristics of swept materials. The study found a strong seasonal correlation between the amount of coarse organic material collected, tree canopy coverage, and seasonal leaf drop. Coarse organic matter was found to be 15% of the total dry weight of swept material, but contributed 36% of the TP and 71% of the TN. The amount of overhead tree canopy was determined to be a significant predictor of recoverable loads of coarse organic matter and nutrients throughout the year (Kalinosky 2015). A similar pattern was identified for nutrient content per curb-mile (see adjacent figures).

Timing and frequency of sweeping



1 – missed opportunity; 2 - good timing but little accumulation; 3 – effective; 4 – though missed, maybe a less effective time to sweep vs. 3

Relationship between dirt accumulation, washoff and street cleaning (modified from Donner et al. 2016).

The impact and effectiveness of street sweeping is affected by when and how often streets are swept. Targeting sweeping prior to major storm events and after major tree flower and leaf dropping events can increase the volume of swept debris. Street dirt and debris, including leaves and other vegetation, build up over a period of time and are then washed off, entering the storm drain system. Effective street sweeping relies on the timing of sweeping to capture dirt and debris before it has the opportunity to wash off. This effect is illustrated in the schematic. If sweeping is too infrequent, the majority of the accumulated materials will be removed via washoff, rather than sweeping. In addition, during smaller rainfall events that do not washoff larger leaf litter particles, leaching from rewetted organic matter can mobilize nutrients into runoff. An appropriate street sweeping frequency will vary based on the frequency of runoff-generating rainfall events and the amount of debris on the street. However, there is a point of diminishing returns when considering street sweeping frequency. If sweeping is conducted too often, dirt and debris will not have accumulated to a point where each individual sweeping pass is collecting a substantial amount of material.

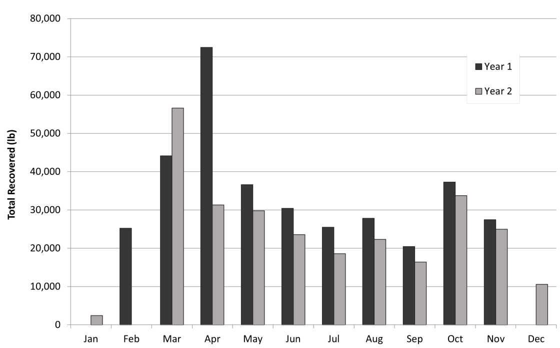
Sutherland and Jelen (1997) modeled the total suspended sediment (TSS) reductions by various sweeper technologies. Most of the improved overall removal efficiencies were gained in sweeping at least once a month and up to weekly sweeping (Sutherland and Jelen 1997). Sweeping less frequently than once a month misses a lot of accumulated street dirt, and sweeping more frequently than weekly, while still reducing overall loads, has a much smaller marginal increase in loads captured.

Seasonal timing of street sweeping should also be considered. Sorenson (2013) found that in Cambridge, MA, fall street sweeping, which included fall leaf litter removal, had the maximum phosphorus yields throughout all four seasons, but the end of winter (March) sweeping had the highest median phosphorus yields. Sorenson (2013) also used SLAMM (Source Loading and Management Model) to model street sweeping pollutant removal and found that it consistently underrepresented leaf litter loadings in the fall. Sorenson (2013) suggested that the model may be underrepresenting TP reductions from street sweeping because of this underrepresentation of leaf litter loading.

Kalinosky et al. (2014) in their sweeping study of Prior Lake, MN found that the amount of coarse organic material recovered per curb-mile increased as the tree canopy cover over the street increased. The study also showed that in areas of medium and high canopy cover, there were benefits to sweeping more than once a month, with biweekly sweeping picking up more material on a per mile basis than monthly sweeping (Kalinosky et al. 2014). Canopy cover was determined qualitatively by the amount of tree canopy over the street, on average, for the sweeping route. Subsequent to the canopy cover determination, canopy cover was analyzed using a geospatial analysis. Medium canopy cover was calculated at 5.6% coverage and high canopy cover was 13.9% coverage over the street.

Average coarse organic (dry weight) recovered per sweep by route type, using regenerative air sweeper technology (Kalinosky et al. 2014).

Sweeping frequency	Low Canopy (lb/curb-mile)	Medium Canopy (lb/curb-mile)	High Canopy (lb/curb-mile)
1x/month	10.6	23.4	59.9
2x/month	10.7	35.3	89.2
8.1		33.0	49.1



Total dry solids collected by month and year in Prior Lake, MN (Kalinosky et al. 2014).

Removing leaf litter soon after it has fallen is important for maximizing the phosphorus removal benefit. Cowen and Lee (1973) showed that the length of time leaves remain in contact with water and the degree to which the leaves are broken down increase phosphorus leaching. Leaching is an important factor in considering stormwater runoff quality. In this context, it is the release of soluble phosphorus from organic matter into stormwater runoff which eventually reaches receiving waters, or downstream BMPs. In a laboratory setting, cut up leaves leached nearly three times as much phosphorus as intact leaves, highlighting the need to collect leaves soon after they drop, to minimize breakdown through natural decay processes and by vehicular and foot traffic, and prior to rainfall events that can mobilize the phosphorus. Hobbie et al. (2013) found that leaf litter in the curb gutter decomposes faster than in natural areas (natural, non-urban forests and prairies) with most species losing 80% of their initial mass after one year but still retaining more than half the nitrogen and phosphorus. After an initial loss period, Hobbie et al. found there were several cycles of phosphorus immobilization and loss, but there was significant variation among species (Hobbie et al. 2013). Kalinosky (2015) found leaching rates of street litter were highest in May and declined throughout the summer.

While traditionally sweeping has been limited to the spring through leaf drop in the fall; it has been shown that winter snowmelt contributes roughly 50% of the annual nitrogen and phosphorus export off roadways in highly urbanized areas of Saint Paul, MN (Bratt et al. 2017). This was attributed to decomposing leaf litter on roadways that leaches phosphorus throughout the winter as snow melts into runoff. Further Bratt et. al. (2017) estimated that winter leaf litter may contribute up to 40% of the annual total dissolved phosphorus loading. In more suburban areas, snowmelt leaching is a much less significant contributor to overall TP loading.

In areas where sweeping is conducted primarily for total solids removal, sweeping throughout the year, especially in the summer, can be just as important as spring and fall sweeping, which may be done for vegetative debris, winter salt and sand, and leaf removal. With the exception of December and January, the total recoverable dry solids collected during sweeping can remain high throughout the year (Kalinosky et al. 2014). Fine sediment is the primary contributor from February through September, while coarse organics increase in the fall.

Recommended sweeping frequencies in the Ramsey-Washington Metro Watershed District (Schilling, J.G. 2005)

Land Use or Special Area	Minimum frequency	Maximum frequency
Arterials	9 times/year	16 times/year
Commercial	9 times/year	16 times/year
Light industrial	6 times/year	9 times/year
Heavy industrial	9 times/year	16 times/year
Residential	6 times/year	9 times/year
Central Business District*	Biweekly	2x/week
	6 times/year	9 times/year

*** Dependent on business and local government expectations.**

While the most appropriate sweeper schedule will depend on local conditions and objectives, an example from Schilling's (2005) assessment of street sweeping policy options for the Ramsey-Washington Metro Watershed District and recommended street sweeping frequencies based on the land use and special area types is presented in the adjacent table. The recommended sweeping frequencies were informed by the sweeping frequencies reported in an earlier survey of jurisdictions in Minnesota and the US and Canada, more broadly. Part of the findings from that survey indicated that Minnesota jurisdictions tend to street sweep less frequently than other jurisdictions. The resulting recommended frequencies represented a balance of closer alignment with typical frequencies and "a reasonable and defendable approach" (Schilling 2005).

Other considerations for sweeping

Curbs

The presence of a curb is an important component to successful street sweeping. The curb system allows material to collect and remain in a concentrated area on the roadway. Without a curb to collect materials, debris will blow or washoff into the adjacent shoulder, ditch or other vegetated area, making sweeping ineffective (Kuehl et al., 2008). Sweeping roadways without a curb can actually lead to more problems, as there is no barrier between the sweeper and the unpaved area adjacent to the roadway to prevent sweeping of compacted dirt and vegetation. Sweeping of unpaved areas will loosen the dirt and vegetation encouraging erosion. In areas without a curb, the lack of a curb may reduce street dirt and pollutants by allowing transport off the roadway and into adjacent vegetated areas (Young et al. 1996 in Zarriello et al. 2002).

Parking Restrictions

Horwatich and Bannerman (2009), Sorenson (2013) and others have noted that most contaminants accumulate in close proximity to the curb. The Northern Virginia Planning District Commission (1996) estimated that most contaminants are within 12 inches of the curb. Parking controls are a key component to an effective street sweeping program to be able to access the full curb and gutter with the sweeper. San Diego was able to achieve a 50-80% increase in the load of debris removed once parking restrictions were implemented (Michael Baker International, 2015).

Managing street sweeping waste

Street sweeping waste material such as sand, salt, leaves, and debris removed from city streets, parking lots, and sidewalks are referred to generally as sweepings . Sweeping debris can range in size and by priority for any particular municipality, including dust, small materials (sand, silt, sediment, aggregate), large materials (road debris, trash), vegetation, and packed dirt.

Sweepings may be managed in several different ways according to the MPCA Solid Waste Street Sweepings Guidance (MPCA, 2010):

1. Disposal via recycling for recyclable materials (e.g. aluminum cans)
2. Disposal via composting for organic materials (e.g. leaves)
3. Disposal via landfill for non-recyclable or non-organic trash materials (e.g. plastic bags)
4. Reuse of sweepings that have been screened for removal of recyclable, organic, and trash

Test results have shown that sweepings from normal street sweeping operations are safe and acceptable for reuse in many areas with the exception of playgrounds, children's play areas, residential yards, areas with continuous human contact, areas near drinking water wells, wellhead protection areas for public drinking water supplies, and sites with **karst** features such as sinkholes. Street sweepings may not be disposed of in or near wetlands or surface waters.

If sweepings are not screened for removal of trash, leaves, or other debris, the sweepings are considered industrial solid waste and must be disposed of collectively at a permitted solid waste facility, and until disposed of, must be managed and stored in accordance with solid waste storage standards (Minn. R. 7035.2855). Sweepings that are screened for reuse must be managed in accordance with Best Management Practices outlined in the site's Industrial Stormwater Permit (if applicable).

Street sweepings may be reused in any of the following ways without MPCA approval after solid waste screening:

1. Mix with new salt/sand mixture for winter application to roads, parking lots, or sidewalks
2. Use as "alternate daily cover" material at approved and permitted solid waste landfills
3. Use as material in commercial or industrial development, road restoration, or construction projects.

For specifics related to these reuse opportunities, refer to the MPCA Solid Waste Street Sweepings Guidance (MPCA, 2010). Any other potential reuse of properly screened sweepings must be approved by MPCA directly.

Links to reports containing data on chemical concentrations in street sweepings can be found here.

Cost considerations

Financial Costs

- Machinery Purchase
- Machinery Maintenance/Upkeep
- Cost of fuel
- Cost of Contracting Services
- Operator Training (Equipment and Background)
- Operator Man-Hours
- Managing Sweepings (e.g. landfill fees)
- Traffic Control
- Laboratory Analyses

Lifecycle Benefits

- Managing Sweepings (e.g. opportunities for material reuse)
- Potential decreased stormwater infrastructure maintenance due to inlet clogging and/or outlet deposition of debris
- Improved aesthetics
- Improved air quality
- Improved water quality
- Improved driver safety (roadway maintenance)

Cost and Benefit Considerations Associated with Street Sweeping (applicability and scale of associated cost varies).

There are many facets related to costs incurred with street sweeping activities which vary depending on the sweeping program. For example, costs vary if a municipality intended to buy and train its own street sweeping staff as opposed to contracting out street sweeping services to a private company. Costs related to street sweeping activities may vary dramatically across different geographies as well due to seasonality, types of debris, etc. According to the Local Road Research Board (LRRB), capital cost for purchasing a street sweeper vehicle can be quite high, ranging from at least $140,000 foramechanicalsweeperto$175,000 - $250,000 for regenerative-air or vacuum type sweepers in 2007 US dollars (Kuehl et al, 2008).

The City of Edina, MN conducted a cost-benefit analysis related to selecting the most appropriate sweeper type based on efficiency in phosphorus reduction

(Edina, 2015). The City also used their analysis to determine a cost-effective frequency of street sweeping. In the end, based on phosphorus load reduction efficiency (pounds per curb-mile), and cost-efficiency (dollars per pound of phosphorus recovered), the City concluded the following.

- Upgrading current mechanical sweepers to regenerative-air sweepers would increase cost-efficiency 24%, increase load recovery of solids by 47%, and increase phosphorus recovery by 37%, while only increasing total costs by 4%,.
- Increasing sweeping frequency during snow-free seasons decreases the cost per curb-mile of sweeping and improves cost-efficiency. Increased sweeping frequency in priority watersheds could increase recovery of solids by 250% and recovery of phosphorus by 200%. The cost-basis lowered from about $66/curb - mileto$37/curb-mile and cost-efficiency improved from $173/lb - Precoveredto$152/lb-P recovered when comparing mechanical to regenerative-air sweeping.

It is difficult to scope the total cost of street sweeping activities for any particular jurisdiction without a site-specific cost-benefit analysis, however the potential considerations for both financial costs and quantitative and qualitative benefits are presented in the adjacent figure. Some municipalities may sweep more or less frequently based on staff availability, roadside tree density, snowfall frequency, or any number of unique combinations of circumstances. Other costs include labor, equipment, maintenance, disposal fees, reuse screening, and potentially lab analysis expenses associated with street sweeping for phosphorus reduction credit.

Relative to other sediment removal strategies to improve water quality (e.g. stream restoration, replacing media in BMPs, constructing new BMPs), targeted street cleaning is considered one of the most affordable options at $3-5$ per pound of sediment removed (2013 dollars) (Hunt, 2017). Additional benefits associated with street sweeping are that programs may be introduced and implemented very quickly and are not limited by space relative to many other structural BMP practices (Hunt, 2017).

For more information on street sweeping costs, link to this resource.

Training for street sweeping professionals

Information: *Reference to any specific commercial product, process, or service by trade name, trademark, service mark, manufacturer, or otherwise does not constitute or imply endorsement, recommendation, or favoring by the Minnesota Pollution Control Agency.*

Street sweeping equipment are complex machines to operate and require operator training. It is recommended that any sweeper operator be trained in understanding both how to safely, effectively, and efficiently operator the sweeper, but also to understand the reasons behind street sweeping as successful programs have enhanced efficiency when operators understand the role sweeping plays relative to stormwater management, trash and debris control, and air quality (Kuehl et al, 2008). Minimum street sweeper operator training should include the following items.

- Familiarity with and understanding of **standard operating procedures**
- Daily operation checklist procedures
- Machine operation
- Trouble-shooting indicators and problems
- Daily and long-term preventative maintenance
- Minor repairs
- Machine and personal safety requirements

Note that factory-training for operators and mechanics often comprises a minimum of 32 hours of lecture and/or hands-of efforts (Kuehl et al, 2008).

If street sweeping activities are contracted out to a private company, it may be beneficial to ensure that those street sweeping professionals have been professionally trained and potentially have obtained professional certification for training in best practices. If street sweeping activities are conducted by municipal staff, it may be beneficial to seek specific training from the equipment manufacturer upon purchase of machinery, as well as seeking certification training.

Below are brief summaries of some organizations that provide training information (click on links to visit the appropriate website).

North American Power Sweeping Association (NAPSA)

NAPSA is a membership-based organization that runs the "Sweeper School", containing training tools for the sweeping industry. Training programs, courses, and certifications are conducted through educational online training modules. Course programs currently include

- Certified Sweeper Operator (CSO),
- Certified Sweeping Manager (CSM), and
- a general training called Fleet Basics.

Training modules cover topics such as legal reasons to adhere to Industry Operating Standards, case studies, safety messaging, and quality control. An individual sweeping organization may also become "NAPSA Certified Sweeping Company" which involves joining NAPSA and training all staff through their courses and adhering to the Power Sweeping Standard developed in accordance with the American National Standards Institute (ANSI).

1-800-SWEEPER

This is a membership-based network of independently owned power sweeping companies. Although largely intended to provide services through national marketing, this organization provides a number of educational video series and blog posts associated with street sweeping best practices, standards, webinars, and news. 1-800-SWEEPER also partnered with Digital Image Studios to develop "SweeperSIM", the first virtual sweeper truck driving training software simulator.

North American Sweeper Magazine

This periodic (semi-monthly) print and digital magazine includes featured articles, trends in sweeper technology, training opportunities, news, commendations, and advertisements/classifieds pertaining to street sweeping companies and equipment. The periodical also has an online presence where they provide industry news and spotlights on technology,

World Sweeping Association (WSA)

This organization provides the contract sweeping community (contractors and those who hire them) with the resources and information needed for effective decision-making.

National Events and Conferences

- National Pavement Expo: Conducted by NAPSA, this expo includes workshops and conference sessions specific to the sweeping industry. Topics include sweeping best practices, industry roundtable discussions, and networking opportunities.
- Sweeper Summit: Leadership conference and equipment expo including vendor displays, general and educational sessions, and networking opportunities to share knowledge.
- Sweeper Roundup: Conducted by WSA, this conference provides a mix of both equipment expo and educational seminars for street sweeping professionals.
- Public Works Expo: American Public Works Association (APWA) annual multimodal learning experience for professionals across the entire spectrum of public works.
- Trade Shows and Demos: These periodic events are opportunities to keep up with technology, best practices, and offer opportunities to learn through demonstrations, lectures, and hands-on workshops (e.g. World of Asphalt Trade Show and Conference).

Street sweeping program development

Street sweeping activities should be planned based on the specific goals of a community, with decisions of equipment, timing, frequency, locations, waste management, etc. being dependent on the specific needs and budget of that community. Developing a street sweeping program involves complex questions and decision making when it comes to executing a street sweeping plan. Street sweeping program and plan development may involve (and is not limited to) the following considerations.

Planning

- Identify the goal or goals of initiating a street sweeping program in your jurisdiction
  - Determine if obtaining **credit (stormwater credit)** for sediment or phosphorus removal from sweeping is a goal, and explore requirements thereof when developing program, plan, and standard operating procedures (SOPs)
- Writing or selecting **standard operating procedures** (SOP) for street sweeping activities
- Consideration of parking ordinances (e.g. is sweeping frequent enough to implement no parking hours on a certain day of the week)
- Informing and collaborating with residents
- Identification of sweeping routes
- Identification of sweeping **hotspots**
- Determination of whether street sweeping activities already occur (e.g. on private properties, private roadways, near landfills, etc.)
- Using understanding of sweeping routes, seasonality, and build-up/ **wash-off** to determine the most appropriate frequency for sweeping particular locations (may vary)
- Determination of funding necessary to support proposed sweeping strategy, or consider modifications to strategy based on available funding

Equipment and Staffing

- Obtain necessary equipment
- Prepare equipment maintenance schedule
- Plan for equipment storage/parking
- Train personnel and assign responsibilities and roles
- Hire a contractor if needed to execute the street sweeping plan
- Plan for storage and disposal or potential reuse of sweeping waste debris

Record Keeping and Tracking

- Plan for centralized, effective, and informative record keeping

- Determine what record keeping is helpful or required to meet your goals, especially with regards to sediment or phosphorus removal crediting, if applicable.
- Develop performance measures
- Allow for adaptive management so the program, plan, and SOPs may change over time upon regular review

Street sweeping program plans may be modeled after plans in other municipalities to pick and choose elements based on the specific needs of the jurisdiction. For example, a large urban city like Minneapolis, Minnesota currently performs street sweeping activities on more than 1,100 miles of street (curb to curb) with an additional 400 miles of alleys twice annually, with additional routine sweeping at other times. Minneapolis identified their reasons for street sweeping to be seasonal removal of trash, debris, and winter road maintenance, keeping the community clean, keeping storm drains clear to avoid flooding, and to avoid waterway pollution due to leaflitter and trash. Alternatively, a small city like Forest Lake , Minnesota may have similar street sweeping goals (removal of particulate and organic matter from impacting downstream water quality, avoiding clogging of stormwater infrastructure and structural BMPs, improving road safety and appearance, etc.); however, they have a very different operational scale relative to Minneapolis (sweeping 240 curb miles twice annually).

Key considerations for water quality targeted street sweeping

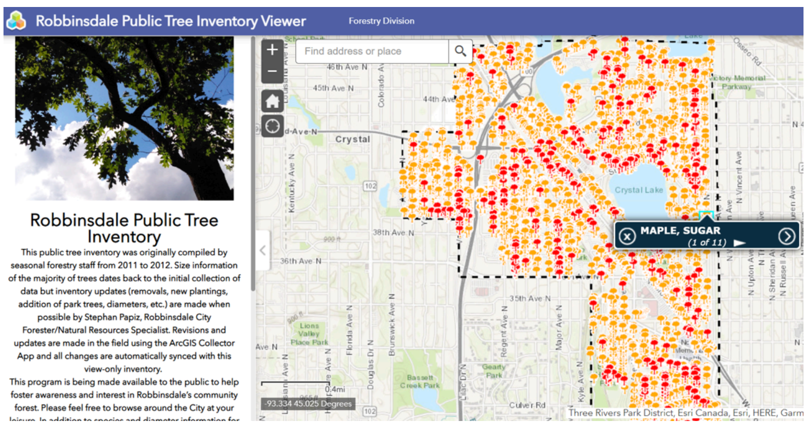
To establish, or modify, a street sweeping program to explicitly address water quality, there are some key considerations that should be included to maximize the pollutant load reductions.

- Identify watersheds with phosphorus or sediment impairments and target streets in these areas for sweeping.
- Identify and prioritize sweeping in areas of high tree canopy cover.
- In areas with tree significant canopy, time spring and fall sweeping events to occur during and after blossoms, fruit and leaves drop and consider multiple

passes to capture materials, as these will continue to drop over a period of weeks.

- Time sweeping to capture organics prior to significant rainfall events to avoid wash-off and leaching to stormwater.
- Consider sweeping during the summer, and winter (as practical) to capture other sediment and debris and lingering vegetative matter.
- Consider investing in a high efficiency sweeper to capture more of the smaller street dirt particles, which have been shown to have higher phosphorus concentrations.

Additional considerations



Screen shot from Robbinsdale's Public Tree Inventory Viewer website. Click on image to enlarge.

- **Tree inventories.** Many cities have urban forestry programs. Increasingly cities are conducting tree inventories. While we know phosphorus loading correlates with canopy cover over impervious surfaces, clear relationships have not been established for the effect of different tree species. Assessing canopy cover and effects of tree species are areas of active research. An example of a detailed tree inventory and associated web tool are the City of Robbinsdale, as shown in the adjacent image and on their public tree inventory viewer website. Example websites, in addition to Robbinsdale, are provided below.
  - Rochester Forestry

    - St. Paul urban tree canopy assessment
    - Minneapolis
    - North St. Paul on-line tree inventory
    - A Step-by-Step Guide to Taking Urban Forest Inventory Measurements - (SeaGrant, Mississippi Alabama)
- **Geographic information Systems (GIS)**. GIS is a potentially powerful tool for conducting a tree inventory. In addition to providing location information, several attributes can be associated with trees, including but not limited to tree species, tree characteristics (e.g. height, diameter), health, and conflicts (e.g. proximity to power lines). An important attribute that can be determined in the field or with aerial photos is canopy cover and canopy cover over impervious surfaces. There are several tree inventory GIS applications which can be found through a simple web search. Some examples of GIS applications for tree inventories include the following.
    - The Boston College Tree Inventory
    - Using Geographic Information System for Trees Assessment at Public Park
    - Tree Inventories and GIS in Urban Forestry
    - CREATING AND USING GIS DATABASES FOR THE INVENTORY OF TREE SPECIES FROM CAMPUS OF BUSAMV "KING MICHAEL 1 st OF ROMANIA" FROM TIMISOARA
    - A STREET TREE INVENTORY FOR MASSACHUSETTS USING A GEOGRAPHIC INFORMATION SYSTEM
    - LOCATING TREES USING A GEOGRAPHIC INFORMATION SYSTEM AND THE GLOBAL POSITIONING SYSTEM

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Related pages

Information on street sweeping

- Overview, water quality benefits, and other co-benefits of street sweeping
- **Recommended street sweeping practices for water quality purposes**

- Pollutant removal associated with street sweeping
- Survey of street sweeping crediting approaches
- Composition, characterization, and management of street sweepings
- Case studies for street sweeping
- Supporting information for street sweeping

Street sweeping crediting and Phosphorus Calculator

- Street Sweeping Phosphorus Credit Calculator
- Street Sweeping Phosphorus Credit Calculator: User Guide
- Methods for sampling street sweeping material - Standard Operating Procedures
- Methods for calculating pollutant reductions (credits) for street sweeping
- Accounting for phosphorus load reductions with street sweeping
- P8 Street Sweeping Modeling
- TSS credits for street sweeping
- Guidance for incorporating street sweeping into the Minimal Impact Design Standards Calculator and MPCA's Simple Estimator - **Coming in summer, 2021**

University of Minnesota research on street sweeping

- Developing a street sweeping credit for stormwater phosphorus source reduction - this page contains information and the final report from the U of M study that led to development of the phosphorus calculator. Researchers: Sarah E. Hobbie, Rachel King, Tessa Belo, Lawrence A. Baker, Jacques C. Finlay.
- Quantifying Nutrient Removal through Targeted Intensive Street Sweeping - summary of Prior Lake study, 2010-2013 (Kalinosky et al., 2013). For additional information related to this project, link here
    - Prior Lake study:Estimating Nutrient Removal by Enhanced Street Sweeping

Links

- Internal
    - Final Street Sweeping: Survey of Crediting Approaches

    - Street sweeping for trees
    - Trees
    - MS4 fact sheet - Street & Parking Lot Sweeping
- External
    - Using leaf collection and street cleaning to reduce nutrients in urban stormwater - This page summarizes on-going research by the United States Geological Survey on street sweeping. Lead researcher - William Selbig.
    - Recommendations of the Expert Panel to Define Removal Rates for Street and Storm Drain Cleaning Practices - Final document produced by Chesapeake Bay expert panel
    - Neat websites and articles for trees

Website feedback form