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| To: | Mike Trojan and Scott Fox, Minnesota Pollution Control Agency |
| From: | Aileen Molloy and Eugenia Hart |
| Date: | March 16, 2023 |
| Subject: | Literature Review on Volume-Mass Relationships for Street Sweeping |

This document addresses Task B of the project work plan: conduct a literature review on volume-mass relationships for street sweeping. This literature review provides a summary of literature that presents relationships between the volume of material collected by street sweepers and the mass of material collected.

The search for literature began with previous street sweeping literature reviews conducted in 2019 for street sweeping crediting approaches and in 2020 for leaf litter management and street sweeping reductions and crediting (for an unrelated project). The search then continued to ageneral Google search for street sweeping studies with mass-volume information. Once results were located using both methods, researchers reviewed document references to locate any additional sources.

A literature review conducted by Hixon and Dymond (2018) found that removal efficiencies for street sweeping increase for all particle size ranges as street loading increases, therefore, “the amount of street material removed (mass/curb length) is a more important performance indicator than removal efficiencies since more material is collected from a dirtier street than a clean street.” If the particle-size distribution and chemistry of samples collected from street sweeper waste are representative of street loadings, it can be assumed that the mass and/or volume can be multiplied by the pollutant concentration in swept material to estimate the amount of contaminants removed. The literature review resulted in limited information regarding the relationship between volume of waste collected by sweepers and the resulting mass. However, the literature that was reviewed supports the idea that mass (and volume) of street sweeper waste can be used to determine pollutant removal.

The literature review is presented in three sections below: section 1 presents a summary of methodologies used by states and other locations to determine pollutant reductions through the amount of sweeper waste volume or mass collected. Section 2 presents a summary of street sweeping studies that have collected both volume and mass data. The third section presents recommendations base don the findings of the literature review.

# Pollutant Load Reductions based on Mass and Volume

Some states and other regions have methodologies to use mass, volume, or both mass and volume of street sweeping material to calculate pollutant load reductions from street sweeping efforts. The literature review found that Florida, Rhode Island, Ohio, Contra Costa County (California), and the Chesapeake Bay region all apply methods that include the determination of volume, mass or both to calculate pollutant load ructions. Each of these methods are described below.

## Florida

The Florida Stormwater Association’s (FSA) MS4 Load Reduction Assessment Tool (FSA Assessment Tool) can be used to estimate the removal of nutrient loads from street sweeping practices in Florida (Bateman 2012 and FSA 2019). The FSA Assessment Tool requires an initial measurement of the weight or volume of material collected by street sweepers to apply this method. Over time, the weight and volume of solids collected may be estimated, but FSA recommends a minimum period of one year of weight and volume street sweeping data collection before making estimates. Enough data needs to be collected to be able to eventually know how much material certain equipment types and transport vehicles are carrying so that the trucks can just be counted rather than having to weigh the material. The weight of street sweeping material can be determined through direct measurement using a scale (typically used at a landfill) – the known weight of an empty sweeper truck can be subtracted from a full sweeper truck to determine the weight of the materials collected. The volume of solids collected by a street sweeper can be estimated because the volume of the hopper on a street sweeper is a known value, so when a street sweeper is full, the volume of solids is known. Volume of waste can also be determined once the street sweeper waste is dumped by measuring material piles (e.g., in cubic feet [ft3]).

The weight measurements collected in the field must be adjusted to the equivalent weight of drysolids for use in the FSA Assessment Tool. An estimate of the moisture content is required in order to convert the wet weight of swept material to dry weight. As with weight and volume, local data should be collected to determine accurate values for moisture content, but the FSA Tool currently uses a moisture content of 6% for street sweepings (this is a median value from Sansalone et al. 2011). For comparison, a study by Hixon and Dymond (2019) included the analysis of 48 samples of street sweeper material collected from six MS4 permittees throughout Virginia. Samples were analyzed for moisture content among other parameters (e.g., particle size distribution and concentrations of total phosphorus [TP] and total nitrogen [TN]) and found moisture content to be fairly consistent with a mean of 2.7% and a median of 2.2%.

In addition, volume measurements must be converted to an equivalent dry mass, which is calculated by the FSA Assessment Tool but requires the input of a representative bulk density (Bateman 2012 and FSA 2019). Local sampling should be conducted to determine an appropriate bulk density, but Florida is currently using a dry bulk density of 1.36 grams (g)/cubic centimeter (cm3), which is equivalent to approximately 84.9 pounds (lbs) dry material/ft3 of solids. Once the dry mass is known, the FSA Assessment Tool uses values of the mass fraction of TN and TP associated with solids collected by street sweepers to convert the amount of solids into TN and TP loads from street sweeping. The values applied are 303 mg/kg for TP and 656 mg/kg for TN (from Sansalone et al. 2019).

## Rhode Island

Rhode Island Department of Transportation (RIDOT) uses the FSA Assessment Tool’s methodology (Bateman 2012 and FSA 2019) to calculate pollutant credits from street sweeping. The equation RIDOT uses to calculate the annual load reduction in lbs/year is (VHB 2018):

where:

* Volume of solids = volume of dry (less than 2% moisture content by weight) solids collected per sweeping event (ft3)
* Bulk density = dry bulk density of solids, assumed to be 85 lbs/ft3
* Annual frequency = number of sweeping events per year
* Ratio = ratio of pollutant to TSS. RIDOT uses estimates for the ratios of nutrients and metals to TSS from typical roadway sediments in Massachusetts (Smith and Granato 2009), which are 0.0007 for TP, 0.007 for TN and 0.0012 for Zn.

## Ohio

Ohio Department of Transportation (DOT) developed a tool to estimate the area or footprint of a storage facility needed to manage waste materials from street sweeping and stormwater system cleanout (Miller et al. 2016). The information is used to size facilities based on material quantities. For street sweepings, the miles swept and the unit collection rate are used to calculate the material weight (in tons). The material density is used to convert the weight to a volume (cubic yards). The equations used to calculate these values are below:

## Contra Costa County, CA

A July 2006 street sweeping study in Contra Costa County, CA (EOA 2007) was conducted to characterize concentrations of pollutants in street sweeping material from residential, commercial and industrial areas and provide estimates of the mass of constituents removed. The study provides a formula to estimate the mass of constituent removal from street sweeping activities; however, it should be noted that EOA (2007) recommends that municipalities report the amount of street sweeping material collected in volume (cubic yards) and weight (lbs) to reduce uncertainties regarding volume to mass conversion factors.

where:

Mx = Dry mass of constituent “x” in kilograms (kg)

Cx = Typical concentration value of constituent “x,” dry basis in mg/kg. A typical concentration value represents the estimated average constituent concentration that one would expect to find in environmental media.

P = Percent (%) of sediment (by volume) in street sweeping material collected that is less than 2mm. EOA (2007) reported that roughly 55% (dry mass) of street sweeping material collected is less than 2 mm in diameter, therefore, 55% was used as the input parameter for this formula. Leaf material greater than 2mm may have some concentration of constituents attached. If concentrations are significant, the percentage of street sweeping material estimated to have pollutants of concern attached (i.e., 55%) may be underestimated (EOA 2007).

V = Total volume (cubic yards) of street sweeping material collected (estimated by municipal staff)

F = Factor for converting sediment volume (cubic yards) to dry mass (kg). The volume to mass conversion factor used was 918.4 kg/cubic yard (EOA 2007). The conversion factor was developed by FEECO International, Inc. who developed conversion factors for a variety of waste materials that are utilized by the California Integrated Waste Management Board. These were considered the best conversion factors available at the time of this study (EOA 2007).

106 = Conversion of milligrams (mg) to kilograms (kg)

## Chesapeake Bay Watershed

The Chesapeake Bay’s Expert Panel to define pollutant removal rates for street sweeping practices (Schueler et al. 2016) supports Contra Costa County’s methods that recommend the collection of local street sweeping volume and mass data to support mass – volume conversion equations. Schueler et al. (2016) recommend the collection of several parameters including volume of sweeper waste collected (cubic feet), total wet mass of the sweeper waste (measured), number of curb-miles swept and sweeper conditions. It is also recommended that a sub-sample of the sweeper waste sample be collected and sent to a laboratory to measure the dry weight of the wet sweeper waste, particle size distribution and average concentrations of pollutants of concern (Schueler et al. 2016).

# Mass – Volume Data

While the information from Florida, Rhode Island, Ohio, California, and the Chesapeake Bay region provide insight on the necessary data to be collected and used to determine pollutant reductions through mass-volume relationships of street sweeping material, studies by Breault et al. (2005), Brown et al. (2011), MassDEP (2013), Hobbie et al. (2020) and Michael Baker International (not dated) provide data collected during street sweeping studies to support the mass-volume relationship. The applicable data from each study are provided in this section.

Breault et al. (2005) presents the results of a study in New Bedford, MA that examined accumulation rates and chemical composition of street sweeping material from residential areas in 2003 and 2004 using mechanical broom and vacuum street sweepers. New Bedford’s Department of Public Works recorded the volume of street sweeper material collected as part of its street sweeping program and in 2004 city street sweepers swept a volume of about 2,500 m3 of street dirt. This is equal to approximately 3.8 million kg of street dirt using an assumed average density of 2.0 g/cm3 (from Pitt et al. 2004).

A study in Incline Village, NV, a community with a population of about 10,000 located on the northeast corner of Lake Tahoe, monitored street sweeping materials in the town for two years (2009 and 2010) to characterize the benefit of frequent street sweeping (Brown et al. 2011). Fourteen sweeping events were analyzed during the two-year study using a mechanical broom sweeper with vacuum assist. Material collected by the street sweeper typically included pine needles, pinecones, sediment, and occasional pieces of trash. Each time the study area was swept, the sweeper would dump the main hopper and measure the volume of the waste pile. The study also used the collected materials to determine the aggregate density for a typical sweeper load. In the second year of the study, the collected street sweeper materials were dumped into one pile and homogenized with a shovel. Bulk samples were collected from the waste pile in 5-gallon buckets in June 2009 and March 2010 to determine an average bulk density of 1.36 g/cm3. Table 1 presents the volume and mass of material collected by the street sweeper in the study area for the entire study period.

Table . Volume and mass of street sweeper material collected in Incline Village, NV

|  |  |  |  |
| --- | --- | --- | --- |
| Date | Volume (m3) | Mass (Kg) | |
| **Total** | **< 16 µm** |
| 1/12/2009 | 0.77 | 1,041 | 75 |
| 1/12/2009 | 0.09 | 116 | 14 |
| 1/20/2009 | 0.17 | 231 | 10 |
| 2/4/2009 | 1.13 | 1,536 | 79 |
| 2/27/2009 | 0.31 | 415 | 9 |
| 3/12/2009 | 0.19 | 259 | 10 |
| *WY09 Summary* | ***2.6*** | ***3,600*** | ***196*** |
| 1/6/2010 | 0.27 | 364 | 23 |
| 2/1/2010 | 0.39 | 524 | 36 |
| 3/22/2010 | 1.87 | 2,538 | 150 |
| 3/24/2010 | 1.05 | 1,425 | 81 |
| 4/8/2010 | 0.17 | 235 | 14 |
| 4/26/2010 | 0.22 | 303 | 13 |
| 5/25/2010 | 0.14 | 188 | 12 |
| 6/1/2010 | 0.05 | 73 | 5 |
| *WY10 Summary* | ***4.2*** | ***5,650*** | ***333*** |
| Study Total | **6.8** | **9,250** | **530** |

Source: Brown et al. (2011)

Massachusetts Department of Environmental Protection (MassDEP) evaluated stormwater and nonpoint source best management practice (BMP) efforts to address the Long Island Sound dissolved oxygen TMDL (MassDEP 2013). The report assessed existing programs and available data that could be used to track BMP practices that reduce nitrogen exports to the Long Island Sound, including street sweeping. The Massachusetts Department of Transportation (MassDOT) was contacted as the lead agency for roadway BMPs and the three MassDOT District Offices (Districts 1, 2 and 3) that cover the Massachusetts Long Island Sound watershed provided an assessment of BMPs within their jurisdiction, including volume and mass of material collected by street sweeping. The mass and volume data provided by the three districts are presented in Table 2. This study did not provide moisture content, but the average bulk density is 1.8 g/cm3 based on the total volume and mass values for collected detritus in Table 2.

Table . Volume and mass of material collected from street sweeping in the Long Island Sound watershed

|  |  |  |  |
| --- | --- | --- | --- |
| Location | Area | Street sweeping detritus collected per year | |
| **Volume (cubic yards)** | **Mass (tons)** |
| District 1 | All towns in the district/District-wide | 3,852 | 5,778 |
| District 2 | All towns in the district/District-wide | 3,000 | 4,500 |
| District 3 | All towns in the district/District-wide | 1,250 | 1,870 |

Source: MassDEP (2013)

Hobbie et al. (2020) evaluated different statistical approaches for estimating phosphorus concentrations, as well as nitrogen and solids, collected in city street sweeping efforts to inform the development of a phosphorus crediting program for street sweeping by the Minnesota Pollution Control Agency. For the purposes of this study, street sweeping waste was collected during routine street sweeping operations in five cities in the Minneapolis‐St. Paul area – Forest Lake, Minneapolis, Prior Lake, Roseville and Shoreview – in the spring, summer and fall of 2019. The final report presents the analysis results of the street sweeping waste for mass, phosphorus, nitrogen, carbon, and moisture content; however, some of the raw data from the street sweeping events in Minneapolis and Roseville also include volume. Volume measurements were available for 43 of the 575 sweeping events and are presented in Table 3 along with the mass and total moisture content. Moisture content based on the full dataset of the study (not just the data with volume in Table 3) was an average of 41.7% with a median total moisture content of 25.6%. The calculated bulk density based on the weight and volume data in Table 3 is 0.8 g/cm3. When broken out further, the bulk density based on wet weights during leaf drop season (October-November) is 0.3 g/cm3 and 0.9 g/cm3 during non-leaf drop season (December-September). These values do not account for moisture content. If moisture content is considered, bulk density decreases to 0.2 and 0.8 g/cm3, respectively.

Table . Volume and mass measurements from Minnesota street sweeping study

| City | Sweeping dates | Sweeping pile weight (Kg) | Sweeping sample volume (m3) | Total moisture content (%) |
| --- | --- | --- | --- | --- |
| Minneapolis | 6/6/2019 | 4,481.49 | 7.65 | 12.79 |
| Minneapolis | 7/2/2019 | 4,690.14 | 6.12 | 26.60 |
| Minneapolis | 8/6/2019 | 2,794.13 | 3.06 | 12.59 |
| Minneapolis | 9/5/2019 | 6,359.36 | 7.65 | 27.72 |
| Minneapolis | 10/8/2019 | 5,869.48 | 13.00 | 51.98 |
| Minneapolis | 6/12/2019 | 4,427.06 | 3.06 | 35.91 |
| Minneapolis | 7/10/2019 | 3,510.80 | 4.59 | 6.16 |
| Minneapolis | 8/14/2019 | 2,349.61 | 3.06 | 14.98 |
| Minneapolis | 9/11/2019 | 2,086.52 | 3.82 | 35.98 |
| Minneapolis | 10/16/2019 | 4,889.72 | 9.17 | 54.75 |
| Minneapolis | 6/18/2019 | 6,831.10 | 9.17 | 9.98 |
| Minneapolis | 7/16/2019 | 1,905.09 | 3.82 | 6.49 |
| Minneapolis | 8/20/2019 | 2,104.67 | 3.82 | 3.04 |
| Minneapolis | 9/17/2019 | 4,626.64 | 7.65 | 18.40 |
| Minneapolis | 6/25/2019 | 4,003.40 | 6.88 | 48.36 |
| Minneapolis | 7/23/2019 | 2,177.24 | 3.82 | 9.10 |
| Minneapolis | 8/27/2019 | 3,274.93 | 3.82 | 20.45 |
| Minneapolis | 9/24/2019 | 3,646.88 | 13.76 | 42.93 |
| Minneapolis | 6/10/2019 | 2,095.60 | 1.91 | 1.05 |
| Minneapolis | 7/2/2019 | 1,714.58 | 1.53 | 10.33 |
| Minneapolis | 8/6/2019 | 3,202.36 | 3.06 | 10.39 |
| Minneapolis | 9/5/2019 | 2,866.70 | 3.82 | 12.82 |
| Minneapolis | 10/8/2019 | 2,948.35 | 6.12 | 19.67 |
| Minneapolis | 6/12/2019 | 1,877.87 | 1.53 | 5.43 |
| Minneapolis | 7/10/2019 | 3,810.17 | 6.12 | 13.54 |
| Minneapolis | 8/14/2019 | 3,184.22 | 3.82 | 2.67 |
| Minneapolis | 9/11/2019 | 1,542.21 | 2.29 | 15.21 |
| Roseville | 4/18/19, 4/19/19, 4/23/19 | 23,985.97 | 29.05 | 27.41 |
| Roseville | 6/11/19, 6/13/19 | 9,942.75 | 15.29 | 13.36 |
| Roseville | 9/16/2019 | 11,339.81 | 2.48 | 37.26 |
| Roseville | 11/1/19 - 11/5/19 | 20,411.66 | 122.33 | 48.10 |
| Roseville | 4/5/2019 | 11,784.33 | 15.67 | 39.28 |
| Roseville | 6/26/19 - 6/27/19 | 7,801.79 | 11.09 | 28.52 |
| Roseville | 9/13/2019 | 2,267.96 | 3.06 | 26.48 |
| Roseville | 10/29/19-10/31/19 | 9,253.29 | 49.70 | 33.16 |
| Roseville | 4/1/2019 | 8,155.59 | 8.50 | 19.32 |
| Roseville | 6/24/2019 | 5,669.91 | 6.12 | 26.75 |
| Roseville | 9/10/2019 | 1,433.35 | 2.68 | 20.36 |
| Roseville | 10/28/19 - 10/29/19 | 5,098.38 | 28.29 | 38.67 |
| Roseville | 4/2/2019 | 12,283.28 | 13.76 | 20.73 |
| Roseville | 6/19/19 - 6/20/19 | 10,432.63 | 3.49 | 16.76 |
| Roseville | 9/5/19 & 9/9/19 | 2,195.39 | 3.44 | 33.10 |
| Roseville | 11/8/2019 | 7,856.22 | 55.05 | 33.31 |

Source: Hobbie et al. (2020)

San Diego's *Targeted Aggressive Street Sweeping Pilot Program* collected over 20,000 cubic yards (more than 5,000 tons) of material from municipal streets during each year of the program (Brown and Evans 2013). The final report for the *Targeted Aggressive Street Sweeping Pilot Program Phase V* (Michael Baker International not dated) presents the total cubic yards of monthly street sweeper waste collected during Phase V of the study (July 2013 through October 2015) and the associated net weight (total weight of the street sweeper minus the tare weight – i.e., weight of the empty vehicle). These results are presented in Table 4. Moisture content was not provided in this study, but the calculated average bulk density based on the total debris volume and weight in Table 4 is 1.0 g/cm3. It is unclear what level of leaf drop occurs in San Diego. Given the arid Mediterranean climate, there may be fewer deciduous trees compared to Minnesota; however, there is a detectible difference in bulk density between leaf drop and non-leaf drop sweeper collection times. Non-leaf drop bulk density is 1.1 g/cm3, while leaf drop bulk density is 0.8 g/cm3.

Table . Street sweeper debris volume and weight collected during San Diego’s Targeted Aggressive Street Sweeping Pilot Program

| Date | Total debris volume (cubic yards) | Net weight (tons) |
| --- | --- | --- |
| Route 402 | | |
| 7/1/2013 | 1.5 | 1.32 |
| 7/1/2013 | 2 | 0.85 |
| 8/5/2013 | 2.5 | 2.38 |
| 8/5/2013 | 2.5 | 2.38 |
| 10/7/2013 | 4.5 | 2.87 |
| 10/7/2013 | 4.5 | 2.87 |
| 11/4/2013 | 2.5 | 2.18 |
| 11/4/2013 | 2.5 | 2.18 |
| 12/2/2013 | 2.5 | 2 |
| 12/2/2013 | 2.5 | 2 |
| 1/7/2014 | 2.5 | 1.37 |
| 1/7/2014 |  | 1.37 |
| 1/7/2014 | 3 | 1.37 |
| 2/3/2014 | 2.5 | 3.02 |
| 2/3/2014 | 2.5 | 3.02 |
| 3/3/2014 | 2 | 2.01 |
| 3/3/2014 | 2 | 2.01 |
| 4/7/2014 | 2.5 | 1.4 |
| 4/7/2014 | 3 | 1.4 |
| 5/5/2014 | 2.5 | 1.84 |
| 5/5/2014 | 2.5 | 1.84 |
| 6/2/2014 | 2.5 | 2.14 |
| 6/2/2014 | 3 | 2.14 |
| 7/7/2014 | 2.5 | 1.52 |
| 7/7/2014 | 2.5 | 1.52 |
| 8/4/2014 | 2.5 | 2.08 |
| 8/4/2014 | 3 | 2.08 |
| 10/6/2014 | 5 | 2.33 |
| 10/6/2014 | 4.5 | 2.33 |
| 11/3/2014 | 3.5 | 2.73 |
| 11/3/2014 | 3.5 | 2.73 |
| 12/1/2014 | 1 |  |
| 12/1/2014 | 3 |  |
| 2/2/2015 | 4.5 | 3.79 |
| 2/2/2015 | 4.5 | 3.79 |
| 4/6/2015 | 2 | 3.3 |
| 4/6/2015 | 1.5 | 3.3 |
| 5/4/2015 | 3.8 | 3.98 |
| 5/4/2015 | 4 | 3.98 |
| 6/1/2015 | 2.5 | 1.44 |
| 6/1/2015 | 3 | 1.44 |
| 7/6/2015 | 2.5 | 3.13 |
| 7/6/2015 | 3 | 3.13 |
| 8/3/2015 | 2.5 | 4.26 |
| 8/3/2015 | 3.5 | 4.26 |
| 10/5/2015 | 2.5 | 1.38 |
| 10/5/2015 |  | 1.38 |
| Route 407 | | |
| 8/19/2013 | 7 | 2.18 |
| 8/19/2013 | 4 | 2.18 |
| 9/16/2013 | 7 | 3.63 |
| 9/16/2013 | 6 | 3.63 |
| 10/21/2013 | 8 |  |
| 10/21/2013 | 4 |  |
| 11/18/2013 | 8 | 1.64 |
| 11/18/2013 | 4 | 1.64 |
| 12/16/2013 | 3 | 1.65 |
| 12/16/2013 | 4 | 1.65 |
| 12/16/2013 | 1 | 1.65 |
| 3/17/2014 | 8 | 6.91 |
| 3/17/2014 | 4 | 6.91 |
| 5/19/2014 | 12 | 4.89 |
| 5/19/2014 | 3 | 4.89 |
| 6/16/2014 | 7 | 3.02 |
| 6/16/2014 | 3 | 3.02 |
| 7/21/2014 | 6 | 3.21 |
| 7/21/2014 | 4 | 3.21 |
| 8/18/2014 | 6 | 3.06 |
| 8/18/2014 | 4 | 3.06 |
| 9/15/2014 | 8 | 2.87 |
| 9/15/2014 | 6 | 2.87 |
| 10/20/2014 | 8 | 3.03 |
| 10/20/2014 | 2 | 3.03 |
| 11/17/2014 | 4 | 2.83 |
| 11/17/2014 | 4 | 2.83 |
| 12/15/2014 | 12 | 10.4 |
| 12/15/2014 | 8 | 10.4 |
| 3/16/2015 | 4 | 2.49 |
| 4/20/2015 | 6 | 7.94 |
| 4/20/2015 | 8 | 7.94 |
| 5/18/2015 | 4 | 5.44 |
| 5/18/2015 | 7 | 5.44 |
| 6/15/2015 | 6 | 5.67 |
| 6/15/2015 | 5 | 5.67 |
| 7/20/2015 | 4 | 12.5 |
| 8/17/2015 | 7 | 5.62 |
| 8/17/2015 | 6 | 5.62 |
| 9/21/2015 | 3 | 2.58 |
| 9/21/2015 | 3 | 2.58 |
| 10/19/2015 | 4 | 4.63 |

Source: Michael Baker International (not dated)

# Conclusions

The literature review shows that both mass and volume can be used to determine pollutant load reductions from street sweeping but mass or weight needs to be converted from wet weight to dry weight for this purpose and volume needs to be converted to an equivalent dry mass. Moisture content of collected street sweeping materials can be used to convert wet weight to dry weight, while bulk density can be used to convert volume to an equivalent dry mass.

Florida uses a 6% moisture content (FSA 2019), while a study in Virginia found an average moisture content of 2.7% and a median value of 2.2% (Hixon and Dymond 2019). Hobbie et al. (2020) found that moisture content in their Minnesota study had an average of 41.7% and a median of 25.6%, which is much greater than Florida’s and Virginia’s values.

As for bulk density, Florida and Rhode Island both use a dry bulk density of 1.36 g/cm3 (FSA 2019 and VHB 2018). Contra Costa County uses a conversion factor of 918.4 kg/cubic yard (yd3) to convert volume to dry mass, which is equal to 1.2 g/cm3. Breault et al. (2005) applied an average bulk density of 2 g/cm3 in their Massachusetts study, and Brown et al. (2011) determined an average bulk density of 1.36 g/cm3 in their Nevada street sweeping study. The other studies presented in this literature review did not provide bulk density values, but they are calculated here based on the available mass and volume data.

Bulk density from three MassDOT districts in the Long Island Sound watershed was calculated as 1.8 g/cm3 (MassDEP 2013). The calculated average bulk density from the Minnesota street sweeping study ranged from 0.2 to 0.9 g/cm3, depending on the season(Hobbie et al. 2020). And finally, the average bulk density calculated from volume and mass data collected in the San Diego study is 1 g/cm3 with an average range of 0.8-1.1 g/cm3, depending on the season(Michael Baker International, not dated).

There is quite a bit a variation between the moisture content and bulk density values either applied in these studies or calculated from these studies. This leads to the recommendation that local street sweeping data be collected to determine appropriate values to be used to convert mass and/or volume to their dry weight equivalents for the determination of pollutant load reductions. Florida provides recommendations that suggest monthly street sweeping samples be collected for a period of no less than one year (FSA 2019). The samples should measure the weight and volume of the street sweeping material, and the samples should also be analyzed for moisture content and dry bulk density. It may be helpful for Minnesota to conduct separate data collection efforts to support the determination of a fall leaf bulk density value and a non-leaf bulk density value.

Appendix 1 of Hobbie et al. (2020) provides methods for collecting subsamples for moisture content determination, while FSA (2019) provides information on the steps to be taken to sample for both moisture content and bulk density.

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