**REPORT FOR OBJ1.TASK 10: TREE, LEAF, & WOODY DEBRIS SWEEPING GUIDELINES**

To: MPCA

From: The Kestrel Design Group Team

Date: October 15, 2013

Re: Contract CR5332

**SCOPE**

**Obj1.Task 10: Tree, Leaf, & Woody Debris Sweeping Guidelines:**

Develop and submit guidelines for street sweeping to remove tree debris.

1. Review scientific literature to identify existing street sweeping guidance for mitigation of potential pollutant (phosphorus) impacts associated with seasonal tree debris. Included case studies of street sweeping programs specifically designed and targeted to address seasonal tree debris. The review shall consider the entire growing season, from leaf out until leaf down. The review shall include estimates of phosphorus loading by coniferous and deciduous tree species appropriate for Minnesota as well as the reduction in loading associated with a range of sweeping practices. Consider effects of different types of sweepers and sweeping schedules.
2. Prepare and submit a Technical memo summarizing recommended street sweeping practices, including estimates of phosphorus removal associated with different levels of sweeping (e.g. frequency of sweeping, type of sweeper, etc.).
3. Prepare and submit a report summarizing the recommended street sweeping practices.

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2. Types of street sweeping equipment available
3. Effectiveness of street sweeping to reduce P in urban runoff
4. Recommended street sweeping practices and estimates of phosphorus removal associated with different levels of sweeping

**REPORT**

1. **Contribution of tree leaves, seeds, and flowers to P in urban runoff**

While it is known that tree leaves, seeds, and flowers that fall on impervious surfaces contain phosphorus (P), and some of that P leaches out and contributes to the nutrient load in urban runoff, the proportion of P in urban runoff that comes from trees varies greatly and is unclear. Hobbie et al (2013) have even found that leaf litter sometimes immobilizes P. This means that if it was possible to time street sweeping to occur after leaf litter had immobilized P, leaf litter could actually decrease total P load in runoff if it was swept at the right time.

**Hobbie, Sarah E., Lawrence A. Baker, Christopher Buyarski, Daniel Nidzgorski, Jacques C. Finlay. 2013. Decomposition of tree leaf litter on pavement: implications for urban water quality. Urban Ecosystems. Published on line September 6, 2013.**

Compared decomposition of leaf litter of five street tree species in a parking lot gutter in St. Paul, MN: Acer platanoides L. (Norway maple), Acer x freemanii (Freeman maple), Fraxinus pennsylvanica (green ash), Quercus bicolor (swamp white oak), and Tilia cordata (little leaf linden).

Found that:

* Litter decomposed about twice as fast in the gutter than in past studies in nearby natural areas.
* Litter P cycling did not seem related to litter mass decomposition, and litter P increased and decreased unpredictably over the year.
* Litter had the potential to lose 27-88% of initial P in 24 hour lab studies via leaching. Found high variability in percent of initial P leached among the 5 tree species.
* “… our results indicated **significant differences between nutrient dynamics in the street and in the laboratory leaching study**. Litter of some species that exhibited substantial leaching losses of N and especially P in the laboratory did not exhibit such losses in the street, likely because of dry conditions during the first 3.5 weeks of deployment... In fact, **some species that lost substantial P in the laboratory study exhibited a period of increase in P mass in the street**. Notably some litter types still retained a high proportion of their initial P 1 year after the litter bags were deployed in the street even though they exhibited substantial P losses initially or after an early period of immobilization (e.g. Quercus bicolor, Acer platanoides). These results suggest that there is a **high capacity for leaf litter decomposing in the street to immobilize P from the environment**, likely as microbes take up P to meet nutritional demands for breaking down and using the organic matter as an energy source. Leaf litter P mass, and to a lesser degree N mass, were dynamic—increasing and decreasing throughout the study period—although the causes and timing of these dynamics are unclear. The dynamics did not relate to precipitation patterns, as changes in N or P (either in total mass or concentration) between any two harvests were not correlated with either the cumulative, daily mean, or daily maximum precipitation during that period, regardless of whether the time during which precipitation fell as snow was included in the analysis (analyses not shown). Thus**, leaching losses triggered by rain events appear to have been offset by P immobilization into litter by decomposers between rain events**.” (bold added).

Concluded that “careful selection of street tree species and timely removal of litterfall have significant potential to reduce nutrient fluxes from streets to storm drains, particularly for P.”

**Hobbie, Sarah. 2013. Personal communication**

* Estimated from their data from subwatersheds in the Twin Cities that the amount of P in leaf litter on streets is equal to about 40-60% of the amount of P that is exported in runoff during the warm season (May-Sept).
* Proportion of this P that gets into runoff depends on effectiveness of street sweeping.

**Allison, R.A., F.H.S. Chiew, and T. A. McMahon. 1998. Nutrient Contribution Of Leaf Litter In Urban stormwater. Journal of Environmental Management 54: 269-272.**

* Gross pollutant monitoring study near Melbourne, Australia.
* Found that the potential nutrient contribution of stormwater leaf litter (greater than 5 mm) was about 2 orders of magnitude smaller than the typical nutrient loads in urban stormwater.
* Concluded that therefore “removing leaf litter from urban waterways will do little to reduce the total stormwater nutrient load.”
* Recommended that even though leaf litter contributed little to stormwater runoff nutrient loading, “because of their large volume, leaf litter and plant matter may need to be considered when designing litter trapping devices, and where they could cause blockages or smother aquatic habitat.”

**Kalinoski, Paula. ,L. Baker, S. Hobbie. 2012.**[**Quantifying Nutrient Load Reductions Through Targeted, Intensive Street Sweeping**](http://larrybakerlab.cfans.umn.edu/files/2012/10/WRC-Street-Sweeping-Kalinosky.pdf) **– A Field Study by the University of Minnesota in Partnership with the City of Prior Lake, Abstract for Minnesota Water Resources Conference, October 17.**

* Two year street sweeping study that investigated carbon, nitrogen and phosphorus content in fine (<2 mm) organic, coarse (>2 mm) organic, and soluble fractions of street sweeper waste material along street.
* Sweeping routes with varying canopy cover and street sweeping frequency in Prior Lake, MN.
* “Results show that coarse organics contain 40-97% of the nitrogen and up to 87% of phosphorus load in sweeper waste each month.”

**Kalinosky****, Paula. Lawrence A. Baker, Sarah Hobbie, and Ross Bintner. 2013. Quantifying Nutrient Removal through Targeted Intensive Street Sweeping. UPDATES: March 2013 (volume 8 - issue 3). Available October 2013 from http://stormwater.safl.umn.edu/updates-march-2013.**

While their final results are not yet published, an interim update on their research reports that they are finding greater P removal from residential streets with higher canopy cover than those with lower canopy cover.

**Dorney JR. 1986. Leachable and total phosphorus in urban street tree leaves. Water Air Soil Pollut 28:439–443.**

Studied how much phosphorus leached from freshly fallen, dry tree leaves and found:

* Urban tree leaves contained a relatively high amount of total P and only a small fraction leached from entire leaves in 2 hours.
* “An average of 148 μg gm−1 (air-dried weight) of P was leachable from entire leaves in 2 hr: this represented 9.3 % of the total P available. The amount of leachable and total leaf P varied significantly among tree species but was not affected by tree diameter”

The author claims that “whether urban street trees are a significant concern of P in runoff is uncertain,” and recommends that since “it is apparent that urban street tree leaves contain fairly high levels of total P, a portion of which is readily leachable and could contribute to P form urban runoff...it would be prudent to collect for disposal urban street tree leaves as rapidly as possible...”

The author contends that although tree leaves contain high amounts of phosphorus, it was unknown at the time of his article whether or not they actually contributed a significant amount of total P to stormwater runoff.

**Cowen WF, Lee GF (1973) Leaves as a source of phosphorus. Environ Sci Technol 7:853–854.**

Tested P leaching from oak and poplar leaves collected in Madison, WI, in laboratory columns, and found potential for leaf litter to release significant soluble reactive P in a lab, but gives no clear indication of order of magnitude contribution on a watershed scale in field conditions:

* “Most of the soluble phosphorus leached was reactive in a molybdenum blue analysis.“
* “The leaves tested yielded 54-230 μg. P/g of leaves.”
* “Consecutive leachings of an oak leaf sample yielded soluble P in amounts related to the effective soaking period between leachings and to the number of preceding leachings.”
* “Cut up leaves released almost three times as much soluble P as intact leaves.”
* “Leaves collected from the littoral zone of Lake Mendota leached less P than control leaves collected on the shore nearby.“
* “The moisture retained on leaves after a rainstorm contained significant soluble reactive P.”

However, as shown by Hobbie et al (2013), P cycling in leaf litter can be significantly different on an impervious surface than in a lab test.

See references in many of the above papers for many more studies that have investigated stormwater runoff nutrient loads from tree leaves.

1. **Types of street sweeping equipment available**

There are three general categories of street sweepers: mechanical broom, regenerative air, and high-efficiency sweepers. See pages 5-9 of “Street Sweeping – Report No. 1, State of the Practice,” Prepared for the Ramsey-Washington Metro Watershed District (Schilling2005a) for a brief description, general cost range, and concise lists for the advantages and disadvantages of each of these types. Appendix A of the report by Schilling (2005a) also lists sweeper manufacturers, available models, and common specifications for street sweepers.

1. **Effectiveness of street sweeping to reduce P in urban runoff**

Since the 1970’s, many studies have investigated the effectiveness of street sweeping to reduce stormwater nutrient load, but results of those studies vary widely.

Moreover, most studies investigating effectiveness of street sweeping to reduce stormwater nutrient loads from trees do not directly measure effects of street sweeping by monitoring P concentration in runoff before and after sweeping. Based on the results of Hobbie et al (2013), studying P in urban runoff before and after street sweeping would more accurately indicate how much P is removed from the total P in runoff through street sweeping, since this study found that leaf litter can actually immobilize P.

Several recent literature reviews provide an in depth review of street sweeping pollutant removal efficiency (e.g. Center for Watershed Protection 2006, Law et al 2008, Schilling 2005a). A sampling of monitoring studies and literature reviews that investigated the effectiveness of street sweeping to reduce stormwater nutrient load are summarized below. Many more street sweeping studies are summarized in the literature reviews listed in the references section of this report.

**Kalinoski, Paula. ,L. Baker, S. Hobbie. 2012.**[**Quantifying Nutrient Load Reductions Through Targeted, Intensive Street Sweeping**](http://larrybakerlab.cfans.umn.edu/files/2012/10/WRC-Street-Sweeping-Kalinosky.pdf) **– A Field Study by the University of Minnesota in Partnership with the City of Prior Lake, Abstract for Minnesota Water Resources Conference, October 17.**

* Two year street sweeping study that investigated carbon, nitrogen and phosphorus content in fine, coarse organic, and soluble fractions of street sweeper waste material along street sweeping routes with varying canopy cover and street sweeping frequency in Prior Lake, MN.
* Found that “Seasonal loads as high as 0.74 lb/curb-mile of phosphorus and 4.96 lb/curb-mile of nitrogen can be removed for as little as $28/lb in targeted sweeping events.”
* Concludes that “Optimization of sweeping practices is expected to keep average costs at $40-100/lb.”

**Kalinosky****, Paula. Lawrence A. Baker, Sarah Hobbie, and Ross Bintner. 2013. Quantifying Nutrient Removal through Targeted Intensive Street Sweeping. UPDATES: March 2013 (volume 8 - issue 3). Available October 2013 from** [**http://stormwater.safl.umn.edu/updates-march-2013**](http://stormwater.safl.umn.edu/updates-march-2013)**.**

This project update summarizes preliminary results from the same project as Kalinosky et al (2012) summarized above. Final results of this study have not yet been published, but according to this project update, this study found the following:

* On the whole, targeted sweeping appears to be a cost-effective strategy for nutrient reduction when compared to treatment ponds, where costs are generally higher.
* Sweeping was most cost effective in the spring and fall when targeted sweeping operations achieved costs as low as $18/lb P removed, and least efficient during mid-summer and mid-winter, when costs were often several hundred dollars per lb P removed.

**Center for Watershed Protection. 2006. Technical Memorandum 1 - Literature Review Research in Support of an Interim Pollutant Removal Rate for Street Sweeping and Storm Drain Cleanout Activities A project supported by the U.S. Chesapeake Bay Program Grant CB-97322201-0**

A 2006 literature review by the Center for Watershed Protection on pollutant removal rate for street sweeping concluded that “Although new street sweeping technology can remove more than 90% of street dirt under ideal conditions, it does not guarantee water quality improvements.”

**Law, Neely L. Katie DiBlasi, Upal Ghosh, With contributions from: Bill Stack, Steve Stewart,Ken Belt, Rich Pouyat, and Clair Welty. 2008. Deriving Reliable Pollutant Removal Rates for Municipal Street Sweeping and Storm Drain Cleanout Programs in the Chesapeake Bay Basin. Prepared by the Center for Watershed Protection as fulfillment of the U.S. EPA Chesapeake Bay Program grant CB-973222-01.**

* Report based on a literature review, a survey of street sweeping and storm drain cleanout practices in the Chesapeake Bay and data generated from monitoring.
* A 2008 publication by the Center for Watershed Protection (Law et al 2008), which is an updated version of the above 2006 report (Center for Watershed Protection 2006).
* Found street sweeping to generally have very low P removal efficiency.
* Concludes that:
	+ “Despite the high pick up efficiencies of newer street sweeping technologies such as regenerative air or vacuum assist street sweepers, current monitoring protocols are challenged to detect significant differences in sediment and nutrient pollutant loading reductions that may be achieved from street sweeping. Additional pollutant contributions from areas other than public streets and roadways provide additional pollutant loadings that are unaffected by street sweeping reducing the effectiveness of this practice, in general. Similar conclusions have been made by other researchers conducting street sweeping studies where there are many sources of variability in such field-based studies that make any potential impact from street sweeping undetectable (e.g., Selbig and Bannerman 2007).”
	+ Points out that if streets are ‘too clean’, for example, due to frequent street sweeping, the percent removal will be low, and that “the National Urban Runoff Program (e.g. Bannerman et al. 1984) suggest that, on average, streets need to have 1,000 lbs/curb mile of SPaM [Street particulate matter] for sweepers to effectively reduce the SPaM loading” (brackets added).
	+ “The predominance of the coarse sediment picked up by street sweepers and standard monitoring study designs for street sweeping have implications for measuring the effectiveness of street sweeping. In general, the particles that are most effectively removed by street sweepers are less effectively captured (or sampled) by automated samplers… As a consequence, the usefulness of standard monitoring protocols to determine the effectiveness of street sweeping by comparing pretreatment and treatment stormwater pollutant loads is questionable.”
	+ “For a given set of assumptions and sweeping frequencies, it is expected that the range in pollutant removal rates from street sweeping for total solids (TS), total phosphorus (TP) and total nitrogen (TN) are: 9 – 31%, 3-8% and 3-7%, respectively. The lower end represents monthly street sweeping by a mechanical street sweeper, while the upper end characterizes the pollutant removal efficiencies using regenerative air/vacuum street sweeper at weekly frequencies.”
	+ They propose the following pollutant removal efficiencies for street sweeping:

Table 10.1: Pollutant Removal Efficiencies from Street Sweeping for TS, TP, and TN (Law et al 2008)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Frequency** | **Technology** | **TS** | **TP** | **TN** |
| Monthly | Mechanical | 9 | 3 | 3 |
|  | Regenerative Air/Vacuum | 22 | 4 | 4 |
| Weekly | Mechanical | 13 | 5 | 6 |
|  | Regenerative Air/Vacuum | 31 | 8 | 7 |

**Sorenson, J.R., 2013, Potential reductions of street solids and phosphorus in urban watersheds from street cleaning, Cambridge, Massachusetts, 2009–11: U.S. Geological Survey Scientific Investigations Report 2012–5292, 66 p., plus appendix 1 on a CD–ROM in pocket. (Also available at** [**http://pubs.usgs.gov/sir/2012/5292/**](http://pubs.usgs.gov/sir/2012/5292/)**.)**

* Studied the performance of a regenerative-air street cleaner to reduce total particulate solid and total phosphorus loading to the Lower Charles River from three streets in Cambridge, MA.
* “Percent reductions of constituent load on streets, as a result of a single pass from the RA [regenerative air] street cleaner, were estimated by using the median values of each constituent measured in 48 to 72 pre- and post-RA street cleaner composite samples of street solids formulated to represent the constituent mass for spring, summer, and fall street-solids...”
* “Total P median reductions resulting from a single pass of a regenerative-air street cleaner on streets in multifamily and commercial land-use types were about 82 and 62 percent, respectively, and were similar in terms of grain size between both land-use types.”
1. **Recommended street sweeping practices and estimates of phosphorus removal associated with different levels of sweeping**

Generally spring and fall are the most cost effective times of the year to sweep streets. Exact recommended sweeping frequency varies depending on the canopy cover and other factors.

Kalinosky et al (2013a) are developing a guidance manual and workshop series on street sweeping best practices, as well as a spreadsheet calculator tool “for predicting sediment and nutrient loads to street surfaces in urban areas based on overhead tree canopy; estimating the amount of material that can be removed and the cost of removal in targeted sweeping operations; and designing sweeping programs to meet nutrient reduction goals.”While they are not yet available at this time, these tools are expected to be available later this fall of 2013, and will be posted on the following website:

<http://larrybakerlab.cfans.umn.edu/the-latest-stuff/> (Kalinosky 2013).

Inputs into the calculator will include:

* Timing and frequency of street sweeping event
* Canopy cover along street sweeping route
* Street sweeping cost per curb mile

Based on those simple inputs, the tool will estimate nutrient recovery and cost per pound of P removed (Kalinosky et al 2013b).

We recommend using this tool to develop street sweeping recommendations.

**REFERENCES**

Allison, R.A., F.H.S. Chiew, and T. A. McMahon. 1998. Nutrient Contribution Of Leaf Litter In Urban stormwater. Journal of Environmental Management 54: 269-272.

Center for Watershed Protection. 2006. Technical Memorandum 1 - Literature Review Research in Support of an Interim Pollutant Removal Rate for Street Sweeping and Storm Drain Cleanout Activities A project supported by the U.S. Chesapeake Bay Program Grant CB-97322201-0

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Dorney JR (1986) Leachable and total phosphorus in urban street tree leaves. Water Air Soil Pollut 28:439–443.

Hobbie, Sarah. 2013. Personal communication.

Hobbie, Sarah E., Lawrence A. Baker, Christopher Buyarski, Daniel Nidzgorski, Jacques C. Finlay. 2013. Decomposition of tree leaf litter on pavement: implications for urban water quality. Urban Ecosystems. Published on line September 6, 2013.

Kalinoski, Paula. ,L. Baker, S. Hobbie. 2012. [Quantifying Nutrient Load Reductions Through Targeted, Intensive Street Sweeping](http://larrybakerlab.cfans.umn.edu/files/2012/10/WRC-Street-Sweeping-Kalinosky.pdf) – A Field Study by the University of Minnesota in Partnership with the City of Prior Lake, Abstract for Minnesota Water Resources Conference, October 17.

Kalinosky, Paula. 2013. Personal communication.

Kalinosky, Paula. Lawrence A. Baker, Sarah Hobbie, and Ross Bintner. 2013a. Quantifying Nutrient Removal through Targeted Intensive Street Sweeping. UPDATES: March 2013 (volume 8 - issue 3). Available October 2013 from <http://stormwater.safl.umn.edu/updates-march-2013>.

Kalinosky, P., L. Baker, S. Hobbie.2013b. [Quantifying nutrient removal by street sweeping](http://larrybakerlab.cfans.umn.edu/files/2011/10/LID-Presentation-no-animations.pdf). Presentation by  Paula Kalinosky at the 2013 International Low Impact Development Conference, St. Paul., August 18-21, 2013.

Law, Neely L. Katie DiBlasi, Upal Ghosh, With contributions from: Bill Stack, Steve Stewart,Ken Belt, Rich Pouyat, and Clair Welty. 2008. Deriving Reliable Pollutant Removal Rates for Municipal Street Sweeping and Storm Drain Cleanout Programs in the Chesapeake Bay Basin. Prepared by the Center for Watershed Protection as fulfillment of the U.S. EPA Chesapeake Bay Program grant CB-973222-01.

Schilling, J.G. 2005. Street Sweeping – Report No. 1, State of the Practice. Prepared for Ramsey-

Washington Metro Watershed District, North St. Paul, Minnesota. June 2005.

Schilling, J.G. 2005. Street Sweeping – Report No. 2, Survey Questionnaire Results and Conclusions.

Prepared for Ramsey-Washington Metro Watershed District, North St. Paul, Minnesota. June 2005

Schilling, J.G. 2005. Street Sweeping – Report No. 3, Policy Development & Future Implementation

Options for Water Quality Improvement. Prepared for Ramsey-Washington Metro Watershed

District, North St. Paul, Minnesota. June 2005.

Selbig, W.R., and Bannerman, R.T., 2007, Evaluation of street sweeping as a stormwater-quality-management tool in three residential basins in Madison, Wisconsin: U.S. Geological Survey Scientific Investigations Report 2007–5156, 103 p.

Sorenson, J.R., 2013, Potential reductions of street solids and phosphorus in urban watersheds from street cleaning, Cambridge, Massachusetts, 2009–11: U.S. Geological Survey Scientific Investigations Report 2012–5292, 66 p., plus appendix 1 on a CD–ROM in pocket. (Also available at <http://pubs.usgs.gov/sir/2012/5292/>.)

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