Prepared for: City of Fort Collins

Colorado Stormwater Center

One Water Solutions Institute

Colorado State University

Nutrient Sources in Urban Areas – A Literature Review

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Table of Contents

Introduction

In the United States, there are over 7,000 water bodies listed as impaired by nutrients on the Clean Water Act Section 303(d) list (United States Environmental Protection Agency 2015). In 2012, the Colorado Department of Public Health and Environment (CDPHE) issued "Regulation 85-Nutrients Management Control Regulation" (Reg. 85) (Colorado Department of Public Health and Environment 2012) to limit nutrient discharges from wastewater treatment plants and in 2016, CDPHE issued a new general municipal separate storm sewer system (MS4) permit (Colorado Department of Public Health and Environment 2016) for Phase II MS4's that requires permittees to provide education and outreach on nutrient discharges in urban stormwater. Specifically, MS4 permittees must 1) determine the primary sources of nutrients that are (or could) discharge nutrients to water bodies, 2) prioritize which sources could obtain nutrient discharge reductions through education and 3) distribute educational materials or perform other outreach activities for the targeted sources. The City of Fort Collins is a Phase II MS4 permittee and therefore must meet these requirements.

The City's Environmental Regulatory Services department is responsible for ensuring compliance with MS4 permit requirements and has requested the services of the Urban Water Center at Colorado State University to perform a literature review on nutrient sources and identify potential education/outreach programs based on that literature review.

This report documents the results of a review of published research pertaining to the sources, fate and transport of nitrogen and phosphorus in urban stormwater, and also provides suggestions for nutrient-reduction education/outreach programs.

Background

MS4 permittees are required to determine the "targeted" sources of nutrients that are (or could) contribute nutrients to waterbodies; and in the stormwater management field it is common to correlate stormwater pollutant concentrations and loads to land use classification (e.g. commercial, residential, industrial etc.) In response to implementation of Reg. 85 (Colorado Department of Public Health and Environment 2012), the Colorado Stormwater Council and Urban Drainage and Flood Control District commissioned a study to summarize existing information on nutrient discharges in urban stormwater. Table 1 and Table 2 summarize some of the Colorado Regulation 85 Nutrient Data Gap Analysis Report results (Wright Water Engineers et al 2013), which were obtained using data collected in Colorado. The data show that stormwater discharges from residential land use (RES) have greater concentrations of total phosphorus and total nitrogen compared to other urban land uses.

Table 1: Statistics of total phosphorus (mg/L) concentrations in urban stormwater by land use classification (Wright Water Engineers et al 2013)

Land Use	#	Min	Max	25th %	Median	75th %	Mean	COV
COM	277	0.01	6.30	0.12	0.22 (0.18-0.26)	0.41	0.36 (0.30-0.42)	1.47
HWY	25	0.07	2.60	0.15	0.28 (0.15-0.41)	0.42	0.39 (0.18-0.60)	1.25
IND	39	0.05	1.30	0.16	0.25 (0.17-0.36)	0.43	0.35 (0.26-0.44)	0.81
OPEN	7	0.21	0.66	0.26	0.41 (0.21-0.53)	0.54	0.41 (0.25-0.58)	0.39
RES	254	0.07	2.71	0.29	0.45 (0.40-0.51)	0.72	0.56 (0.51-0.61)	0.69
Combined Land Use Category								
COM-HWY-IND	341	0.01	6.30	0.12	0.23 (0.19-0.26)	0.42	0.36 (0.31-0.41)	1.39

Table 2: Statistics of total nitrogen (mg/L) concentrations in urban stormwater by land use classification (Wright Water Engineers et al 2013)

Land Use	#	Min	Max	25th %	Median (Upper & Lower 95% CI)	75th %	Mean (Upper & Lower 95% CI)	COV
COM	168	0.54	16.63	2.01	2.79 (2.52-3.10)	3.88	3.45 (3.08-3.83)	0.71
HWY	9	1.30	6.10	2.30	3.6 (1.30-5.50)	5.50	3.78 (2.39-5.17)	0.45
IND	23	1.20	8.70	2.15	3.60 (2.00-4.37)	4.44	3.56 (2.78-4.34)	0.49
OPEN	7	1.49	6.12	2.08	3.76 (1.49-4.11)	4.14	3.40 (1.90-4.90)	0.44
RES	191	0.51	22.77	2.83	4.19 (3.68-4.82)	6.38	5.06 (4.60-5.53)	0.64
Combined Land Use Category								
COM-IND	191	0.54	16.63	2.01	2.84 (2.55-3.11)	3.93	3.47 (3.12-3.81)	0.69

The information in Table 1 and Table 2 can be further extrapolated to average annual nutrient loads using the Simple Method Equation:

$$L = 0.226 * P * A * Rv * Pr * C$$

Where L = pollutant load (lbs), P = precipitation (inches), A = watershed area (acres), Rv = runoff coefficient, Pr = fraction of annual precipitation that produces runoff and C = pollutant concentration in runoff (mg/L). The average annual precipitation is about 15 inches in Fort Collins (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?co3005) and Pr is typically assumed to be 0.9. Runoff coefficients for commercial, highway, industrial, open space and residential are 0.95, 0.95, 0.9, 0.2 and 0.6 based on the City's storm drainage criteria manual. Table 3 below shows the average annual load of total nitrogen and total phosphorus in urban stormwater, respectively, estimated to be discharged from different land uses in Fort Collins using the Simple Method Equation.

Table 3: Estimated average annual nutrient loads in Fort Collins, CO urban stormwater from various land uses

Land Use	Load (lbs/acre-year)	
	Total Nitrogen	Total Phosphorus
Commercial	5	0.6
Highway	9	0.8
Industrial	8	0.7
Open Space	3	0.3
Residential	11	0.8

However, developing nutrient reduction outreach/education programs based on land use classification alone may have limited impact because it does not identify the specific sources of nutrients and runoff-generating mechanisms that might contribute to the differences in observed nutrient discharges from various land uses. The remaining sections of this report discuss potential sources of nutrients in the urban environment, and their potential fate and transport to urban stormwater in more detail. Those sources include:

- Leaf Litter
- Atmospheric Deposition
- Fertilizer (for turfgrass)
- Pet Waste
- Street Solids

Sources of Nutrients

Leaf Litter

A mature tree can drop 33-55 lbs of leaf litter each fall (Novotny et al. 1985) and the nutrient content of leaf litter has been measured to be about 1-2% nitrogen and 0.1-0.3% phosphorus (Heckman and Kluchinski 1996; Hobbie et al. 2013) (Heckman and Klusinski 1996, Hobbie et al 2013). Several studies have revealed significant correlations between tree canopy cover and the nutrient content of street solids (Figure 1 and Figure 2, Kalinosky 2015) and urban street runoff (Waschbusch et al. 1999). (Waschbusch et al. 1999) found that upwards of 80% of the total phosphorus mass in street solids was attributed to leaves during the fall season. Kalinosky (2015) found that leaves and other "coarse organic materials" made up 15% of total streets solids measured, but 36% of the total phosphorus and 71% of total nitrogen content of the street solids.

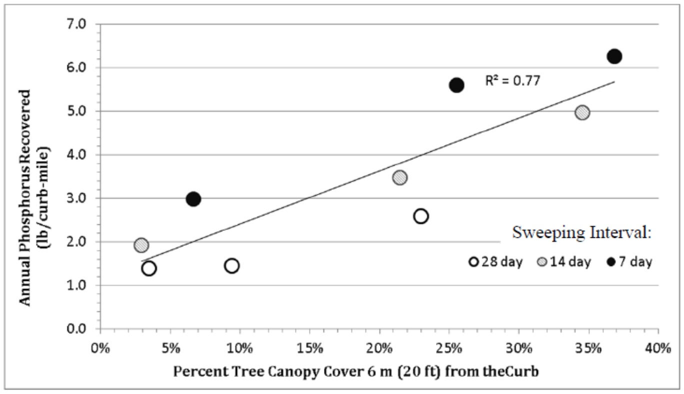


Figure 1: Correlation between phosphorus recovered in street solids and percent tree canopy cover (Kalinosky 2015)

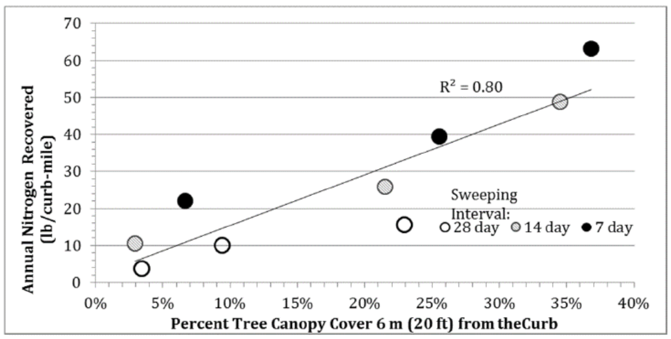


Figure 2: Correlation between nutrient recovered in street solids and percent tree canopy cover (Kalinosky 2015)

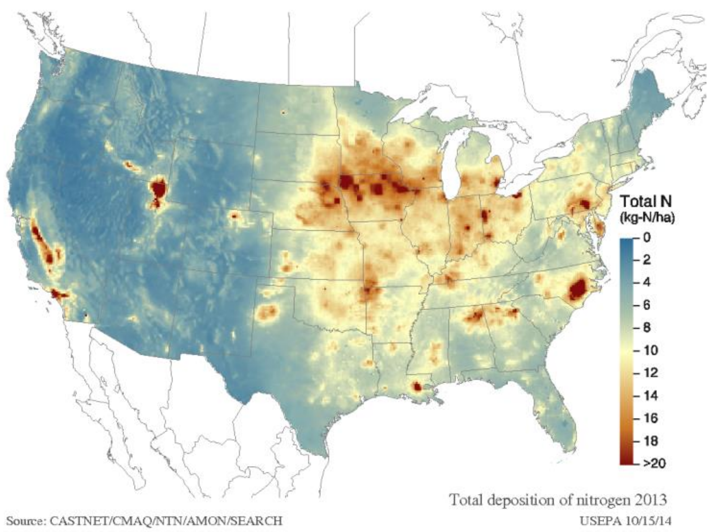
Once leaf litter is deposited onto impervious surfaces, it begins to decompose due to mechanical (e.g. vehicle traffic) and biological processes and the nutrients become subject to leaching during rainfall events. Hobbie et al. (2013) found that leaf litter decomposition on urban impervious surfaces was over twice as fast as was measured in forested land, with 20-40% of the leaf mass decomposing within one month of deposition. Mechanical decomposition processes result in large leaves being broken down into smaller particles, which are more easily transported in stormwater runoff and which leach nutrients quicker during runoff events due to increased surface area of smaller leaf pieces (Dorney 1986). Cowen and Lee (1973) measured nutrient leaching from leaves in a simulated rainfall event. Over 2 hours of time, 5-21% of the total phosphorus in leaves leached and over 80% of the leached phosphorus was in the reactive soluble form. In addition, leaves that were cut into small pieces leached at three times the level as intact leaves. Hobbie et al. (2013) found that leaves sitting in water for 24 hours can leach close to 10% of their nitrogen content and up to 90% of their phosphorus.

Allison et al. (1998) measured leaf litter collected in a continuous deflective separation device for a 50 ha urban catchment during May-August in Australia. A total of 283 kg of organic matter was captured with 0.08-0.28% total phosphorus and 0.7-2.2% total nitrogen by weight. The total captured weight of total phosphorus was 0.4 kg and total nitrogen was 4.0 kg, which is much lower than what was expected. However, these low numbers may be explained by the effects of leaching and leaf decomposition discussed above. Since the device only captured materials greater than 4mm in size, it is likely that much of the nutrients in the runoff was in soluble form (leached) and/or contained within very small leaf particles (less than 4mm diameter).

Atmospheric Deposition

Another potential source of nutrients in urban stormwater runoff is atmospheric deposition. Emissions from vehicles, power plants, industry, and agricultural are the primary anthropogenic activities that contribute to nitrogen to the atmosphere (FENN et al. 2003). Atmospheric deposition of nitrogen is monitored throughout the United States using two different monitoring networks, the National Atmospheric Deposition Program (NADP) network and the Clean Air Status and Trends Network (CASTNET). NADP sites measure wet deposition of nitrate (NO_3), ammonia gas (NH_3) and ammonium (NH_4) (National Atmospheric Deposition Program 2016) and CASTNET measures dry deposition of nitric acid (HNO_3) and particulate NO_3 and NH_4 (United States Environmental Protection Agency 2016). Figure 3 shows the total atmospheric deposition of nitrogen throughout the US in 2013. In Colorado, the values are generally 2-4 kg-N/ha (1.8-3.6 lb-N/acre). Burns (2003) estimated that 70-75% of atmospheric deposition occurs as wet deposition (i.e. deposited on the land surface through precipitation) along the Front Range and Rocky Mountain regions. Wet deposition measurements at the Pawnee NADP site (NTN Site CO22), which is closest to Fort Collins, has shown NO_3 concentrations ranging from 0.3-6.7 mg/L with an average of 1.3 mg/L and NH_4 concentrations ranging from 0.1-2.6 mg/L with an average of 2.6 mg/L. The average measured concentration of NO_3+NH_4 is 2.0 mg/L, which is a considerable portion of the typical total nitrogen concentrations measured in urban runoff in Colorado. In Iowa, Anderson and Downing measured total nitrogen rainfall concentrations from 0.4-0.6 mg/L.

Figure 3: Total atmospheric deposition of nitrogen in 2013 (National Atmospheric Deposition Program 2016)



The NADP and CASTNET monitoring sites are intended for long-term, regional trends and are purposefully located at least 10 km (~6 miles) away of large urban areas to avoid measuring localized pollution sources (Bettez and Groffman 2013). It is believed that these monitoring networks underestimate the amount of nitrogen atmospheric deposition within urban areas because the NOx emissions from vehicles have a high deposition velocity and often are deposited within tens or hundreds of meters of roadways. For example, Redling et al. (2013) measured nitrogen dry deposition values four times larger next to a highway compared to the nearest CASTNET site. Bettez and Groffman (2013) found nitrogen dry deposition 47% higher in urban areas and 22% higher in suburban areas compared to nonurban areas. They suggest that vehicle emissions play a considerable role in the deposition of nitrogen in urban areas.

Several researchers have estimated how much atmospherically-derived nitrogen contributes to nutrient loading in waterbodies. Fisher and Oppenheimer (1991) estimated that atmospheric deposition contributed about 25% of nitrogen loading to Chesapeake Bay. Divers et al. (2014) estimated that 34% of nitrate measured in a local stream during storm events was due to atmospheric deposition, with a net export rate of approximately 0.19-0.32 kg/ha-year. Burns et al. (2009) found that 40-53% of nitrate in an urban stream was due to atmospheric deposition, Hale et al. (2014) estimated 34% and Kaushal et al. (2011) concluded that nitrate from the atmosphere was the dominant source in an urban stream during small and medium storm events.

The atmospheric deposition of phosphorus is much less understood as there is no monitoring network dedicated to measuring it nationwide. A limited number of studies, primarily conducted in non-urban environments, suggest that the primary sources of phosphorus deposited from the atmosphere are organic matter, wind-blown dust and agricultural fertilization.

Cole et al. (1990) measured total phosphorus deposition of 0.65 lbs/acre-year at a lake located in a forested watershed in New Hampshire. The deposition rate was highest near shore and quickly declined to about at distances greater than 30 feet from shore. About 60% of total phosphorus deposition was particulate and comprised from plant fragments and insects believed to have been blown into the measurement canisters from nearby forests. They estimated that atmospheric deposition phosphorus input was 50-60 times larger than the fluvial input of phosphorus to the lake during the same period of time. Lewis et al. (1985) measured average phosphorus deposition rates of 0.1 lb/acre-year in Summit and Boulder Counties (Colorado) and also found that deposition of soluble phosphorus correlated with the growing season. While sampling in agricultural regions of Iowa, Anderson and Downing (2006) measured average phosphorus rates of 0.3 lbs/acre-year and found the highest phosphorus deposition rates during the planting and harvesting seasons (Figure 5), suggesting that field tillage and fertilization of fields were the primary contributing activities. However, they were surprised to find that deposition rates were not considerably different from other locations with less-intensive agriculture.

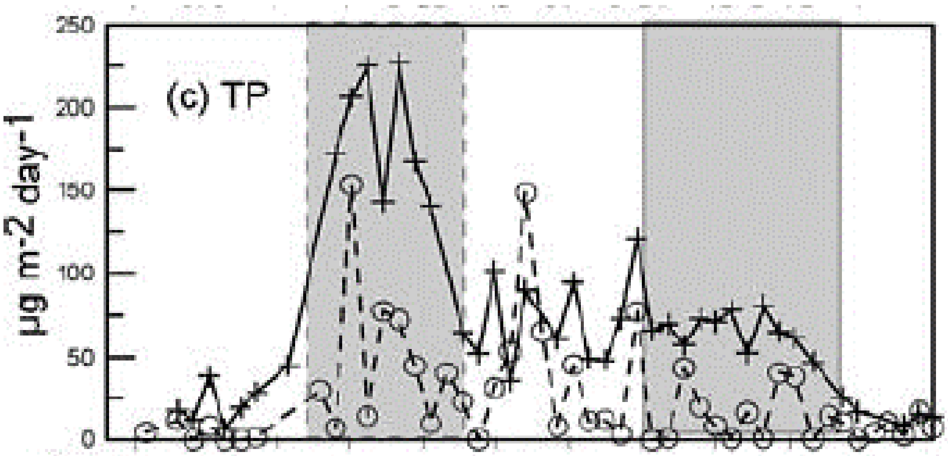


Figure 4: Measured deposition of total phosphorus near Ames, IA from February-December 2003. Highlighted regions represent agricultural planting (April-June) and harvesting (Sept-November) periods (Anderson and Downing 2006).

Because of the effects of infiltration on pervious surfaces, not all nutrients that are deposited in the urban environment end up in stormwater runoff. Most likely, only those that are deposited on impervious surfaces will be mobilized via rainfall. For example, Divers et al (2014) estimated that only 5-8% of the total nitrate deposited in a watershed ended up entering a local stream while Groffman et al. (2004) estimates that only 25% of deposited nitrogen ended up in urban/suburban streams.

Fertilizers (Turfgrass)

Fertilizers are used extensively in most urban environments, mostly to support the growth of turfgrass lawns. There is little doubt that fertilizers are the source that is most often targeted to reduce nutrient discharges from urban stormwater.

In Colorado, CSU Extension recommends that turfgrass fertilizers be applied at a rate of 1-5 lbs of nitrogen per 1000 square per year (44-220 lbs-N/acre-year) and distributed over 2-4 applications during the growing season (Koski and Skinner 2012), which is in line with most manufacturer's recommendations. Osmond and Hardy (2004) surveyed residents in North Carolina and found that 70-80% of residents applied fertilizer rates according to Extension and/or manufacturer recommendations; however in the same study respondents reported a wide range of average fertilizer rates from about 30-150 lbs-N/acre-year. In addition, the percentage of residents that fertilize their lawns has been found to range from about 50-90% in various cities and neighborhoods (Carpenter and Meyer 1999; Carrico et al. 2012; Nielson and Smith 2005; Osmond and Hardy 2004; Varlamoff et al. 2001).

Since soils generally contain adequate amounts of phosphorus for healthy turfgrass lawns, most commercially-available fertilizers no longer contain significant amounts of phosphorus. Table 4 presents the nutrient ratios of several fertilizers available at a local home supply store in Fort Collins. Only 3 of the 7 fertilizers reviewed contained any phosphorus, with N-P ratios varying from 2.5:1 to 5.5:1.

Table 4: Nitrogen and phosphorus ratios of different fertilizers and estimated phosphorus application rates

Brand/Type	N-P-K Ratio	Potential Fertilizer P Application Rate (lbs-P/acre-year)*
Milorganite	5-2-0	53
Scott's Turf Builder Lawn Food	32-0-4	0
Vigoro Weed and Feed	29-0-3	0
Scott's Natural Lawn Food	11-2-2	24
Vigoro Lawn Fertilizer	29-0-4	0
Scott's Green Max Lawn Food	26-0-2	0
Richlawn Turf Food	10-2-5	26
Source: Informal survey of fertilizers at Home Depot in Fort Collins * - assuming fertilizer application rate of 132 lbs-N/acre-year		

Based on the information above, it is clear that fertilizers are major input source of nitrogen (and potentially phosphorus) in the urban environment; however the fate and transport of fertilizer nutrients into urban stormwater is dependent on several other factors.

One factor that contributes highly to the mobility of fertilizers to urban stormwater runoff is the health of the turfgrass. Perhaps contrary to intuitive thinking, multiple studies have shown that non-fertilized turfgrass results in higher losses of nutrients to runoff compared to lawns that are fertilized (Bierman et al. 2010; Easton and Petrovic 2004; Spence et al. 2012). This is because unfertilized turfgrass is less dense and has smaller roots compared to fertilized turfgrass. Higher turfgrass density will slow down runoff, trap soil particles, and prevent erosion. The combination of higher turfgrass density and larger root structures also increases infiltration of rainfall/runoff, thus preventing nutrients from entering the stormwater system.

The effects of turfgrass management on nutrient mobilization has also been studied with varying results. Bierman et al. (2010) did not measure any significant differences in runoff phosphorus levels when grass clipping were returned (mulched) to the lawn versus removed (bagged). However, Ippolito et al. (2014) found that dissolved phosphorus levels were higher in runoff where grass clippings were mulched compared to bagged and/or not mowing at all. The discrepancy may be due to unknown factors that contributed to the variability of uptake of applied nutrients. For example, Frank et al. (2006) found that only 7-10% of applied nitrogen could be recovered in grass clippings, whereas Easton and Petrovic (2004) found much higher nutrient recovery percentages in grass clippings (Figure 5).

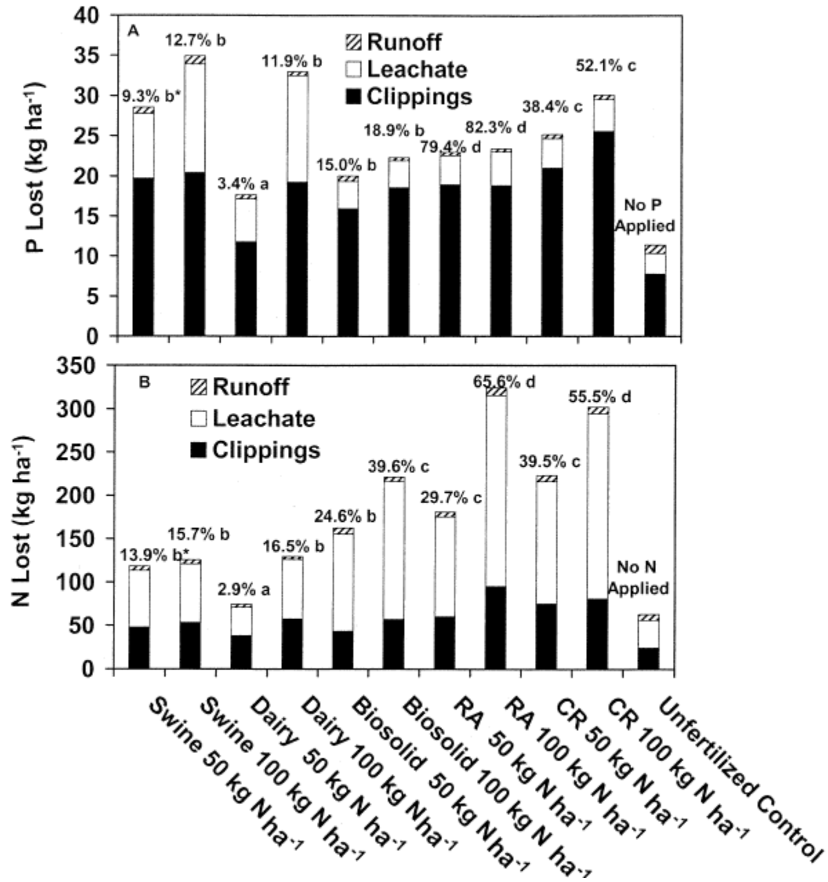


Figure 5: Nutrient fate and transport measurements for different types of fertilizer and application rates (Easton and Petrovik 2004)

Another factor is the type of fertilizer applied. There many different types of fertilizers available, ranging from organic (composted waste) to synthetic and fast-release to slow-release. Easton and Petrovik (2004) found that organic fertilizers (dairy/swine compost and biosolids) resulted in greater phosphorus losses to runoff compared to synthetic fertilizers, but synthetic fertilizers resulted in greater nitrogen loss than natural fertilizers (Figure 5). Guillard and Kopp (2004) found that fast-release, fully soluble ammonium nitrate urea fertilizer leached nitrogen into the groundwater much faster than composted turkey litter, which generally releases nutrients more slowly.

Lastly, the timing of fertilizer application has been shown to correlate with nutrient concentrations in runoff. Bierman et al. (2010) found that the highest rates of phosphorus runoff occurred when the ground was frozen and suggested that fertilizers not be applied in the fall to reduce runoff during winter. Guillard and Kopp (2004) found similar results in New England and concluded that fall applications of fertilizers should be avoided because turfgrass is beginning to go dormant (less nutrient uptake) and frozen ground in winter and early spring results in increased runoff from lawns.

Few studies have attempted to estimate the percentage of nutrients in urban stormwater due to fertilizers. Hale et al. (2014) estimated that fertilizer was the source of 6-65% (average of 44%)

of total nitrate in urban stormwater for various storm events in Phoenix, AZ and Easton et al. (2007) estimated that fertilizer was responsible for 19% of the dissolved phosphorus load in a watershed in New York state.

Pet Waste

Pet urine and excrement can also act as a source of nitrogen and phosphorus in the urban environment. Baker et al. (2006) estimated that a typical dog (45 lbs) would excrete 12 lbs of nitrogen and 2.6 lbs of phosphorus per year. Most nitrogen is excreted as urine, which renders its management rather unpractical; however phosphorus is generally contained within feces and its availability for transport to receiving waters could be managed by disposing of pet feces in the landfill. One survey conducted in the Chesapeake Bay watershed showed that about 60% of dog owners usually picked up feces while taking their dogs on walks (Swann 1999), but it did not report how many pick up dog feces from their yards. Ervin et al. (2014) reported significant reductions in canine-derived bacteria along a stream in California after an education and outreach campaign to households living adjacent to the stream.

Street Solids

This section presents a review of research associated with "street solids", which is a term that refers to the particles that accumulate on roadways, parking lots and similar impervious driving surfaces. Understanding the composition of street solids is perhaps the most important aspect to controlling nutrient discharges from urban areas since streets and parking lots are typically "directly connected" to the stormwater system. Street solids are also an aggregate measure of all of the potential nutrient sources discussed in the prior sections of this report.

Typically, street solids tend to build up over time and reach a maximum value within one or two weeks after the previous rainfall event (Sartor et al. 1974; Seattle Public Utilities 2009; Sorenson 2013). During rainfall events, some or all of the street solids might be washed off the surface, after which the process of solids buildup begins again. This process is known at the "buildup/washoff" phenomenon in stormwater management. Table 5 summarizes the average street solids loads that have been measured in various parts of the US. Note that the reported loads are not total annual loads, but what has been measured instantaneously.

Table 5: Measured street solids accumulations

Reference	Location	Average[1] Measured Street Solids Buildup	
		lbs/curb-mile	lbs/acre[2]
Sorenson (2013)	Cambridge, MA	520-740	26-37
Seattle Public Utilities (2009)	Seattle, WA	800-1100	40-55
Sartor et al (1974)	Various	290-3500	15-175
Selbig and Bannerman (2011)	Madison, WI	500-800	25-40
DeBlasi (2008)	Baltimore, MD	650-1100	33-55

Notes:

[1] – ranges are averages for multiple sites sampled as part of the studies. Ranges of individual samples are larger and often vary by 2 orders of magnitude.

[2] - Calculated value - 1 lb/curb-mile is approximately equal to 0.05 lbs/acre assuming urban street density of 20 miles/sq. mile

The variability of street solids buildup rate and maximum mass is affected by factors such as traffic speed, traffic volume, curb height, wind speed and climate Novotny (2003). A common finding among a large number of studies is that street solids loads are higher in the fall season and near the end of winter compared to other seasons. Figure 6 shows an example of seasonal variability of street solids loads in Massachusetts. In this particular study, the fall loads were higher than summer loads for the multifamily-residential neighborhood, but not for the commercial area. The researchers attributed to the difference to the density of trees in the areas (i.e. residential area had more trees than the commercial area and the increase in street solids loads were due to tree leaf litter). An even more pronounced difference is apparent for samples collected at the end of winter ("EOW"), with measured street solids loads 4-10 times higher than summer loads. This is the result of solids buildup over the course of winter. Unlike other months were solids can be mobilized off impervious surfaces via traffic, wind, etc.; during winter the snow tends to trap solids and make them immobile until the snow melts later in the season.

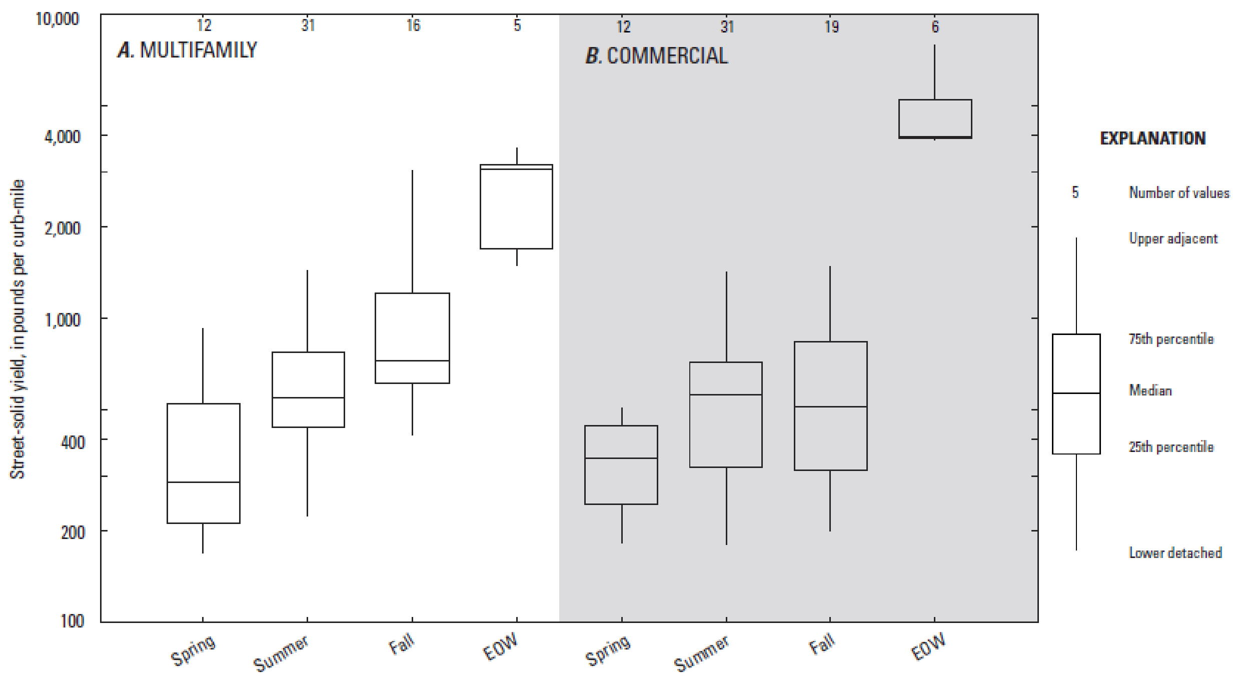


Figure 6: Seasonal distribution of street solids in Cambridge, MA (Sorenson 2012)

Street solids are complex mixture of materials with various particle sizes and nutrient content. Particle size plays a significant role during runoff events, where the ability of runoff to mobilize a particle from the impervious surface to the storm sewer is directly related to particle size. The smallest particles can be mobilized by almost any runoff-producing storm event, whereas the largest particles may only be mobilized during high intensity storms. Table 6 shows results from several studies that measured the distribution of particle sizes in street solids. The reported values show the percent of total solids mass that was attributed to particles in different size ranges. Particles greater than 250µm are generally classified as coarse sands/gravels, particles 63-250µm are generally considered fine sands and those less than 63µm are silts and clays. The majority of street solids mass is attributed to larger particles and typically less than 10% of solids mass can be attributed to particles in the silts and clays.

Table 6: Particle size distribution of street solids

Study	Particle Size Distribution (percent)		
	>250um	63-250um	<63um
Sorenson (2012)	9-21	58-68	21-27
Selbig and Bannerman (2011)	75	22	3
Seattle Public Utilities (2009)	58-76	16-27	8-9
Breault et al. (2005)	62-81	22-28	2-5
DiBlasi (2008)	71	25	4

Table 7 is a summary of the nutrient content measured in street solids. In most cases, the percent of street solids mass that is phosphorus is less than 0.1% and that which is nitrogen is less than 1%. However, as depicted in Figure 7, this nutrient content is clearly sufficient enough to support the growth of corn in street solids. Comparing the annual mass estimate (normalized by area) in Table 3 with those reported in Table 7, one will notice that the numbers for both phosphorus and nitrogen are t he same order of magnitude. This strongly suggests that the nutrients associated with street solids represent the majority of nutrients that are measured in stormwater runoff.

Table 7: Nutrient content measured in street solids

Nutrient	Reported Content	Percent of Total Mass	Annual Mass (lbs/acre-year)[2]	Reference
TP	500-700 mg/kg	0.05-0.07	0.5-0.7	Sorenson 2012
TP	488-906 mg/kg	0.05-0.09	0.5-0.9	Seattle Public Utilities (2009)
TP	1.1 lb/curb-mile	0.08[1]	0.8	Sartor et al (1974)
TP		0.03-0.16	0.3-1.6	Breault et al (2005)
TP	1034-3309 mg/kg	0.10-0.33	1.0-3.3	DiBlasi (2008)
TKN	1770-8660 mg/kg	0.18-0.86	1.8-8.6	Seattle Public Utilities (2009)
TKN	1477-3067 mg/kg	0.15-0.3	1.5-3	DiBlasi (2008)
Nitrate	0.09 lb/curb-mile	0.006[1]	0.06	Sartor et al (1974)
Nitrate	<0.6 mg/kg	0	0	DiBlasi (2008)
Nitrite	<0.6 mg/kg	0	0	DiBlasi (2008)

Notes:

[1] – calculated assuming an average of 1400 lbs/curb-mile of total solids

[2] – Assuming 40 lbs/acre maximum street solids buildup every 14 days

Figure 7: Picture showing corn growing in accumulated street solids in Fort Collins, CO

SUMMARY AND RECOMMENDATIONS

This report provides a summary of relevant research that is intended to help the City identify potential sources of nutrients in urban stormwater and develop education and outreach programs to reduce nutrients in urban stormwater.

Research shows that leaf litter, atmospheric deposition, fertilizers and (to a lesser extent) pet waste are all potential sources of nutrients in stormwater. When the above sources are deposited onto impervious surfaces, they accumulate as street solids and become “directly-connected” to the stormwater system. Rough estimates of average annual nutrient loads show that the nutrients measured in street solids are on the same order of magnitude as those measured in urban stormwater runoff.

Although leaf litter is a “natural” source of nutrients, education and outreach programs could focus on keeping fallen leaves out of the stormwater system through proper collection and recycling. Activities such as blowing leaves and other vegetative debris into roadways should be discouraged. A side benefit of this type of program would be reduced maintenance to the stormwater system due to leaves clogging pipes and inlets.

The control of nutrients contributed by atmospheric deposition through a local education and outreach program would likely be limited as many of the sources are non-local and/or naturally-occurring. However, several studies did identify vehicle emissions as a significant localized source of nitrogen. This suggests that any education and outreach campaign that focuses on reducing vehicle usage may also be contribute to a reduction of nitrogen in stormwater.

Fertilizer use is the most often targeted source of nutrients in stormwater management campaigns. While it may seem most intuitive that a reduction or elimination of the use of fertilizers may be the most effective education and outreach approach, in fact research shows that poorly maintained lawns (those with low/no fertilizer applied) actually export more nutrients to runoff compared to fertilized lawns. Research also shows that the highest export of nutrients from lawns occurs in during the late fall through early spring months when the ground is frozen and/or vegetation growth is limited. Therefore, an education and outreach program targeting fertilizer use should focus on applying the proper amounts of fertilizer (according to manufacturer and/or Extension recommendation) during the proper seasons.

Research on the contribution of pet waste to stormwater nutrients is rather limited, but few studies have identified it as a potential source. Many cities already have education and outreach programs targeting the proper collection and disposal of pet waste for bacteria reduction, however the same programs may also contribute to nutrient reduction.

Lastly, a review of research on street solids was included because they represent an aggregate measure of nutrients accumulating in the urban environment. Street sweeping programs operated by local utilities are an obvious activity that can significantly reduce nutrients in stormwater, however such operations may be limited to certain streets and do not specifically target private citizens. Education and outreach programs that aim to “keep the streets clean” could educate citizens that what appears to be relatively innocuous “dirt” is actually akin to trash and litter collecting on the streets. Engaging citizens to prevent materials such as leaves, grass clippings, fertilizer from reaching streets and potentially even remove dirt and other accumulated materials as they would trash and litter would be an interesting (and potentially highly effective) program.

SUMMARY AND RECOMMENDATIONS

This report provides a summary of relevant research that is intended to help the City identify potential sources of nutrients in urban stormwater and develop education and outreach programs to reduce nutrients in urban stormwater.

Research shows that leaf litter, atmospheric deposition, fertilizers and (to a lesser extent) pet waste are all potential sources of nutrients in stormwater. When the above sources are deposited onto impervious surfaces, they accumulate as street solids and become "directly-connected" to the stormwater system. Rough estimates of average annual nutrient loads show that the nutrients measured in street solids are on the same order of magnitude as those measured in urban stormwater runoff.

Although leaf litter is a "natural" source of nutrients, education and outreach programs could focus on keeping fallen leaves out of the stormwater system through proper collection and recycling. Activities such as blowing leaves and other vegetative debris into roadways should be discouraged. A side benefit of this type of program would be reduced maintenance to the stormwater system due to leaves clogging pipes and inlets.

The control of nutrients contributed by atmospheric deposition through a local education and outreach program would likely be limited as many of the sources are non-local and/or naturally-occurring. However, several studies did identify vehicle emissions as a significant localized source of nitrogen. This suggests that any education and outreach campaign that focuses on reducing vehicle usage may also be contribute to a reduction of nitrogen in stormwater.

Fertilizer use is the most often targeted source of nutrients in stormwater management campaigns. While it may seem most intuitive that a reduction or elimination of the use of fertilizers may be the most effective education and outreach approach, in fact research shows that poorly maintained lawns (those with low/no fertilizer applied) actually export more nutrients to runoff compared to fertilized lawns. Research also shows that the highest export of nutrients from lawns occurs in during the late fall through early spring months when the ground is frozen and/or vegetation growth is limited. Therefore, an education and outreach program targeting fertilizer use should focus on applying the proper amounts of fertilizer (according to manufacturer and/or Extension recommendation) during the proper seasons.

Research on the contribution of pet waste to stormwater nutrients is rather limited, but few studies have identified it as a potential source. Many cities already have education and outreach programs targeting the proper collection and disposal of pet waste for bacteria reduction, however the same programs may also contribute to nutrient reduction.

Lastly, a review of research on street solids was included because they represent an aggregate measure of nutrients accumulating in the urban environment. Street sweeping programs operated by local utilities are an obvious activity that can significantly reduce nutrients in stormwater, however such operations may be limited to certain streets and do not specifically target private citizens. Education and outreach programs that aim to “keep the streets clean” could educate citizens that what appears to be relatively innocuous “dirt” is actually akin to trash and litter collecting on the streets. Engaging citizens to prevent materials such as leaves, grass clippings, fertilizer from reaching streets and potentially even remove dirt and other accumulated materials as they would trash and litter would be an interesting (and potentially highly effective) program.