QUANTIFYING NUTRIENT LOADS ASSOCIATED WITH URBAN PARTICULATE MATTER (PM), AND BIOGENIC/LITTER RECOVERY THROUGH CURRENT MS4 SOURCE CONTROL AND MAINTENANCE PRACTICES

(Maintenance Matters !)

Final Report

To

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EXECUTIVE SUMMARY

Day-to-day maintenance of urban stormwater (rainfall-runoff) management systems (urban drainage or storm sewer systems) and pavement significantly reduces pollutant loads contributing to the impairment of receiving waters. In short, MAINTENANCE MATTERS and quantifying load recovery from maintenance activities is beneficial for all stakeholders. The hypothesis that maintenance matters is quantifiable and critical for implementation of the knowledge developed in this study and presented herein. While this knowledge may not be revolutionary in that the study results are expected, the knowledge represents a defensible foundation to build the allocation of stormwater load reduction credits based on maintenance practices. These maintenance practices remove gross solids (detritus), coarse particulate matter (PM) and associated constituents (such as nutrients) from the urban inventory of PM that is transported through and stored in stormwater management systems. This PM is a source and sink of nutrients that result from the interaction and imposition of anthropogenic/biogenic activities and urban infrastructure design practices/materials on the hydrologic cycle.

For this study, the University of Florida (UF), fourteen (14) MS4s (municipal separate storm sewer systems) across Florida, the Florida Department of Environmental Protection (FDEP), and the Florida Stormwater Association (FSA) actively participated in the creation of this knowledge base through their experience, intellect, funding, sampling, and labor. For each of eleven (11) MS4s, samples were obtained under conditions where there was no known reclaimed wastewater impacting the hydrologic functional unit (HFU) and land use locations of the samples. For the 11 MS4s twenty seven (27) samples from three hydrologic functional units (HFU) were obtained. HFUs consisted of a planned variety of best management practices (BMPs) most frequently maintained by the MS4, paved area street sweepings (SS), and catch basins (CBs). HFUs were sampled for three land uses: highway (H), commercial (C) and residential (R). For each sampling matrix category, three independent locations were utilized. In the remaining three MS4s, the same matrix of 27 samples was also taken as well as 27 paired samples from inside areas where reclaimed water was used. In total, four hundred and fifty nine (459) samples were recovered, delivered and analyzed. Each location and details are provided in a report appendix.

Knowledge from this effort is categorized in terms of HFU and land use for nitrogen (N, as TN), phosphorus (P, as TP) and PM. This study was designed to create a Florida-based metric for TN and TP and a separate objective was to examine whether reclaimed wastewater is a contributor of TN and TP. This study was not designed to compare and contrast results for individual MS4s or between classes of BMPs. Germaine to this study, it is noted that the results presented are a function of many variables, and while vendors promote differences between BMPs the reality is that such treatment and cost differences are rarely if ever significant given a lack of BMP maintenance and the benefits of urban maintenance practices. While the Florida-based results indicate differences between HFUs and between land uses, results consistently indicates that the metrics of TN and TP are log-normally distributed. This observation is important for allocation of load credits because the results are not represented by a singular concentration [mg/kg] but by log-normal distributions thereof whether examined based on HFU categories or land use categories as lumped together for the entire state of Florida. While a number of statistical indices could be selected (mean, median, 25th, 75th quartiles, …) the consistent log-normality of results leads to the use of a median (50th percentile) concentration [mg/kg] from each distribution. It is recommended that the metric or yardstick by which dry mass equivalent of PM recovered is equated to TN and TP be based on the median value from the Florida-based distributions (either as a function of land use or with all land uses combined). The following table summarizes these Florida-based results as a function of HFU and land use **outside** MS4 areas loaded by reclaimed wastewater. These tabular results represent the mg of TN or TP per equivalent dry kg of PM and/or gross solids recovered by a maintenance practice, but cannot be construed as an index for BMP treatment effectiveness or "removal efficiency". Based on the numerical value and associated units in the table, the dry kg of urban PM detritus recovered can be converted to mg of TN or TP recovered by a maintenance practice.

Table S 1 This table represents the Florida-based metrics (yardstick) to convert dry-equiv. PM (and/or gross solids) mass to a PM-based TP or TN in units of [mg of TP or TN per dry mass in kg of PM recovered]. Metrics are presented in this table as a function of land use and HFU from PM recovered in this study by maintenance practices (street cleaning, catch basin cleaning, BMP cleaning). Metrics are presented as statistics developed from log-normal distributions illustrated in the report. This table combines Table 5 and 6 of the report. Metrics in this table (this study recommends the median) or in Table 8 (also medians and also Florida-based but combines all land uses) are used to illustrate methods and costs in examples presented later in this report. These metrics are to be used with the dry-equiv. PM recovered and documented by each MS4.

TP	**Street Sweeping (SS)**			**Catch Basin (CB)**			**BMP**		
[mg/kg]	**Mean**	**Median**	**St. Dev.**	**Mean**	**Median**	**St. Dev.**	**Mean**	**Median**	**St. Dev.**
C	482.6	381.2	476.9	530.9	300.8	524.9	474.6	295.7	412.6
R	425.8	374.9	284.7	559.2	423.4	543.0	702.8	382.7	670.5
H	622.0	349.7	778.5	566.6	536.9	363.3	759.4	513.7	972.1
TN	**Street Sweeping (SS)**			**Catch Basin (CB)**			**BMP**		
[mg/kg]	**Mean**	**Median**	**St. Dev.**	**Mean**	**Median**	**St. Dev.**	**Mean**	**Median**	**St. Dev.**
C	789.1	429.6	944.2	1459.7	467.2	2237.8	1999.0	602.1	3104.1
R	1439.0	832.4	2169.9	1803.9	773.8	2955.8	3587.7	1169.0	4991.9
H	826.6	546.4	654.8	1926.3	785.4	2587.8	2342.4	939.2	3496.6

A second objective of this study was to examine the role of irrigating urban areas with reclaimed wastewater. Results indicate that reclaimed wastewater irrigation adds N and P loads to urban environs based on 3 MS4s. The added load is somewhat muted in the distributions for several reasons. The reclaimed database is smaller. HFUs such as structural BMPs and catch basins do not capture dissolved and suspended nutrients that dominate the N and P loads in reclaimed wastewater and can represent a significant fraction in stormwater. However, results demonstrate there is enrichment of the PM recovered for all HFUs including street sweeping.

In comparison to maintenance practices, this study examined a diverse population of BMPs utilized in Florida, from common screened hydrodynamic separators to what can be nominally identified as "French Drains". This intentional diversity represents many of the small watershed or site-based structural BMPs in Florida that are maintained through recovery of PM. For MS4s outfitted with such BMPs, this study concludes maintenance practices are more economical and sustainable than such BMPs. Such BMPs are expensive and not sufficiently maintained resulting in small load reductions as compared to maintenance practices or hydrologic restoration. Maintenance practices and hydrologic restoration can provide the primary benefits for economical load reduction however engineered treatment and models are still required. In lieu of such current BMPs and methods of BMP implementation, engineered unit operation and process systems at regional scales and centralized locations designed for soluble and fine PM-based pollutants are needed. Such systems incorporate modern tools such as continuous simulation (as with the Storm Water Management Model, SWMM) and computational fluid dynamics (CFD). As a result these systems are significantly more effective and sustainable than current BMPs while also benefiting from maintenance practices and hydrologic restoration.

A summary of the cost ($/lb) for BMPs and maintenance practices are shown in Table S2 (same as Table 9) are shown below. The detailed results are provided in the example section of the report. Depending of the metric chosen (either as a function of land use, or independent of land use) the length units for street sweeping, the number of catch basin units cleaned or the number of BMPs required with cleaning are summarized as follows and detailed in the example section.

<u>Example Illustration:</u>

An example is illustrated utilizing for simplicity the Florida-based metrics independent of land use. For street sweeping the median metrics (Table 8, mg/kg of PM) and median of the PM recovery distribution of MS4s from sweeping one mile of pavement (147 dry kg PM/mile swept) are combined resulting in 0.12 lb TP and 0.18 lb TN recovered. **<u>In this example the pavement miles that need to be swept (cleaned) to recover 1 lb of TP and TN, are respectively, 8.5 and 5.5 miles.</u>** This mass is thereby removed as a potential runoff load. For a catch basin the median TP concentration is 417 mg of TP/kg of PM and for TN is 679 mg of TN/kg of PM. The result yields 0.04 lb TP and 0.07 lb TN recovery per catch basin per 100 lb of PM recovered. **<u>In this example 1.0 lb of TP and TN requires 24.0 and 14.7 catch basins, respectively</u>**. For a BMP (in this example a screened hydrodynamic separator, HS) using details of the Example section results in 627 lb of PM (284 Kg) separated annually. By installing this BMP and recovering PM mass it is possible to calculate through Table 8 the associated TP and TN mass. In particular these values are 363.9 mg TP/kg of PM and 898.5 mg TN/kg of PM. Multiplying by the PM recovered in the BMP results yield 0.23 lb TP and 0.56 lb TN separated for one BMP in one year. **<u>In this example to recover 1.0 lb of TP or TN it is necessary to purchase and maintain 4.4 and 1.8 screened HS units, respectively on an annual basis while assuming no scour and washout of PM.</u>** This is an illustrative example. PM load recovery by street cleaning, catch basin or BMP cleaning varies by MS4. These dry-equiv. PM loads must be documented by each MS4.

Separate from the above illustrative example, Florida-based BMPs and maintenance practice costs are summarized in Table S 2 (Table 9) and detailed in the Example section of the report.

Table S 2 Comparison of BMPs vs. maintenance costs ($/lb) for PM, TP and TN. For BMPs, separation and recovery are required, while only recovery is required for maintenance practices.

Separation and/or Recovery Method	**Median Cost ($/lb)**		
	TN	**TP**	**PM**
BMP Treatment Train[a]	935	32,600	26
FL Database for BMPs[b]	1,900	10,500	41
Screened Hydrodynamic Separator (HS)[c]	3,730 (1,280 - 14,860)	9,210 (3,170 - 36,680)	4 (1 - 13)
Baffled Hydrodynamic Separator (HS)[c]	3,020 (1,280 - 14,860)	7,450 (3,170 - 36,680)	3 (1 - 13)
Street Sweeping	165	257	0.10
Catch Basin Cleaning[d]	1,016	1,656	0.70

[a] Wet basin sedimentation followed by granular media filtration. Squadra Tempesta, (2010) *Green Infrastructure Design for Pollutant Control from Transport Systems Crossing Land-Water Interfaces - A Bridge too Far?*, Water Environment Federation, WEFTEC, New Orleans, LA.

[b] TMDL database for Florida Best Management Practices, 2009

[c] Based on 2000 m^2 urban catchment draining to a hydrodynamic separator (HS) with 50% PM annual removal efficiency based on clean sump conditions. This result assumes no scour or washout from the screened hydrodynamic separator in order to compare to other separators. Accounting for scour and washout will result in costs higher than the median costs shown.

[d] Based on 100 dry pounds of PM recovery based on an annual cleaning frequency

In summary, study results reinforces the knowledge that source controls or urban maintenance practices such as street sweeping are very cost effective tools in reducing stormwater constituent loads as compared to catchment-based structural BMPs. With respect to recovery costs for PM, TP or TN, a detailed example illustrates street sweeping costs compared to other maintenance practices. This example also compares maintenance practice costs to the costs of BMPs to separate and then recover PM, TP and TN. Results as illustrated in this example indicate that street sweeping (cleaning) practices using a variety of existing technologies is significantly more economical than BMPs for PM, TP and TN. This example relates dry-equiv. solid-phase (PM) separation and recovery for PM-based TP and TN to an example with runoff loadings given that BMP designs are primary runoff-based. For dry-equivalent PM mass, MS4 data must include measured moisture content. If measured on a volumetric basis, dry-equiv. PM must also include measured "loose" dry bulk density representative of the reported volume. Any results utilized from this study must be referenced back to this study report to provide a foundation and basis for the result utilized. The body of this report and the extended appendix form the basis of the results and recommendations for maintenance practices as presented herein.

INTRODUCTION: Nitrogen, Phosphorus and Particulate Matter (PM)

For the ecological health of receiving waters, phosphorus (P) and nitrogen (N) are limiting for eutrophication (Correll 1998). Eutrophication has been recognized as a common condition for many receiving water systems impacted by urban runoff due to anthropogenic generation and mobilization of N and P at elevated concentrations and loadings (Wendt and Corey, 1980, Welch 1992, Sharply 1999, Dean et al. 2005, Berretta and Sansalone 2011). Urban runoff is recognized as nonpoint source of N and P as well as inorganic and organic particulate matter (PM) (USEPA, 1990; Duda, 1993). With demographic changes, land use and anthropogenic activities, runoff impacts are increasing (Brezonik and Stadelmann, 2002). For example, two decades ago Smith et al. (1993) demonstrated that 48% of 410 water chemistry monitoring sites did not meet a widely-accepted USEPA level of 0.10 mg/L at that time, as total P (TP). An impact of eutrophication and PM delivery is oxygen depletion (anaerobic conditions) in unmaintained stormwater appurtenances such as catch basins, unmaintained BMPs such as wet vaults or hydrodynamic separators, or BMPs with wet sumps and ultimately in receiving waters. Such impairments impact aesthetics, ecology and water use designations (Ahn et al., 2005). Eutrophication imposes a high economic, environmental, ecological, and health cost (Pretty et al., 2003).

Loads of nutrients are generated and transported through the combination of anthropogenic activities and the altered rainfall-runoff relationships generated from urban infrastructure imposed on the hydrologic cycle (EPA 1993). For example, specific urban land use designs such as grassed and vegetated areas with runon to impervious pavement are identified as significant sources of biogenic P (Garn 2002, Berretta and Sansalone 2011). Anthropogenic sources of P besides fertilizer include P-based admixtures, for example phosphogypsum in concrete, released from the pavement during abrasion and weathering (Sansalone and Ma 2011), and irrigation with reclaimed wastewater. N and P are introduced to the aquatic environment in different chemical forms, but nominally partition between aqueous and PM phases (Compton, et al., 2000, Ma et al. 2010). In addition to a simple two-component partitioning between dissolved and particulate phases, N and P partition to and distribute across PM sizes transported in runoff (Kim et al. 2007). Knowledge of PM-based N and P and extractable loads is needed to evaluate source control, fate, treatment mechanisms and MS4 maintenance practices (Ma et al. 2010).

While low impact development practices (LID) at the parcel or catchment-level often are increasingly used for urban land uses (Sample et al. 2006) providing hydrologic restoration and therefore load reduction, structural unit operations (commonly known as Best Management Practices, BMPs) such as wet and dry basins, vaults, or manufactured systems such as hydrodynamic separators continue to be most commonly applied. Without frequent maintenance viable performance of such units for nutrient reduction is not sustainable. Even with frequent maintenance for many of these unit operations, the control of dissolved and suspended N and P has been much less effective compared to separation of coarser sediment-size PM-bound N and P through sedimentation mechanisms and physical filtration (Jenkins et al., 1971, Liu et al. 2010, Sansalone et al. 2010). During inter-event storage of PM, gross solids, and runoff in stormwater appurtenances and BMPs, coupled redox and pH changes occur. The speciation, partitioning and distribution of P are relatively stable as compared to N. Approximately one-third of P in source area runoff is dissolved and PM-based P typically ranges from 0.01 to 10 mg/g with the highest values for suspended and lowest for coarse sediment PM, noting that the predominance of the runoff PM mass is sediment-size or coarser. Source area N is approximately 40% dissolved and can be biologically-mediated under anaerobic redox conditions. The highest PM-based values are associated with suspended PM depending on the biogenic PM fraction (Berretta and Sansalone 2011). One of the major concerns with small footprint BMPs such as vaults, tanks and screened hydrodynamic separators is scour of PM and associated nutrients. Maintenance not only has the potential to provide load credits but irrespective of load credits will always result in the intended unit behavior.

BACKGROUND: A Florida-based MS4 Focus

Total Maximum Daily Loads (TMDL) and their associated allocations often are based on watershed-scale estimations or modeling evaluations of constituent loads, for example, N, P and PM. Providing an accurate and precise assessment of an anticipated load reduction from stormwater program activities and BMPs is a formidable task for an MS4. Because of the financial ramifications of meeting TMDL load reduction allocations, tools are needed to provide more scientifically accurate estimates of loads and load reductions by BMPs or source control practices. Additionally, an MS4 consisting of drainage systems, drainage appurtenances and BMPs will “inventory” a significant load of constituents. Within an MS4 this load distribution begins with source areas such as pavement and ends at the point of discharge to the receiving system.

Conceptually, a TMDL is easily understood. However, quantification of current stormwater loadings from an MS4 requires knowledge of the individual hydrologic functional units (HFU) that make up an MS4 system or a watershed. Individual HFUs in an MS4 include for example, a contiguous unit area of pavement that drains to the same catch basin or BMP within a given land use, a single catch basin or a relatively hydrologically-homogeneous landscaped area. Such HFUs are examples of the basic building blocks of an MS4 system or an urban watershed. These are a few HFU examples of the building blocks in an MS4 serving as pollutant sources and sinks and can represent components of an urban hydrologic model for pollutant load build-up/wash-off or transport/fate. In an MS4 or urban watershed these three HFUs illustrated are commonly interconnected hydrologically and hydraulically. For example, paved or landscaped source areas drain to catch basins which are hydraulically connected to BMPs. Such information provides important potential sources of constituent loading, beginning with traffic deposition and runon for impervious pavement, drainage appurtenances such as catch basins, and BMPs. While each HFU is a potential sink for constituents, each HFU is a potential source if not maintained. While on an individual HFU-basis the loads are small compared to a watershed-scale load, the number of these HFU of a specific type is very large for an MS4. As a result, most MS4s have potentially significant and non-stationary load inventories within these HFUs that require quantification and management (maintenance, cleaning, and recovery). The recovery of these materials is rarely (if ever) defensibly quantified to illustrate the potential load reduction that may be carried out expeditiously by an MS4 through maintenance practices. It is noted that at a larger scale nearly all TMDLs are based on calculation and not load measurement. Furthermore, in the absence of such load management, these HFU load sinks become potential acute and chronic constituent load sources in which constituents otherwise associated with a less mobile particulate phase are leached, becoming mobile soluble pollutant loads that most downstream BMPs are incapable of treating and retaining to a significant extent. While the focus of this report is nutrients and PM, toxics and emerging chemicals also require similar management and maintenance strategies.

The 2007 report submitted to the Florida Stormwater Association (FSA) by the University of Florida's Department of Environmental Engineering Sciences (UF-EES) entitled "Assessing the Environmental Benefits of Selected Source Control and Maintenance Practices for MS4 Permits", demonstrated that constituent (including metals) load inventory analysis as a function of pollutant, land use and HFU is potentially viable. The UF-EES report examined over 100 published studies from around the world on pollutant load inventories and provided a statistical evaluation of the results. Since most of these studies were not undertaken for the purpose of quantifying constituent load inventories (but did allow load inventories to be quantified) the methodologies were highly variable and in most studies there was very limited quality assurance and quality control. While the composite result statistical distributions from these previous studies provide current guidance and proof-of-concept, the distributions exhibited a much wider dispersion than if such studies were specific to Florida MS4s, as well as designed, implemented and analyzed using consistent and defensible methodologies. None the less, results of this ad-hoc study clearly pointed to development of a Florida-specific and Florida-based load assessment tool which has the potential to generate smaller statistical distributions.

Previous studies, whether nationally, regionally or MS4 specific, have not focused on a Florida-based examination of nutrients and the leachable (extractable) fractions of nutrients associated with PM that accumulate on urban surfaces (pavement) and is recovered by street cleaning, in drainage systems and appurtenances and in BMPs which are effective in separating coarse PM and associated nutrients. Also these previous studies were site- or MS4-specific in contrast to State-specific. While such studies are very important for the overall body of knowledge these studies do not provide Florida-based information and guidance beyond analogs to the site or specific conditions of the land use or BMP. Given the scope of these previous studies a tool, metric or yardstick to relate PM mass recovered by typical MS4 maintenance practices, to nutrient mass does not exist, in particular a Florida-based yardstick. Furthermore, such studies have not examined leach-ability of N and P from the recovered PM. This project generates information for Florida MS4s that is currently not available and is needed since MS4s are faced with quantifying load reductions in MS4 permits and Basin Management Action Plans (BMAP) to achieve TMDLs. In addition to a consistent sampling/analysis methodology the statistical (or probabilistic) analysis of results from Florida MS4 studies is the key component to any potential quantitative analysis of nutrient load reductions resulting from MS4 management/maintenance practices. However, the methods must be robust, representative and defensible. In order to obtain representative values of nutrient loading or reduction in this tabular loading framework (for example, P loadings in street sweepings from residential land use pavements) it is necessary for an MS4 to collect replicate samples. For example, samples obtained by the Florida MS4s in a particular category (for example, TP loading in street sweepings from residential land use pavements) will be sufficient in number so that statistics such as the mean, median, standard deviation, quartiles and range levels such as a 95th or 5th percentile level can be provided. The metric for these results is a non-parametric form (without relying on analysis based on a probabilistic distribution) as “box and whisker” plots or in many cases probabilistic distributions.

Based on previous results for recovery of urban residuals from BMPs and recovered urban PM inventories (Sansalone and Cristina 2004), results demonstrated relationships between dry mass of recovered PM and metal mass (Cd, Cu, Pb, Zn). In this study, PM mass is utilized as an economical index instead of the more appropriate (but less economical) granulometry measure of PM surface area. From these previous results, this study quantifies the relationship between dry mass of residuals and nutrients (Sansalone and Ma 2010, Ma et al. 2010, Sansalone et al. 2010). From analysis of these sets of Florida-based data an MS4 can convert dry mass of residual PM recovered to mass of nutrients recovered. As a result of the study, a Florida-based yardstick developed from this study will allow an MS4 to quantify N and P mass recovered from dry PM mass recovered without requiring N and P analysis for each maintenance operation undertaken by a MS4. Recognizing that the relationships between dried PM mass that is recovered to N or P mass has a distribution range there is a range of levels that load credits can be apportioned, for example at a quartile such as the 25th, 50th (median and in many cases the representative statistic or the resulting distributions), 75th, or at another chosen level.

METHODOLOGY

The detailed methodology was provided in the Quality Assurance Project Plan (QAPP) and the details are not repeated herein. The QAPP is a separate appendix from the report and contains detailed methods and analysis quality assurance. The nutrient path to runoff in a common urban HFU configuration is from source areas (in this study, pavement) to drainage appurtenance (in this study, catch basins), to drainage conveyance system, to a BMP (representative of the BMP commonly deployed and maintained by an MS4 in this study), with discharge to the stormwater system or receiving water. For perspective, Figure 1 illustrates major water bodies and networks around Florida. Potential recipients of nutrient loadings from the HFUs are both fresh and saltwater receiving waters down-gradient of stormwater system discharges. In Florida many primary receiving waters are proximate to the MS4s of this study. Hence, providing encouragement in the form of load credits for regular maintenance and cleaning practices will have a positive impact on HFU performance and beneficial impacts to receiving waters.

Figure 2 illustrates the distribution of major impervious areas across Florida including major roadways. Figure 2 indicates that high imperviousness and dense road network are attributes of urbanized MS4s. Many MS4s in this study are in areas with more than 30% imperviousness. Highly impervious areas generate increased runoff (altered rainfall-runoff relationships), PM, metals, nutrients and emerging chemicals ultimately resulting in the potential for such urban inventory to generate higher loads to receiving waters. While urban generation and transport of load is not solely or linearly a function of imperviousness, imperviousness is an index that can be tied directly to hydrologic and hydraulic modification as well as anthropogenic activities and design, resulting in increased loads. Hydrologic alterations drive load through altered characteristics of the hydrograph. Increased imperviousness has a demonstrable impact on the three primary attributes of a hydrograph: peak, volume and temporal attenuation.

The 14 MS4s are listed below and Figure 3 illustrates the distribution of the MS4s across Florida.

1. Gainesville (GNV)
2. Hillsborough County (HC)
3. Jacksonville (JAX)
4. Lee County (LC)
5. Miami-Dade County (MDC)
6. Orange County (OC)
7. Orlando (MCO)
8. Pensacola/Escambia County (PEC)
9. Sarasota County (SAC)
10. Seminole County (SEC)
11. St. Petersburg/Pinellas County (SPP)
12. Stuart (ST)
13. Tallahassee (TAL)
14. Tampa (TPH)

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Samples and Sample Number

Pursuant to the QAPP, each MS4 collected 27 PM-based samples that were pooled in a Florida-based analysis. Samples were collected from 3 different HFUs within 3 different land uses; highway (H), commercial (C) and residential (R). HFUs include street sweeping, catch basins and BMPs. The BMPs that each MS4 maintain most frequently are included in this study and their locations are reported in Table 1, Table 2 and Table 3. For each HFU in a land use, samples were collected from 3 different locations. Samples were collected from outside reclaimed water usage areas in all MS4s, but 3 MS4s (Gainesville, Tampa and Sarasota County) also collected samples from inside the reclaimed areas. These 3 MS4s collected 54 (27 out and 27 in) samples.

Cleaning and Decontamination

Pursuant to the QAPP, each MS4 was responsible for cleaning and providing all the sampling equipment. The sweepers required cleaning with potable water prior to sweeping the sampling area. Detailed cleaning process for the sampling equipment and the collection bottles is provided in the QAPP. Figure 4 and Figure 5 illustrates examples of the equipment cleaning process.

Sampling Methodology

Pursuant to the QAPP, sampling was performed using QAPP methods by each of the participating MS4s. Detailed information about the sampling method used for each location is provided in the field information submitted by the MS4s for each sample collected. A brief description of the variety of sampling equipment used is provided in the QAPP. Figure 6 shows an example of the sampling process. The sample containers had to be labeled in detail to provide clarity for storage purposes. The nomenclature provided in the QAPP was used to provide the sampling ID. Figure 7 shows an example of the sample container labels.

Sample Preservation and Handling

After collection, the samples were stored on ice until receipt at University of Florida. The samples were delivered to the laboratories at the University of Florida within the maximum holding time as stated in the QAPP. All wet or moist samples were immediately refrigerated. Details on preservation and delivery are provided in the QAPP.

Sample Field Information and Spatial Mapping

Each MS4 provided a detailed set of field information related to each collected sample. An example with all the required field information for a Jacksonville highway street-sweeping sample location is shown in Figure 9. Each MS4 provided information for the spatial location of samples, water bodies in the area, photos associated with the locations, and local and major roadways. Figure 10 is an example of Gainesville information for BMPs and catch basins (CBs).

Sample Analyses

Pursuant to the QAPP, all laboratory analyses were conducted by the University of Florida laboratories. The following analyses were performed for each PM-based sample: moisture content and volatile particulate matter fractions (VPM) and particle size distribution (PSD) for PM size indices. Triplicate sub-samples were generated from each sample and analyzed for total phosphorus (TP) and extractable P (as an aqueous phase concentration), total Kjeldahl nitrogen (TKN), nitrate-nitrogen (NO_3^{-1}-N) and total ammonia nitrogen (TAN). Extractable N was also an aqueous phase concentration and the extractable values represent the only aqueous phase nutrient results in this study. The TKN represents the sum of organic-nitrogen, ammonia (NH_3) and ammonium (NH_4^{1+}). Total nitrogen (TN) values were calculated by summing the nitrate-nitrite to the TKN. Along with sampling and field information requirements the project methods can be found in the QAPP. Detailed descriptions of the QA/QC are reported in the QAPP. The measurement parameters and quality assurance objectives for the project are reported in Table 4.

RESULTS

PM-based N and P results are presented through probability density function distributions (pdf) expressing the probability of occurrence for N or P (in this study as PM-based concentrations, mg per dry kg of PM) similar to studies of other urban constituents (Maestre and Pitt 2005). Results predominately illustrate lognormal distributions for TN and TP. The lognormal distribution of the results indicates that the representative statistic is the median (the 50th percentile). However, results are also summarized through box plots which provide non-parametric statistics for the median, upper (75th) and lower (25th) quartiles and minimum and maximum values. Given the predominance of the lognormal distributions ($\alpha = 0.05$), results are predominately compared based on the median of the distributions.

Phosphorus (P)

P results expressed in [mg of TP/kg of PM] for the 14 MS4s for all land uses and all HFU locations outside (OUT) areas treated with reclaimed wastewater are shown in Figure 11. The discrete histograms synthesize measured results and the curves represent the lognormal distribution continuous model of the results. The median value is 374 mg of TP/kg of PM.

P results (as TP) as a function of HFUs for all land uses lumped together are compared in Figure 12. The distributions as well as the box plots illustrates that the highest median concentrations are associated with samples collected in the catch basins. The median values [mg/kg] for catch basins is 417 followed by BMPs at 364 and street sweepings at 361.

P results (as TP) as a function of land use for all HFUs lumped together are compared in Figure 13. The distributions as well as the box plots illustrate that the highest median concentrations are associated with highway land use. The median values [mg/kg] for highway land use is 388 followed by residential at 380 and commercial at 331.

In order to compare the P concentration values from different HFUs collected in the areas characterized by the same land use, the box plot representation of Figure 14 was created. The red lines represent the range of median values among the three different HFUs. The corresponding mean and median values are reported in Table 5. The highest median values correspond to highway CBs, highway BMPs, residential CBs. With respect to street sweeping, no appreciable difference is observed for these results when comparing different land uses for TP [mg/kg]. The existing body of scientific knowledge provides abundant evidence that managing urban PM and detritus to avoid contact of this material with rainfall, with runoff or stored within BMPs or urban conveyance appurtenances (for example, catch basins) results in lower runoff concentrations. For example, Ying and Sansalone (2008) illustrated these phenomena for urban PM and detritus in a highway land use. They demonstrated that common water chemistry indices in actual runoff were largely generated from such PM/detritus that was not managed (recovered from the urban surface) and contacted by rainfall or runoff, or transported and then stored under wet conditions in a BMP for 24 hours. From the results of Ying and Sansalone (2008) and from the results of this study a critical conclusion is that efforts to maintain and clean urban pavement and drainage systems on a regular basis can have a significantly greater economic, environmental and ecological benefit than myriads of disconnected and isolated structural BMPs that are expensive, can have a propensity to scour and that cannot possibly be managed effectively in a Florida MS4. In this current study and in many urban conditions, highways and parking areas that are landscaped and vegetated delivers biogenic material to the impervious areas. This does not mitigate the benefits of landscaping, but indicates that the challenge is integrated design for all components of civil and urban design. For example, the use of depressed vegetated islands accepting pavement flow and combined with concrete permeable pavement can provide quantifiable nutrient and also PM load reduction that is statistically significant as compared to civil design that utilized raised vegetated islands that drain to impervious asphalt pavement served by conventional drainage conveyance systems. Studies have also demonstrated that depending on the pavement mix design and waste-additives, P from highway runoff can be due to the phospho-gypsum admixture in the pavements eroded by vehicular traffic (Berretta and Sansalone, 2011).

In contrast to the results just presented for land uses and HFUs from outside the reclaimed areas, Figure 15 contrasts P distributions (as TP) between inside (IN) and outside (OUT) reclaimed wastewater areas for the three MS4s (GNV, TPH, SAC) from which paired IN and OUT samples were examined. Results indicate that the median P concentration (as TP) combining all land uses and HFUs inside the reclaimed areas [520 mg/kg] is slightly higher than the same combination for outside the reclaimed areas [500 mg/kg].

While N distributes between the PM-bound, the aqueous and the volatile fraction, P is mainly bound to urban PM and generally a smaller fraction in the order of 30% of the mass is in the dissolved phase (Berretta and Sansalone, 2011). PM-bound P can leach or re-partition to the aqueous phase (runoff) under anaerobic conditions, conditions that readily occur in an unmaintained BMP that stores PM and runoff. Therefore this study quantified the leachable fraction of P (extractable P) and the PM-bound TP. PM constitutes a reservoir of pollutants in addition to nutrients, such as metals, that can be released in the aqueous environment under reducing conditions. The comparison between PM-based TP and extractable P concentrations is shown in Figure 16. The TP concentrations are one order of magnitude higher that the extractable P mean values of 374 and 19 mg of TP/kg of PM, respectively.

Nitrogen (N)

N loads are commonly considered in terms of aqueous species either in rainfall or runoff. However urban source areas such as the HFUs of this study can generate total nitrogen (TN) in runoff that is predominately PM-bound. N results expressed in [mg of TN/kg of PM] for the 14 MS4s for all land uses and all HFU locations outside (OUT) areas treated with reclaimed wastewater are shown in Figure 17. The median value is 701 mg of TN/kg of PM.

N results (as TN) as a function of HFUs for all land uses lumped together are compared in Figure 18. The distributions as well as the box plots illustrates that the highest median concentrations are associated with samples collected in the BMPs. The median values [mg/kg] for BMPs is 899 followed by CBs at 679 and street sweepings at 563. N results (as TN) as a function of land use for all HFUs lumped together are compared in Figure 19. The distributions as well as the box plots illustrate that the highest median concentrations are associated with residential land use, potentially as a result of landscape fertilization practices. The median values [mg/kg] for residential land use is 908 followed by highway at 710 and commercial at 506. In order to compare the N concentration values from different HFUs collected in the areas characterized by the same land use, the box plot representation of Figure 20 was created. The red lines represent the range of median values among the three different HFUs. The corresponding mean and median values are reported in Table 6. The highest median values correspond to highway BMPs, highway catch basins and residential street sweepings. Differently from the results just presented for land uses and HFUs from outside the reclaimed areas, Figure 21 contrasts N distributions (as TN) between inside (IN) and outside (OUT) reclaimed wastewater areas for the three MS4s (GNV, TPH, SAC) from which paired IN and OUT samples were examined. Results indicate that the median N concentration (as TN) combining all land uses and HFUs inside the reclaimed areas [711 mg/kg] is higher than the same combination for outside the reclaimed areas [552 mg/kg]. The median values of the TP and TN concentrations per each MS4 are reported in Table 7 at the request of FSA. These values were not a function of specific land use or HFUs. While these values provide a singular number for each MS4 their use is not reflective of the design or purpose of this study. Table 7 does not provide a statistical basis for comparing MS4s.

Volatile Fraction

The volatile fraction of the samples collected is an index for the biogenic (organic) fraction of the PM residuals. These results are summarized in Figure 22. In this figure, box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values of the volatile fraction across the whole monitoring program, for different HFUs and within areas characterized by different land uses are reported. Biogenic material mean and median value are respectively 10.7% and 5.4% of the total PM recovered. No significant difference is observed by HFUs, while samples from residential land use show the highest median value as expected. Results indicate that the recovered material is largely inorganic, consistent with sand and gravel-size material, which was confirmed by particle size analysis.

Geospatial and Statistical Analyses of Phosphorus and Nitrogen

GIS is a tool used to represent analysis results spatially. To provide further analysis to the visual nature of the spatial analysis, a statistical analysis was performed. The Kruskal-Wallis multiple comparison test ($\alpha = 0.05$) was performed on the regions followed by the Dunn's test for pair-wise comparison ($\alpha = 0.05$). For the purpose of the statistical analysis, the MS4s were divided into 6 regions, namely, Panhandle West, Panhandle East, North Central, Peninsula, West Central and South. These were based on the divisions provided by the EPA in their Numerical Nutrient

Criteria (NNC) supporting documentation. The 14 MS4s participating in the project are spread across the State of Florida as shown in Figure 3. Pensacola/Escambia county lies in Panhandle West, Tallahassee lies in Panhandle East, Jacksonville, Gainesville, Orlando, Orange county Seminole county, St. Petersburg/Pinellas county, Tampa, Stuart and Lee County lie in the Peninsula, Hillsborough county and Sarasota County are located in West Central and Miami-Dade county lies in the South. Geospatial maps can help interpret whether there are any spatial state-wide trends for nutrient loadings analyzed from the samples collected at these 14 places. These GIS results can also help establish trends, if any, to compare nutrient loads between locations inside and outside the reclaimed water usage areas.

Figure 23, Figure 24 and Figure 25 show the TN distribution across the State of Florida for highway, commercial and residential land use respectively. It is observed for the highway land use that the Florida Panhandle and the MS4s in South Florida show higher TN measurements than Central Florida. For commercial land use, higher values are observed in South Florida. Seminole and Sarasota counties also exhibit higher TN values than the rest of the MS4s. In Figure 25 it is observed that for residential land use the values of TN seem higher across the state than the other two land use. This may be attributed to the generally higher tree population and activities like use of fertilizers for gardening and regular grass clipping usually occurring with greater frequency in residential areas as compared to commercial and highway. Over all the three land uses it is observed that the cities of Orlando and Tampa show consistently higher values than the counties in which they are located. Given the density and diversity of anthropogenic and biogenic activity within largely impervious areas such a result is expected. This shows the effect of greater urbanization on nutrient transport. It is also observed that the city of Stuart and Miami-Dade County situated in South-Florida show higher TN values for all three land uses. In the statistical analysis performed, only residential land use showed a statistically significant difference ($\alpha = 0.05$) among the groups, potentially due to fertilizer use or overuse.

Figure 26, Figure 27 and Figure 28 show the state-wide distribution of TP for highway, commercial and residential land use respectively. It is observed that the southern counties of Sarasota, Lee and Miami-Dade show consistently high P numbers for each of the 3 land uses. Major cities of Tallahassee, Orlando and Tampa also show medium to high P content in their PM for all 3 land uses. In general across the state, highway and residential land use P values are somewhat higher than the values for commercial land use. This may be attributed to the somewhat lower tree coverage found in commercial areas. As observed for TN, the cities of Tampa and Orlando similarly show higher TP numbers than the counties they are situated in. It is seen that Escambia County consistently shows low TP values for the 3 land uses. The statistical analysis showed a statistically significant difference among the groups for all 3 land uses.

Figure 29, Figure 30 and Figure 31 show the spatial distribution of TN for street-sweepings, BMPs and CBs respectively. Figure 32, Figure 33 and Figure 34 show the spatial distribution of TP for street-sweepings, BMPs and CBs respectively. CBs are expected to retain lower volumes of PM, since they are at the beginning of the flow-train, runoff passes through CBs mostly unrestricted and CBs in the USA are designed to be self-cleaning since most drain to storm sewer systems and not combined sewers. High flows displace the PM from the CBs and transport PM to BMPs. The lower values in Figure 31 and Figure 34 for most of the MS4s support the aforementioned phenomenon. In theory (but not necessarily reality) it is the function of BMPs to trap PM as flow passes through a BMP. It is observed in Figure 30 and Figure 33 that BMPs in most MS4s display very high TN and TP loads. In particular it is observed that Lee County and Seminole County has very high TN content in its BMPs. Street-sweeping loads are dependent on factors like previous dry hours, efficiency of sweeping equipment and the frequency of sweeping. Cities of Gainesville, Stuart, Tallahassee and Jacksonville display higher nutrient loads in their street-sweeping samples as compared to CBs and BMPs. For TN, the statistical analysis showed a significant difference only for the CB, whereas for TP, all the 3 HFUs showed statistically significant difference.

Reclaimed water application for irrigating medians and swales along roadways is prevalent across the state of Florida, to a larger degree than any state in the USA. Depending on the level of wastewater treatment, reclaimed water can contain high nutrient concentrations which can increase the TN and TP loads associated with the PM in the HFUs. Figure 35 and Figure 36 show the comparison of TN and TP values respectively; between samples collected inside (IN) and outside (OUT) the reclaimed water usage areas. The bar plots display median values, and both the median and mean values are provided. With only three MS4s participating, the median values plotted do not show any consistent trend to clearly portray the effect of reclaimed water usage on TN content. Tampa does display a higher median value for IN samples as compared to OUT samples, though for Gainesville this difference is less. Sarasota County displays the opposite trend with OUT samples having higher TN content than IN samples, though the difference is small. For TP, Gainesville and Tampa display higher median values for samples in reclaimed as compared to outside reclaimed areas. Sarasota County again shows an opposite trend, with an OUT median value higher than IN values. It is observed that in some cases, means are markedly higher than median values. There are specific locations that contain considerably higher nutrient content than others. Given last-minute Sarasota sampling conditions as the last MS4 samples to arrive, there is quality assurance sampling unknowns for Sarasota.

The effect of reclaimed water also depends on the effectiveness of the tertiary treatment provided at the Publicly Owned Treatment Works (POTW) prior to reuse along with other factors. Though variable and muted in some cases, the effect of reclaimed water application on nutrient loading cannot can be observed given that effluent TN and TP from POTWs to the reclaimed system are typically on the order of 2 to 10 mg/L without advanced nutrient treatment**.** This study was not primarily designed to study how a POTW’s reclaimed water influences TP and TN loads to their respective discharge areas, but simply to observe the likely impacts of reclaimed water usage on PM-based nutrient loads in comparison to loads from areas without reclaimed water usage.

ILLUSTRATION OF PM-ASSOCIATED NUTRIENT RECOVERY COSTS

Costs of PM and PM-associated nutrient ***recovery*** through the non-structural maintenance practices of (1) street sweeping (pavement cleaning by sweeping, vacuum or washing) or (2) catch basin cleaning are illustrated. These costs are compared to structural practices (BMP) costs for PM and PM-associated nutrients which require a BMP (or BMPs) first for ***separation*** followed by ***recovery*** (BMP maintenance). Results use Florida-based values independent of land use from Table 8 (mg of nutrient/kg of PM) or with land use information could use Table 5 and 6.

Load Recovery and Cost Method for Street Sweeping:

Of the 14 MS4s participating in this study 10 MS4s have provided 67 discrete values of the amount of PM swept in regular cleaning procedures. These values were provided as masses of PM per mile swept or volume of PM per mile swept. A bulk density of approximately 1.5 g/cm^3 was used to convert volumetric data to gravimetric data. Results ranged from 40.8 to 1130 kg of PM/mile swept. These 67 values resulted in a median and mean of 147 and 268 kg PM/mile swept. These results are summarized non-parametrically in Figure 37; with no assumption of an underlying probability distribution. These values were collected and provided by the MS4s.

No attempt has been made to independently validate these values but the very wide range of values suggests inaccuracies associated with the lower and upper end of the tabulated range. However this study accepted the values provided by the MS4s without having direct knowledge of any inaccuracies associated with the values provided. Furthermore, this study makes a strong recommendation that for credits there must be documented validation and verification by an MS4 for dry-equivalent PM load recovery per spatial dimension (for example, lane-mile or area swept) per inter-cleaning frequency (time interval between sweeping). Based on the strong engineering and scientific credentials of the MS4s that participated in this study this dry load accounting can be easily developed by each MS4. Given the metrics provided in this report and this example, there is no need for additional spreadsheets or tabular methods. While the methods for calculating PM, N (as TN) and P (as TP) load recovery is now possible without additional tools, what is required for future credits is MS4 validation and verification documentation.

Quantitative results of this study can be utilized as a metric or yardstick by which a mass of N or P can be directly determined from the dry-equivalent of PM recovered from street sweeping. Similar metrics will also be presented later in this example for catch basins and BMPs. For example, on a Florida-basis irrespective of land use, from Table 8 for P (as TP) the median and mean concentrations are 361 and 513 mg of TP/kg of PM, respectively from the Florida-based distribution of street sweeping results. With respect to TN from Table 8, (again, combining all land uses for all MS4s), the median and mean are 563 and 1012 mg of TN/kg of PM, respectively from the Florida-based distribution of street sweeping results. In this example median values are used. By multiplying the dry-equivalent kg of PM per mile swept by TP and TN as [mg/kg], nutrient mass recovered per mile swept is obtained. An MS4 must determine moisture content (by measurement) of street sweepings and subtract this moisture mass in order to also report and utilize a dry-equivalent mass of PM. Even PM recovered from pavements in the dry season that appear dry contain moisture in equilibrium with the atmosphere. Reporting PM moisture mass is required along with reporting of PM on a dry mass basis.

Utilizing the median metrics combined with median PM recovery from sweeping one mile of pavement, 147 kg PM/mile swept, 0.12 lb TP and 0.18 lb TN are recovered, thereby eliminating this mass as a potential nutrient load in runoff. **In this example the number of pavement miles that need to be swept (cleaned) to recover 1 pound of TP and TN, are respectively 8.5 and 5.5 miles given the use of Table 8 that is Florida-based but independent of land use.** The cost of street sweeping in Table 9 (Table S2) is obtained by multiplying the unit cost of street sweeping by the number of miles that need to be swept to recover 1 pound of TP and TN.

The cost associated with street cleaning varies depending on many factors including equipment type. These units have differing purchase costs, lifetime, operation and maintenance. In addition the cleaning frequency influences the costs (Finley, 1996; SWRPC, 1991; Satterfield, 1996; USEPA, 1999). An early published cost for street cleaning was $68 per curb mile and approximately 11 curb miles per day on average were swept (Ferguson et al., 1997). In another example, the City of Livonia, Michigan (2001) study reported a street sweeping cost per curb-mile of $76.90, based upon 1998-99 dollars, sweeping of 3 to 7 times per year using broom and regenerative-air sweepers. The City of Jackson, Michigan (Sutherland and Jelen, 2003) reported a cost of $140 per curb-mile, based upon 2000 dollars, mechanical sweepers and a frequency of four times per year. The City of Urbandale, Iowa spent $122 per curb-mile based upon a frequency of three times per year (2001-2002 dollars) and mechanical broom sweeper.

In this study the cost of street sweeping is based on utilizing a street sweeping contractor, a common practice in Florida. Equipment cost as well as the operation and maintenance thereof are borne by the contractor and therefore reflected in the contract cost between the street sweeping contractor and the MS4. A cost of $30.14 per mile was contracted between Florida Department of Transportation (FDOT) and a street sweeping firm as reported in a City Commission Report of 9 January 2011 for the City of Oakland Park, Florida. This cost ($30.14/mile) is used in these calculations. Examples of additional street sweeping contract prices the City of Stuart, St. Petersburg and Gainesville provided; $23.60, $28.30 and $17.20 respectively. Although this example is based on a contracted cost for street sweeping, costs can also be examined based on MS4 ownership of operations and street sweeping equipment.

Load Recovery and Cost Method for Catch Basins:

In the USA catch basins are most commonly designed to be self-cleaning although the participating MS4s will readily acknowledge that despite the design intent that catch basins must be cleaned occasionally as part of any maintenance program. In this study a catch basin can be a curb inlet, an area catch basin, a pavement catch basin; all of these are appurtenances that allow surface flows to be collected and conveyed to a pipe sewer or drainage conveyance.

From the basis of American urban drainage practice the catch basin serves a drainage and conveyance function, and by American practice a catch basin is designed to be self-cleaning and a catch basin does not provide a treatment function by design. No Florida MS4 ever installs a catch basin for treatment; catch basins are designed to be self-cleaning. The flip-side to this is, for example, Italian practice where catch basins are not self-cleaning (designed to protect the sewers, not vent sewer gases and protect WWTPs) and there can be 1 catch basin per every 5 to 10 people in an MS4. The Italians have found that the cost of cleaning (including vector control) tens of thousands of catch basins annually in an MS4 is simply not sustainable but their systems were designed to provide treatment (separation of PM) and be cleaned. Capture of PM by an American catch basin is a real-life artifact and as a result, capture and recovery is an O&M requirement for catch basins that MS4s do not relish, yet unlike appurtenance called "BMPs", a catch basin is not designed or intended to provide treatment of PM. If catch basins were designed for PM separation and recovery then Florida MS4s would not need self-cleaning storm sewers; which are not always self-cleaning. Therefore the capital cost of a catch basin is not included in this cost evaluation given that the intent, design and functionality of a catch basin in the USA are drainage and conveyance, not treatment. The cost of maintenance is included.

With respect to catch basin cleaning, this example assumes that there is 100 lbs of PM recovery per each catch basin cleaned. Depending on the MS4 and specific catch basin location a typical range of PM recovery is 50 to 100 lbs of PM at a cleaning frequency of once annually. It is noted that while the drainage area is not required in this example for catch basin cleaning, the BMP drainage area of 2000 m^2 in the next section of this example is also hydraulically applicable for a set of double-length curb and gutter inlets (catch basins) in order to translate results to a runoff volume basis. With the proper unit conversions (for example lbs to kg) and multiplying the resulting value by the concentration of TP and TN in Table 8 the nutrient load recovered based on 100 lbs of PM recovered (this example) can be determined. Specifically, the median TP concentration for a catch basin is 417 mg of TP/kg of PM and for TN is 679 mg of TN/kg of PM. The resulting calculations produce a value of 0.04 lb TP and 0.07 lb TN recovery per catch basin per 100 lb of PM recovered. **In this example the number of catch basins needed to recover 1.0 pound of TP and TN are 24.0 and 14.7, respectively given the use of Table 8 that is Florida-based but independent of land use**. The costs in Table 9 with respect to catch basins cleaning are obtained then by multiplying the CB cleaning costs by the number of catch basins needed to recover 1.0 pound of TP and TN.

With respect to CB cleaning costs, the cost used in these calculations is $69 per catch basin. This cost is based on a crew of three operators cleaning for 16 basins per day and the use of a truck. The number of catch basin per day reflects the 2010 maintenance activities provided by St. Petersburg. The truck cost is $200 per day, and the labor is $300 per day per operator (which includes benefits). These costs do not include solid waste landfill disposal (on the order of $80 to $95/ton). Unlike street sweeping where a number of MS4s in this study contract street sweeping to an outside contractor, catch basin maintenance is largely facilitated by MS4 employees and equipment. While costs can vary these costs were obtained from Florida MS4s.

Load Recovery and Cost Method for BMPs:

As appropriate for the constitutive properties of urban drainage, the vast majority of structural BMPs that have been utilized, are utilized and will be utilized are PM-based separation unit operations, whether by intention or otherwise. While the term "BMP" or best management practice is utilized in this report, the use of BMP is only utilized nominally and this term should be abandoned in favor of the conventional mechanistic nomenclature that utilizes unit operation (a physical phenomenon), unit process (a chemical or biological phenomenon) or combinations thereof (Sansalone, 2005). While the majority of BMPs in urban areas of Florida are volumetric; basins, tanks, vaults and ponds there are also many proprietary manufactured BMPs that are not volumetric and function for temporary coarse PM separation. One of the most common is the "hydrodynamic separator" (HS) which like a basin is a gravitational settling device for PM but with a much smaller footprint. In urban areas the smaller footprint or area of a BMP such as a HS is a critical attribute for any treatment appurtenance that is on- or off-line from the drainage system. However, this smaller footprint also provides only coarse PM separation and results in very high flow intensity through the BMP that can generate the "Achilles Heel" of such BMPs which is scour and washout without frequent maintenance. Such BMPs are now common across the USA and are utilized in Florida. There are many forms and types of such structural BMPs, and even many forms of HS. This examples utilizes a common screened HS and monitored data for the performance of a screened HS subject to actual storm events (Kim and Sansalone, 2008; Sansalone and Ying, 2008; Sansalone and Pathapati, 2009; Dickenson and Sansalone, 2009). With respect to costs, a baffled HS is also tabulated for comparison.

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The BMP costs in this example are obtained by assuming a drained urban area of 2000 m^2, treatment by a screened HS at an annual removal efficiency of 50% for PM, a yearly rainfall depth of 1270 mm (Gainesville historical data series from NOAA-National Oceanic and Atmospheric Administration), and rainfall-runoff data from 22 rainfall-runoff monitored events for a Gainesville urban source area (76% asphalt surface parking and 24% raised vegetated islands) and a total PM concentration of 400 mg/L which includes the entire gradation of PM, not just suspended PM (Berretta and Sansalone, 2011a; Berretta and Sansalone 2011b). Through these data a yearly runoff volume drained in the BMP of 1,422 m^3, that is multiplied by the PM concentration and considering the removal efficiency of the screened HS, results in 627 lb of PM (284 Kg) separated by the BMP. It is noted that scour and washout from the screened HS is not accounted for in this example and would result in a much lower mass of PM separated based on a once per year cleaning frequency. By recovering this mass of PM it is possible to calculate through the values in Table 8 (as BMP), the associated TP and TN mass. In particular these values are 363.9 mg TP/kg of PM and 898.5 mg TN/kg of PM. By multiplying these values by the PM recovered in the BMP results yield 0.23 lb TP and 0.56 lb TN separated for one BMP in one year. **To recover 1.0 lb of TP and TN it is necessary to purchase and maintain 4.4**

screened HS units and 1.8 screened HS units, respectively on an annual basis while assuming no washout and scour of PM and given the use of Table 8 that is Florida-based but independent of land use. The values in Table 9 are obtained by multiplying these numbers to the yearly cost of one BMP, in this case a screened HS for a 2000 m^2 drainage area. An entry in Table 9 is also provided for a baffled HS unit based on the use of the same 2000 m^2 drainage area and data utilized for the screened HS. The differences between the same hydraulic capacity units is that the baffled HS isolates the separated PM from the flow in a deep sump of the full footprint of the baffled HS and extends the maintenance period for PM based on the isolation of separated PM depth. However, the deterioration of water chemistry within days is the same for both types of HS units. The total capital and installation costs for either of these units are within 15%. The example results will indicate that while a vendor will accentuate cost differences or unit performance differences which are also within 15% ignoring washout and scour, that such a differences have a negligible impact on the conclusion drawn from Table 9.

The recommended period between maintenance activities (cleaning) of a BMP should be one year and preferably in terms of months due to biological and chemical processes occurring inside the BMPs between storm events. During storm events, BMPs such as screened HS are prone to scour. These processes influence BMP treatment. For example, re-partitioning of pollutants from PM to the dissolved form can occur with subsequent washout, thus eliminating the benefit of a BMP such as a screened HS that function as preliminary unit operations to separate PM and the pollutants bound to coarse PM and detritus. Such water chemistry changes have been shown to occur in BMPs in a period of one to two days after a runoff event (Sansalone et al., 2010). Differently than for street sweeping and catch basin cleaning, the BMP costs include the capital cost and the cost of maintenance. For the drainage area of this example for Florida hydrology the capital and installation cost of either HS unit is approximately $25,000 (ranging between $20,000 and $30,000), an interest rate of 4%, 25 years design life that results in a yearly cost of $1,600. This cost is calculated by using the following expression for the Uniform Series Capital Recovery Factor (Collier and Glagola, Addison-Wesley, 1998).

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

n = years
i = interest rate
A = periodic payment
P = total initial cost
The maintenance cost is $500 per year consisting of once a year cleaning activity for the screened HS. A total cost of $2,100 per year is used in Table 9.

The range in the brackets expresses two opposite cases for two classes of HS units, in which the interest rate varies from 0 to 6%, the initial capital cost varies from $20,000 to $30,000, the PM removal efficiency ranges from 90% to 20%, and the maintenance frequency ranges between once a year to twice a year for the catchment area and Florida climate given in this example.

Based on this information and resulting calculations, Table 9 summarizes the costs for PM and nutrients control through structural and non-structural solutions. The treatment train in Table 9 represents a conventional re-inforced concrete primary clarifier followed by a high rate sand filter and backwash. It is noted that sand filters cannot remove soluble or suspended TP or soluble or suspended TN as compared to the physical separation of PM by the sand filter. This example also illustrates two classes of HS units, a screened HS prone to scour and a baffled HS designed to isolate separated PM from flow intensity in the unit. Hydrodynamic separators are prone to changing water chemistry in their sumps and without frequent maintenance the PM and stored runoff in the sump can go anaerobic with 48 hours or less. This should not be a surprise given the nutrient and carbon enrichment of unmaintained BMP sumps, stagnant storage of runoff, warm Florida temperatures, high surface area of PM captured in BMP sumps and a hospitable habitat for biological diversity from micro-organisms to reptiles (both of which were readily observed, or measured in BMPs in Gainesville). The other BMP category represents larger BMPs from a Florida-based TMDL study, primarily basins or ponds. While a sensitivity analysis can be conducted for each parameter utilized for Table 9, results indicate that the lowest costs to recover TN and TP mass are very clearly associated with maintenance practices and in particular with street sweeping and catch basin cleaning, as compared to the use of structural BMPs even at very high levels of BMP separation performance and very low BMP costs.

IMPLEMENTATION EXAMPLES

This section illustrates the use of the results of this study. This study provides concentrations of nutrients per kg of PM recovered which is the required metric to quantify recovery of nutrients along with the dry mass of PM recovered through street sweeping, catch basin cleaning or BMP maintenance. Two examples are provided. The first example calculates nutrient recovery from measured dry PM recovered. In contrast, the second example illustrates maintenance activities planning to recover a fixed amount of nutrients. In particular, the median values in Table 5 (Table S 1 in the Executive Summary) are illustrated for example 1, while median values from Table 8 are utilized for example 2. The choice of these tables depends on knowledge of land use.

Example 1

The following example shows the procedure to calculate nutrients and in particular TP, removed by street sweeping in a residential area (therefore this is for a specific land use and requires the residential metrics in Table 5 for TP or from Table S 1 :

1) Measure the PM mass removed through sweeping and convert to a dry weight based on measurement of moisture content. As an example PM mass recovered by street sweeping by an MS4 is used. The value for residential areas is 468 kg of PM/mile swept.

2) Calculate the TP associated to the PM recovered by using the median value in Table 5 (or Table S1) of this report corresponding to Street Sweeping and Residential land use that is 374.9 mg TP/kg of PM. By multiplying this value by the PM recovered the value obtained is 175453.2 mg TP/mile swept. Converting with a factor of kg/mg 10^{-6} and multiplying by the conversion factor lb/kg 2.2046 results a value of 0.4 lb TP/mile swept.

The greater the PM mass recovered by a maintenance practice such as street sweeping (cleaning), the higher is the associated TP and TN recovered. PM removal can be improved by using more efficient sweepers, like vacuum-assisted systems, and by optimizing the frequency/routing of street sweeping practices. Not only can the frequency increase, but optimizing sweeping schedule based on rain events and seasonal conditions (wet vs. dry), can improve the recovery efficiency. The same calculations can be performed for catch basin or BMP maintenance.

Example 2

The following illustrate load recovery planning with maintenance practices necessary to recover a fixed amount of nutrients, for example 1 Kg of TP and TN. While Florida-based Table 8 is used in these examples, Table 5 or 6 can be used as a function of land use or HFU.

Load Recovery Planning with Street Cleaning. In order to recover 1 Kg of TP it is necessary to sweep 19 miles, while 1kg of TN is recovered in 12 miles swept. From the concentrations in Table 8 regarding street sweeping it is possible to calculate the mass of PM necessary to recover 1 Kg of nutrients. For example for TP, by multiplying 361 mg of TP/ Kg of PM by the conversion factor kg/mg 10^{-6} it is obtained a value in Kg of TP/Kg of PM. To obtain the mass of PM necessary to recover 1 Kg of TP, 1 Kg TP has to be divided by the value in Kg of TP/Kg of PM. It results 2770 Kg of PM. At this point, by knowing that 147 Kg of PM are recovered in 1 mile swept (as reported at the beginning of this paragraph) by dividing the mass of PM by 147 Kg PM/mile swept it results 18.8 miles. The same procedure can be used for TN recovery.

Load Recovery Planning with Catch Basin Cleaning. Assuming 100 lb PM recovery per catch basins, in order to recover 1 kg TP it is necessary to clean 53 catch basins and 33 for 1 Kg TN recovery. From the concentrations in Table 8 regarding catch basins it is possible to calculate the mass of PM necessary to recover 1 Kg of nutrients. For example for TP, by multiplying 416.8 mg of TP/ Kg of PM by the conversion factor kg/mg 10^{-6} it is obtained a value in Kg of TP/Kg of PM. To obtain the mass of PM necessary to recover 1 Kg of TP, 1 Kg TP has to be divided by the value in Kg of TP/Kg of PM. It results 2399 Kg of PM. It is assumed 45.4 Kg PM recovery per catch basins and dividing 2399 Kg of PM by 45.4 Kg PM/catch basin, it results 53 catch basins that need to be cleaned. The same procedure is used for TN.

Load Recovery Planning with BMP Cleaning. As for BMP maintenance, 1kg of TP is recovered by maintaining 10 BMPs and 1 Kg of TN is recovered by maintaining 4 BMPs. The BMP results are based on an urban area of 2000 m^2, a screened HS as a BMP with 50% removal efficiency. The data and assumptions previously described for the calculation of the cost for a HS are utilized. For this case a value of 284 kg of PM per single screened HS is obtained based on an annual loading and cleaning period, again assuming that there is no scour and washout of PM. From the concentrations in Table 8 regarding the BMP it is possible to calculate the mass of PM necessary to recover 1 Kg of nutrients. For example for TP, by multiplying 363.9 mg of TP/ Kg of PM by the conversion factor kg/mg 10^{-6} it is obtained a value in Kg of TP/Kg of PM. To obtain the mass of PM necessary to recover 1 Kg of TP, 1 Kg TP has to be divided by the value in Kg of TP/Kg of PM. This calculation results in 2748 Kg of PM. By dividing this value by 284 Kg PM/ BMP, 10 BMPs are required to separate PM and then recover PM.

CONCLUSIONS: Florida-based Metrics of Maintenance Practices

Maintenance matters. To demonstrate this statement, this study created a Florida-based set of metrics based on triplicate sampling as a function of land use (residential, commercial and highway) and the common urban hydrologic functional units (HFUs) that collect particulate matter and detritus (pavements - street sweeping, catch basins and best management practices) across 14 MS4s in Florida. Across Florida, 459 samples were collected and analyzed to create this set of Florida-based metrics to provide nutrient load credits for maintenance. For a given land use or HFU this Florida-based metric equates the equivalent dry load of particulate matter (PM) and urban detritus recovered by maintenance to the TN and TP load recovered from this PM and detritus. Recognizing the inherent variability of the results across 14 MS4s even as a function of HFU and land use, results were consistently represented by a log-normal distribution and as a result the median of the distribution was used in the set of Florida-based metrics. The essence of this study is reproduced in the following table of Florida-based metrics that relate equivalent dry mass recovered to mass of TN and TP as a function of land use and HFU.

Table C 1 Florida-based TP and TN values for PM recovered as a function of HFU and land use.

TP [mg/kg]	Street Sweeping (SS)			Catch Basin (CB)			BMP		
	Mean	Median	St. Dev.	Mean	Median	St. Dev.	Mean	Median	St. Dev.
C	482.6	381.2	476.9	530.9	300.8	524.9	474.6	295.7	412.6
R	425.8	374.9	284.7	559.2	423.4	543.0	702.8	382.7	670.5
H	622.0	349.7	778.5	566.6	536.9	363.3	759.4	513.7	972.1
TN [mg/kg]	Street Sweeping (SS)			Catch Basin (CB)			BMP		
	Mean	Median	St. Dev.	Mean	Median	St. Dev.	Mean	Median	St. Dev.
C	789.1	429.6	944.2	1459.7	467.2	2237.8	1999.0	602.1	3104.1
R	1439.0	832.4	2169.9	1803.9	773.8	2955.8	3587.7	1169.0	4991.9
H	826.6	546.4	654.8	1926.3	785.4	2587.8	2342.4	939.2	3496.6

Furthermore, the study illustrates through 3 MS4s, Gainesville, Sarasota and Tampa that urban land use and HFUs subject to reclaimed wastewater will have PM and urban detritus enriched with P and N. This study illustrates that the cost of regular maintenance practices per load of TN, TP and PM, in particular for street sweeping is significantly lower than current structural BMPs, even assuming such catchment or site-based BMPs are maintained annually and do not scour. For MS4s outfitted with such BMPs, this study concludes maintenance practices are more economical and sustainable than such BMPs. Such BMPs are expensive and not sufficiently maintained resulting in small load reductions as compared to maintenance practices or hydrologic restoration. Maintenance practices and hydrologic restoration can provide the primary benefits for economical load reduction however engineered treatment and models are still required. In lieu of such current BMPs and methods of BMP implementation, engineered unit operation and process systems at regional scales and centralized locations designed for soluble and fine PM-based pollutants are needed. Such systems must incorporate modern tools such as continuous simulation (as with the Storm Water Management Model, SWMM) and computational fluid dynamics (CFD). As a result these systems are significantly more effective and sustainable than current BMPs while also benefiting from maintenance practices and hydrologic restoration.

While the essence of the study is summarized in the above table and Executive Summary the study was not designed to compare MS4 to MS4, BMP to BMP or between BMP classes. This study was designed to develop a set of metrics for nutrients associated with PM recovered through maintenance practices (street cleaning, catch basin cleaning and BMP cleaning) and further examine whether such maintenance practices could be cost effective with respect to the use of “BMP” to recover nutrient loads. The results of this study clearly indicate that street sweeping provides the greatest recovery of PM, TP and TN per unit of economic investment, in particular in comparison to BMPs as summarized in Table 9 and in Table S2. Any and all results utilized from this study must be referenced back to this study report and the appendix thereof to provide a foundation and basis for the result utilized. Results and illustrations of this study are based on use of the median from each resulting distribution and the use of the median metric or yardstick from Table S1, 5, 6, 8 or C1 is recommended. The executive summary provides a comprehensive summary of the findings of this study, associated cost projections and recommendations as to the role of maintenance practices. It is reiterated that the metrics provided by this study are provided on a dry weight of PM recovered basis (a standard basis) and therefore documentation must provide moisture content (and mass) and dry PM mass. If measured on a volumetric basis, dry-equiv. PM must also include measured “loose” dry bulk density representative of the reported volume. Any results utilized from this study must be referenced back to this study report to provide a foundation and basis for the result utilized. The body of this report and the extended appendix form the basis of the results and recommendations for maintenance practices as presented herein. Reclaimed wastewater utilized for irrigation in an MS4 imposes an added load of TN and TP (identifying only nutrients) to the urban environs and receiving systems. To date this study provides the most detailed examination of urban residuals inside and outside reclaimed areas that utilized wastewater for irrigation. A study has been proposed to develop a parallel set of metrics (inside MS4 reclaimed loading areas) as developed herein for MS4 areas outside of reclaimed irrigation loadings.

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Table 1 List of types of BMPs and their Florida MS4 locations (abbreviations on page 14)

Reclaim	Land use	Sample	BMP Type	BMP Classification
OUT	H	GNV-BMP-H-OUT-1	Detention Pond	Pond (Basin)
OUT	H	GNV-BMP-H-OUT-2	Baffle Box	Baffle Box
OUT	H	GNV-BMP-H-OUT-3	Ditch	Swale, Ditch or Sediment Accumulation
OUT	C	GNV-BMP-C-OUT-1	Hydrodynamic Separator	Manufactured BMP
OUT	C	GNV-BMP-C-OUT-2	Sediment Trap	Manufactured BMP
OUT	C	GNV-BMP-C-OUT-3	Baffle Box	Baffle Box
OUT	R	GNV-BMP-R-OUT-1,2	Hydrodynamic Separator	Manufactured BMP
OUT	R	GNV-BMP-R-OUT-3	Natural Pond	Pond (Basin)
IN	H	GNV-BMP-H-IN-1	Natural Pond	Pond (Basin)
IN	H	GNV-BMP-H-IN-2,3	Ditch	Swale, Ditch or Sediment Accumulation
IN	C	GNV-BMP-C-IN-1,2,3	Retention Area	Pond (Basin)
IN	R	GNV-BMP-R-IN-1,2,3	Retention Basin	Pond (Basin)
OUT	H	HC-BMP-H-OUT-1,3	Detention Pond	Pond (Basin)
OUT	H	HC-BMP-H-OUT-2	Ditch	Swale, Ditch or Sediment Accumulation
OUT	C	HC-BMP-C-OUT-1,3	Ditch	Swale, Ditch or Sediment Accumulation
OUT	C	HC-BMP-C-OUT-2	Retention Pond	Pond (Basin)
OUT	R	HC-BMP-R-OUT-1	Detention Pond	Pond (Basin)
OUT	R	HC-BMP-R-OUT-2	Swale	Swale, Ditch or Sediment Accumulation
OUT	R	HC-BMP-R-OUT-3	Ditch	Swale, Ditch or Sediment Accumulation
OUT	H	JAX-BMP-H-OUT-1,2,3	Concrete Box	Drainage or Sump Box
OUT	C	JAX-BMP-C-OUT-3	Baffle Box	Baffle Box
OUT	R	JAX-BMP-R-OUT-1,2	Concrete Box	Drainage or Sump Box
OUT	R	JAX-BMP-R-OUT-3	Baffle Box	Baffle Box
OUT	H	LC-BMP-H-OUT-1	Hydrodynamic Separator	Manufactured BMP
OUT	H	LC-BMP-H-OUT-2	Sump Box	Drainage or Sump Box
OUT	H	LC-BMP-H-OUT-3	Filter Box	Baffle Box
OUT	C	LC-BMP-C-OUT-1	Hydrodynamic Separator	Manufactured BMP
OUT	C	LC-BMP-C-OUT-2,3	Filter Box	Baffle Box
OUT	R	LC-BMP-R-OUT-1,2,3	Filter Box	Baffle Box
OUT	H	MCO-BMP-H-OUT-1,2,3	Hydrodynamic Separator	Manufactured BMP
OUT	C	MCO-BMP-C-OUT-1,2,3	Inlet Basket	Manufactured BMP
OUT	R	MCO-BMP-R-OUT-1,2,3	Inlet Basket	Manufactured BMP
OUT	H	MDC-BMP-H-OUT-6,7,8	"French Drain"	Drainage or Sump Box
OUT	C	MDC-BMP-C-OUT-3,6,9	"French Drain"	Drainage or Sump Box
OUT	R	MDC-BMP-R-OUT-4,6,9	"French Drain"	Drainage or Sump Box
OUT	H	OC-BMP-H-OUT-1	Hydrodynamic Separator	Manufactured BMP
OUT	H	OC-BMP-H-OUT-2,3	Sump Box	Drainage or Sump Box
OUT	C	OC-BMP-C-OUT-1	Inlet Basket	Manufactured BMP
OUT	C	OC-BMP-C-OUT-2,3	Sump Box	Drainage or Sump Box
OUT	R	OC-BMP-R-OUT-1	Hydrodynamic Separator	Manufactured BMP
OUT	R	OC-BMP-R-OUT-2	Baffle Box	Baffle Box
OUT	R	OC-BMP-R-OUT-3	Inlet Basket	Manufactured BMP
OUT	H	PEC-BMP-H-OUT-1	Median Ditch	Swale, Ditch or Sediment Accumulation
OUT	H	PEC-BMP-H-OUT-2	Road Side Ditch	Swale, Ditch or Sediment Accumulation
OUT	H	PEC-BMP-H-OUT-3	Baffle Box	Baffle Box
OUT	C	PEC-BMP-C-OUT-1,2	Stormwater Pond	Pond (Basin)
OUT	C	PEC-BMP-C-OUT-3	Hydrodynamic Separator	Manufactured BMP
OUT	R	PEC-BMP-R-OUT-1	Stormwater Pond	Pond (Basin)
OUT	R	PEC-BMP-R-OUT-2	Drainage basin	Swale, Ditch or Sediment Accumulation
OUT	R	PEC-BMP-R-OUT-3	Sump Box	Drainage or Sump Box

Table 2 List of types of BMPs and their locations (continued)

Reclaim	Land use	Sample	BMP Type	BMP Classification
OUT	H	SAC-BMP-H-OUT-1,2	Baffle Box	Baffle Box
OUT	H	SAC-BMP-H-OUT-3	Advanced BMP	Manufactured BMP
OUT	C	SAC-BMP-C-OUT-	Baffle Box	Baffle Box
OUT	R	SAC-BMP-R-OUT-1	Baffle Box	Baffle Box
OUT	R	SAC-BMP-R-OUT-2	Advanced BMP	Manufactured BMP
OUT	R	SAC-BMP-R-OUT-3	Baffle Box	Baffle Box
IN	H	SAC-BMP-H-IN-1,2	Advanced BMP	Manufactured BMP
IN	H	SAC-BMP-H-IN-3	Pond	Pond (Basin)
IN	C	SAC-BMP-C-IN-1	Baffle Box	Baffle Box
IN	C	SAC-BMP-C-IN-2	Advanced BMP	Manufactured BMP
IN	C	SAC-BMP-C-IN-3	Pond	Pond (Basin)
IN	R	SAC-BMP-R-IN-1,2	Advanced BMP	Manufactured BMP
IN	R	SAC-BMP-R-IN-3	Pond	Pond (Basin)
OUT	H	SEC-BMP-H-OUT-1		
OUT	H	SEC-BMP-H-OUT-2,3	Hydrodynamic	Manufactured BMP
OUT	C	SEC-BMP-C-OUT-1	Grate Top Inlet	Swale, Ditch or Sediment
OUT	C	SEC-BMP-C-OUT-2	Baffle Box	Baffle Box
OUT	C	SEC-BMP-C-OUT-3	Sump Box	Drainage or Sump Box
OUT	R	SEC-BMP-R-OUT-1	Baffle Box	Baffle Box
OUT	R	SEC-BMP-R-OUT-2		
OUT	R	SEC-BMP-R-OUT-3	Diversion Box	Manufactured BMP
OUT	H	SPP-BMP-H-OUT-3,5,9	Swale	Swale, Ditch or Sediment
OUT	C	SPP-BMP-C-OUT-1,4,7	Swale	Swale, Ditch or Sediment
OUT	R	SPP-BMP-R-OUT-2,6,8	Swale	Swale, Ditch or Sediment
OUT	H	ST-BMP-H-OUT-1,2,3	Hydrodynamic	Manufactured BMP
OUT	C	ST-BMP-C-OUT-1,2,3	Baffle Box	Baffle Box
OUT	R	ST-BMP-R-OUT-1,2,3	Baffle Box	Baffle Box
OUT	H	TAL-BMP-H-OUT-	Detention	Swale, Ditch or Sediment
OUT	C	TAL-BMP-C-OUT-	Detention	Swale, Ditch or Sediment
OUT	R	TAL-BMP-R-OUT-	Detention	Swale, Ditch or Sediment
OUT	H	TPH-BMP-H-OUT-1	Sediment Sump	Swale, Ditch or Sediment
OUT	H	TPH-BMP-H-OUT-2,3	Ditch	Swale, Ditch or Sediment
OUT	C	TPH-BMP-C-OUT-1	Swale	Swale, Ditch or Sediment
OUT	C	TPH-BMP-C-OUT-2,3	Ditch	Swale, Ditch or Sediment
OUT	R	TPH-BMP-R-OUT-1	Swale	Swale, Ditch or Sediment
OUT	R	TPH-BMP-R-OUT-2,3	Retention Pond	Pond (Basin)
IN	H	TPH-BMP-H-IN-1	Drainage Canal	Swale, Ditch or Sediment
IN	H	TPH-BMP-H-IN-2	Ditch	Swale, Ditch or Sediment
IN	H	TPH-BMP-H-IN-3	Swale	Swale, Ditch or Sediment
IN	C	TPH-BMP-C-IN-1,2,3	Swale	Swale, Ditch or Sediment
IN	R	TPH-BMP-R-IN-1,3	Swale	Swale, Ditch or Sediment
IN	R	TPH-BMP-R-IN-2	Open Canal	Swale, Ditch or Sediment

Table 3 Classification of BMPs analyzed

BMP Classification	**IN**	**OUT**
Pond (Basin)	10	11
Baffle Box	1	27
Swale, Ditch or Sediment Accumulation	11	35
Manufactured BMP (such as hydrodynamic separators)	5	28
Drainage or Sump Box	0	23
Total	**27**	**124**

Table 4 Measurement parameters and quality assurance objectives for the project

Measurement parameter (1,2,3,4)	**Sample matrix**	**Precision**		**Accuracy**		**Method detection limits (MDLs)**
		Uncertainty /RSD	**Conc. Range[4]**	**% recovery**	**Conc. Range[5]**	
Total P (TP)	W,D	±3.9%	M	85-115	M	0.01 mg/L
Extractable P	W,D	±3.6%	M	85-115	M	0.01 mg/L
Extractable NO_3^-	W,D	±3.61%	M	85-115	M	0.50 mg/L
Extractable NH_3+NH_4^+	W,D	±2.61%	M	85-115	M	0.50 mg/L
Total Kjeldahl N (TKN)	W,D	±6.58%	M	85-115	M	0.20 mg/L
TSS	W,D,L	0-10% RSD	M	90-110	M	1 mg
VSS	W,D,L	N.A.	M	90-110	M	1 mg
Moisture Content	W,D,L	0-2% RSD	M	95-105	N.A.	.1 %
Particle Size Distribution (PSD)	W,D		N.A.	98-102	N.A.	

The following acronyms are used in this table:

N.A. – Not applicable MDL – Method detection limit
W – Wet sediment D – Dry or moist sediment L – Leaf/Litter

Method references from QAPP

1. SM: Standard methods for the examination of water and waste water, 19th Ed., 1995;
2. HACH, 2008
3. American Standard Test Method (ASTM), 1998
4. EPA Test Method, SW-846 (EPA, 1998)
5. L: low range is the lower 20% of the linear calibration range; M: mid range from 20% to 80%; and H: high range in the upper of 80%

Table 5 Florida-based PM phosphorus concentration mean, median and standard deviation values for each HFU differentiated based on separate land uses.

TP	Street Sweeping (SS)			Catch Basin (CB)			BMP		
[mg/kg]	Mean	Median	St. Dev.	Mean	Median	St. Dev.	Mean	Median	St. Dev.
C	482.6	381.2	476.9	530.9	300.8	524.9	474.6	295.7	412.6
R	425.8	374.9	284.7	559.2	423.4	543.0	702.8	382.7	670.5
H	622.0	349.7	778.5	566.6	536.9	363.3	759.4	513.7	972.1

Table 6 Florida-based PM nitrogen concentration mean, median and standard deviation values for each HFU differentiated based on separate land uses.

TN	Street Sweeping (SS)			Catch Basin (CB)			BMP		
[mg/kg]	Mean	Median	St. Dev.	Mean	Median	St. Dev.	Mean	Median	St. Dev.
C	789.1	429.6	944.2	1459.7	467.2	2237.8	1999.0	602.1	3104.1
R	1439.0	832.4	2169.9	1803.9	773.8	2955.8	3587.7	1169.0	4991.9
H	826.6	546.4	654.8	1926.3	785.4	2587.8	2342.4	939.2	3496.6

Table 7 Median PM-bound TP and TN concentrations per each MS4 independently of the land use or HFU. These results are not Florida-based and are presented based only on MS4 interest.

MS4	TP [mg/kg]	TN [mg/kg]
Gainesville (GNV)	325.6	319.4
Hillsborough County (HC)	384.3	360.1
Jacksonville (JAX)	304.1	430.4
Lee County (LC)	407.5	483.6
Miami-Dade County (MDC)	735.0	1129.7
Orange County (OC)	288.9	595.8
Orlando (MCO)	552.5	1659.8
Pensacola/Escambia County (PEC)	96.2	419.1
Sarasota County (SAC)	969.0	648.5
Seminole County (SEC)	350.5	1229.8
St. Petersburg/Pinellas County (SPP)	249.1	614.2
Stuart (ST)	286.7	814.8
Tallahassee (TAL)	506.2	1219.5
Tampa (TPH)	388.1	771.1

MS4 (Reclaimed Areas)	TP [mg/kg]	TN [mg/kg]
Gainesville (GNV)	455.6	374.1
Sarasota County (SAC)	849.2	613.4
Tampa (TPH)	451.8	1117.0

Table 8 Florida-based PM phosphorus and nitrogen concentration mean, median and standard deviation values for each HFU independent of land use. These numbers have been obtained from Figure 12 and Figure 18.

	TP [mg/kg]			TN [mg/kg]		
	Mean	Median	St. Dev.	Mean	Median	St. Dev.
Street Sweeping (SS)	512.5	361.0	599.9	1012.2	563.0	1422.2
Catch Basin (CB)	552.2	416.8	481.8	1729.1	679.1	2601.6
BMP	647.1	363.9	728.9	2648.1	898.5	3983.1

Table 9 Comparison between structural and non-structural solutions costs for PM and nutrients removal expressed in $ per pound of constituent.

Separation or Recovery Method	**Median Cost ($/lb)**		
	TN	**TP**	**PM**
BMP Treatment Train[a]	935	32,600	26
FL Database for BMPs[b]	1,900	10,500	41
Screened Hydrodynamic Separator[c]	3,730 (1,280 - 14,860)	9,210 (3,170 - 36,680)	4 (1 - 13)
Baffled Hydrodynamic Separator[c]	3,020 (1,280 - 14,860)	7,450 (3,170 - 36,680)	3 (1 - 13)
Street Sweeping	165	257	0.10
Catch Basin Cleaning[d]	1,016	1,656	0.70

[a] Wet basin sedimentation followed by granular media filtration. Squadra Tempesta, (2010) *Green Infrastructure Design for Pollutant Control from Transport Systems Crossing Land-Water Interfaces - A Bridge too Far?*, Water Environment Federation, WEFTEC, New Orleans, LA.

[b] TMDL database for FL Best Management Practices, 2009

[c] Based on 2000 m^2 urban catchment draining to a hydrodynamic separator (HS) with 50% PM annual removal efficiency based on clean sump conditions

[d] Based on 100 dry pounds of PM recovery based on an annual cleaning frequency

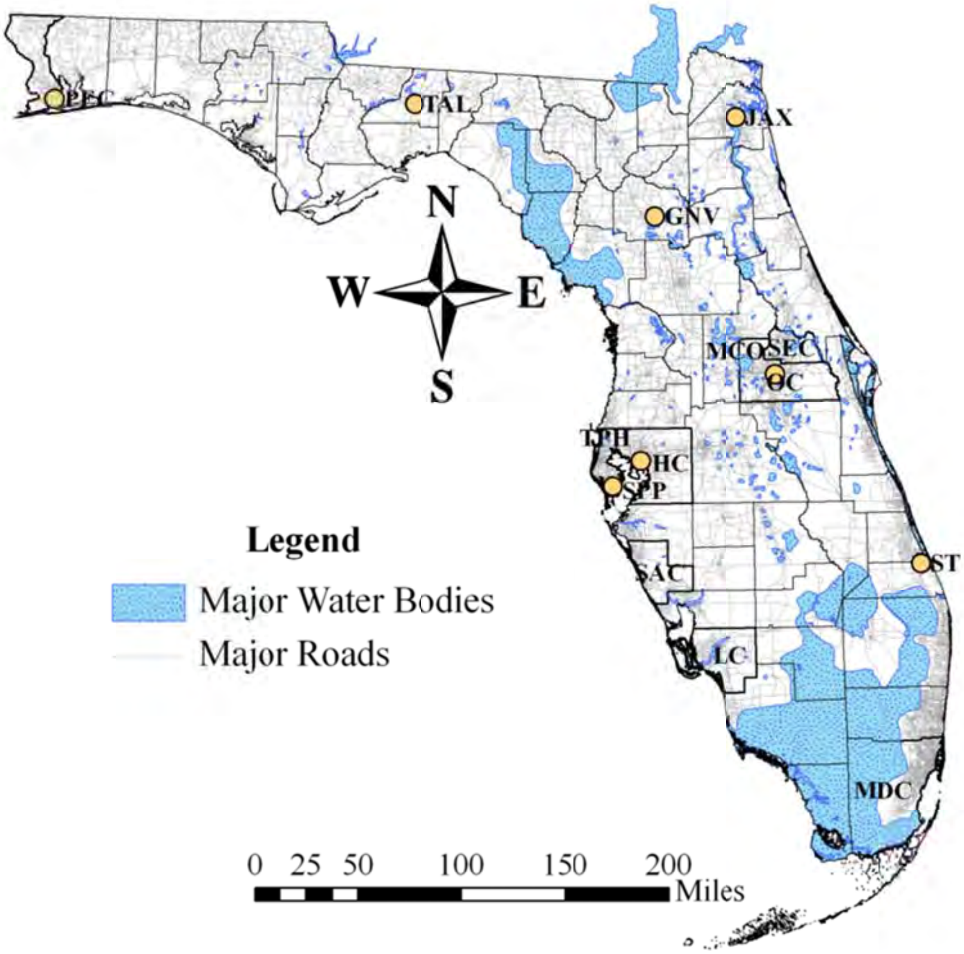

Figure 1 Water bodies and major roads across Florida

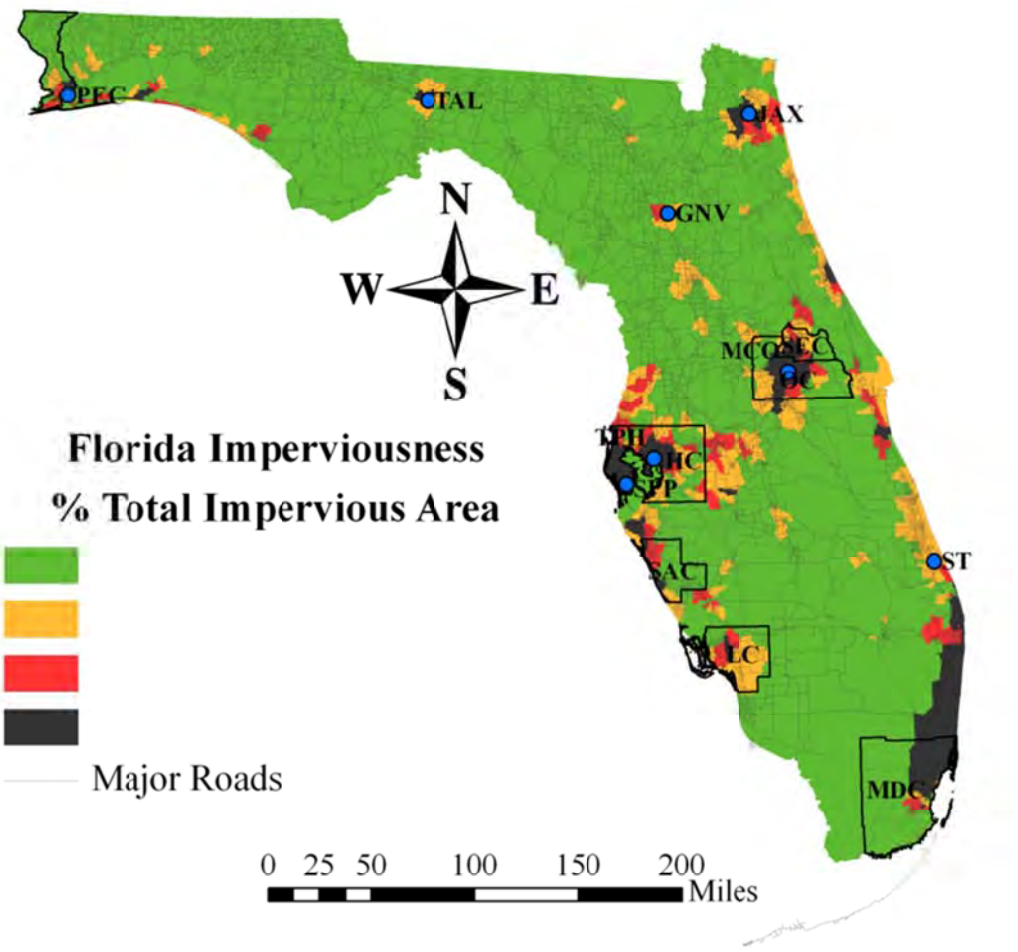

Figure 2 % Total impervious area (TIA) for the State of Florida

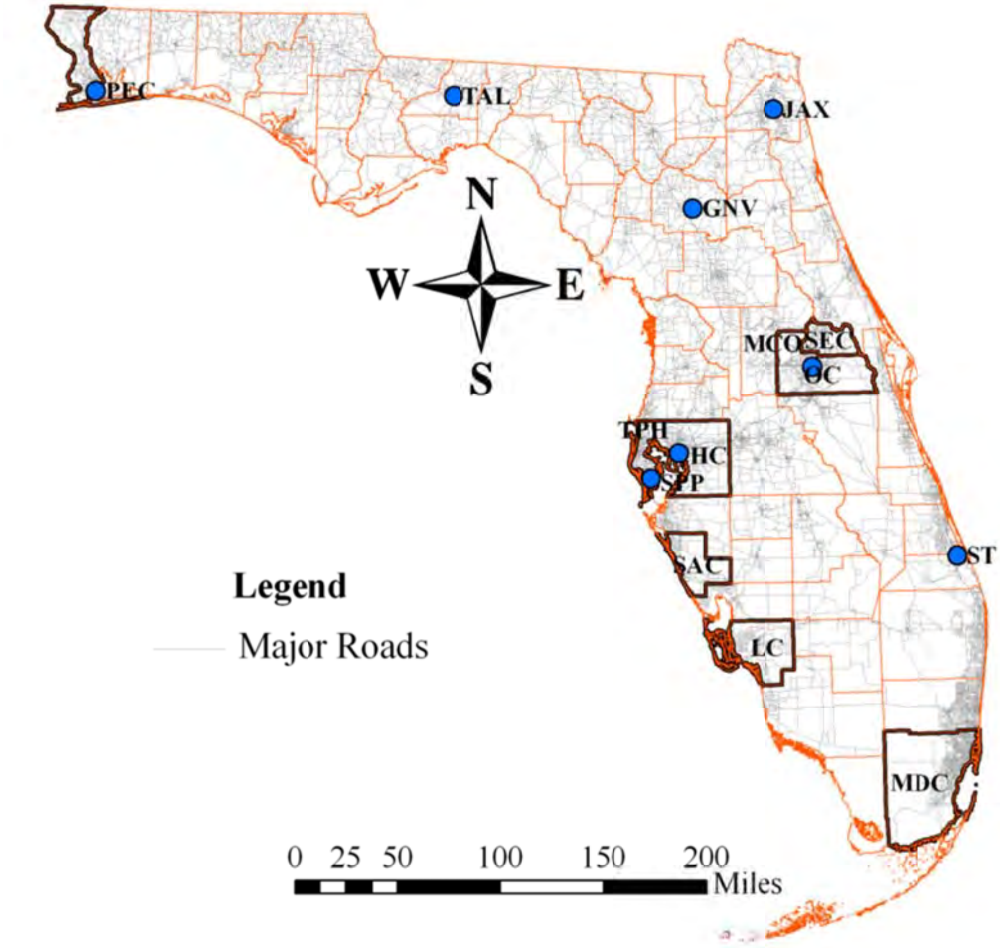

Figure 3 State-wide distribution of MS4 sampling locations

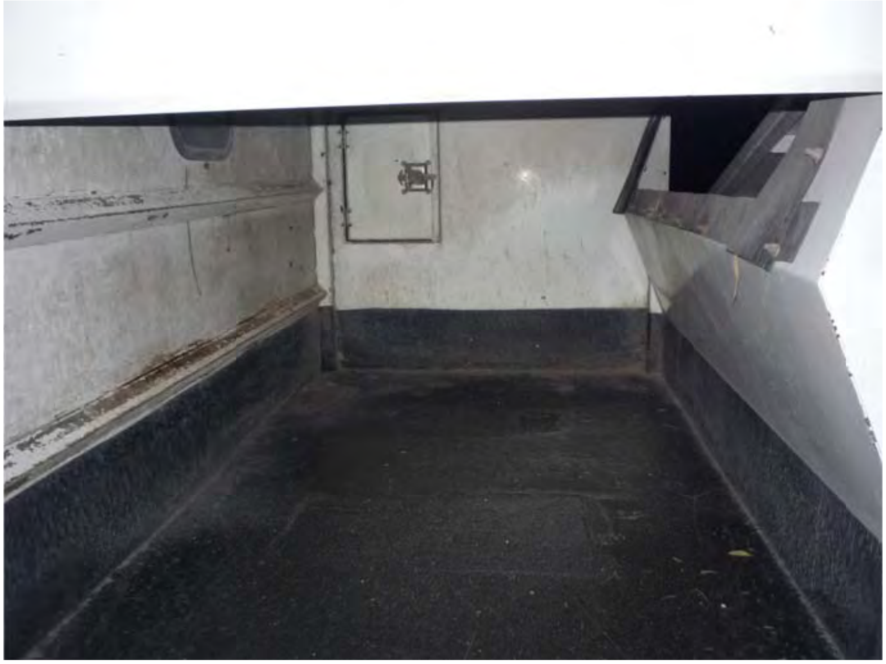

Figure 4 A. cleaned street cleaner bay prior to obtaining sampling batch

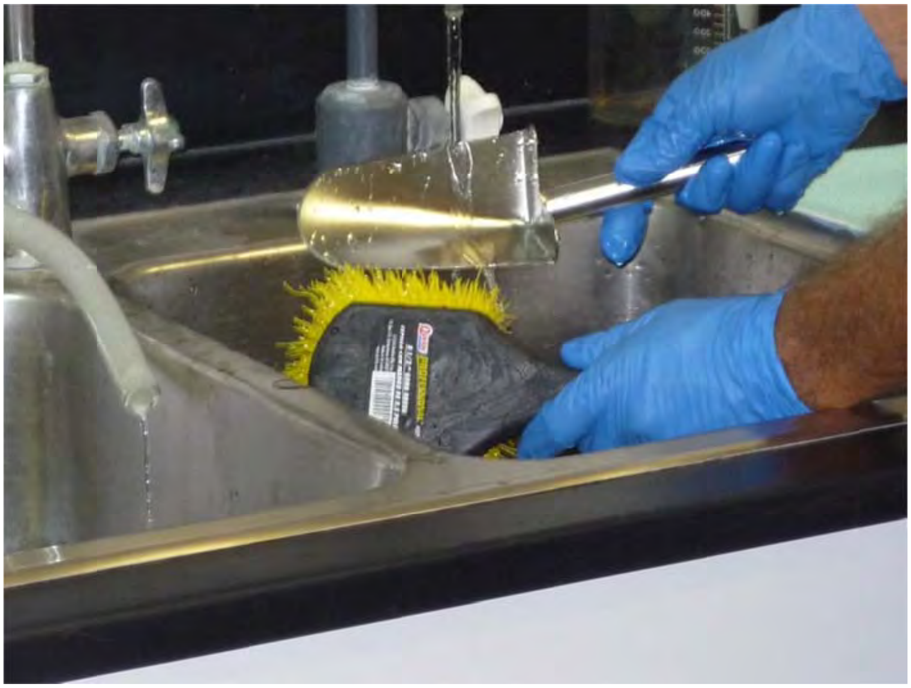

Figure 5 Cleaning of sampling equipment

Figure 6 Sediment sampling process

Figure 7 Example of sample bottle labeling

Figure 8 Samples in a cooler ready to be shipped

FIELD INFORMATION - JACKSONVILLE (JAX - SS - H - OUT - 3)

Sample ID
- JAX – SS – H – OUT – 3

Jurisdiction
- City of Jacksonville

Land Use Zoning
- Highway

Location
- 6217 Merrill Road/Red Oak Dr. Arlington Neighborhood

Co-ordinates
- 30° 21′ 6.658″ N 81° 35′ 35.426″ W

Date and Time (with Previous Dry Hours)
- 01/28/2010 11:50 am
- Approximately 0.94 inch of rain on 1/25/2010; and no rain on 1/28/2010, during the sampling event day.

Sampling Personnel
- Barry Cotter and Kehinde Adeshile

Description of Catchment

Pavement Type
- Asphalt pavement roadway with curbs and gutters; concrete side-walks on both sides of the roadway. Few dense tree canopies and grassy areas are adjacent to the side-walks.

Typical Geometry and R/W Section
- Average cross slope: 3.0%, Average longitudinal slope: 0.5%

Run-on Conditions
- Run-offs from roadway and properties' frontage flow to the edge of roadway into drainage system

Drainage Appurtenances in the Catchment Area
- Catch-basins, reinforced concrete pipes, and ponds

Significant Features that may affect PM, N and P loadings
- Leaf litter, grass clippings, trash, and sediment

Predominant Source
- Leaf litter, grass clippings, trash, and sediment

Reclaimed Water Application
- No

Description if Sweeping Equipment
- Stewart Amos Sweeper Co. International, CF 600, VT275, S4; manufactured in 2009

Dimensions of Area Cleaned
- 18913.50 ft X 12 ft = 226,962 sq ft

Previous Cleaning Activity
- Sweeping is normally done approximately every 6 to 8 weeks

Traffic Estimate (ADT)
- 25,430

Approx. Weight of Recovered Sample
- Approximately 700 lbs

Description of Sample and COC
- Grab sample; moist particulate matter
- COC provided on 01/29/2010

ADT : average daily traffic
COC : chain of custody
H : highway land use
JAX : Jacksonville
N : nitrogen
OUT : outside reclaimed water area
P : phosphorus
pdh : previous dry hours
PM : particulate matter
R/W : right of way
SS : street sweeping

Figure 9 Example of field information document for each sample collected

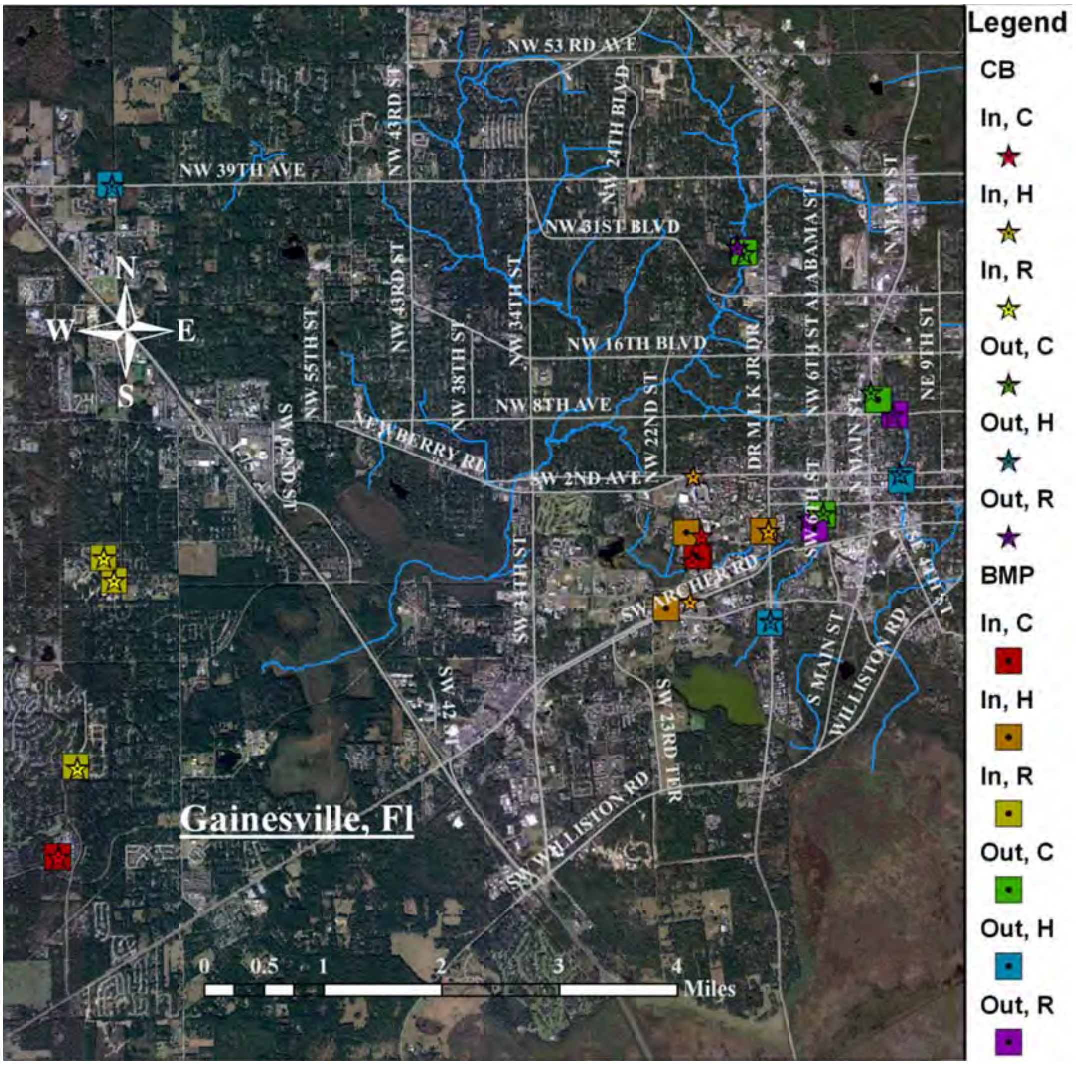

Figure 10 Spatial information example - Gainesville BMP and catch-basin (CB) locations

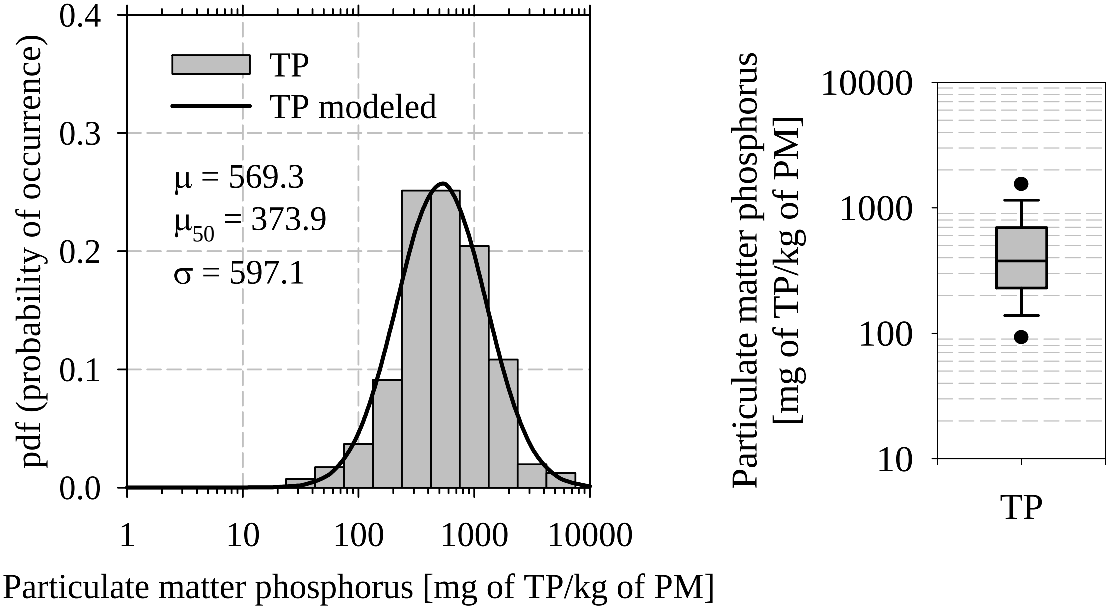

Figure 11 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter phosphorus data and box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values across the whole monitoring program. The mean (μ), median (μ_{50}) and standard deviation (σ) are also reported.

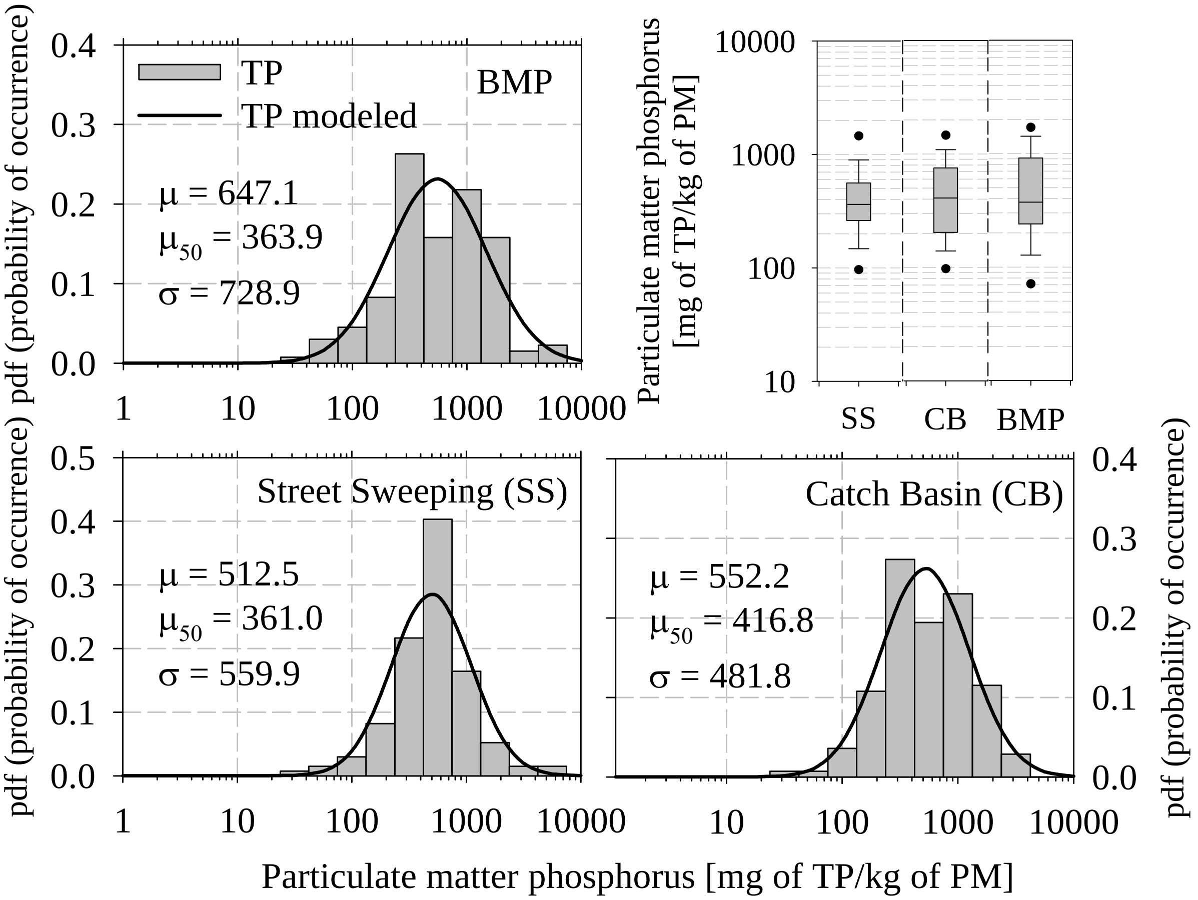

Figure 12 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter phosphorus data and box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values across the whole monitoring program for different HFUs. The mean (μ), median (μ_{50}) and standard deviation (σ) are also reported.

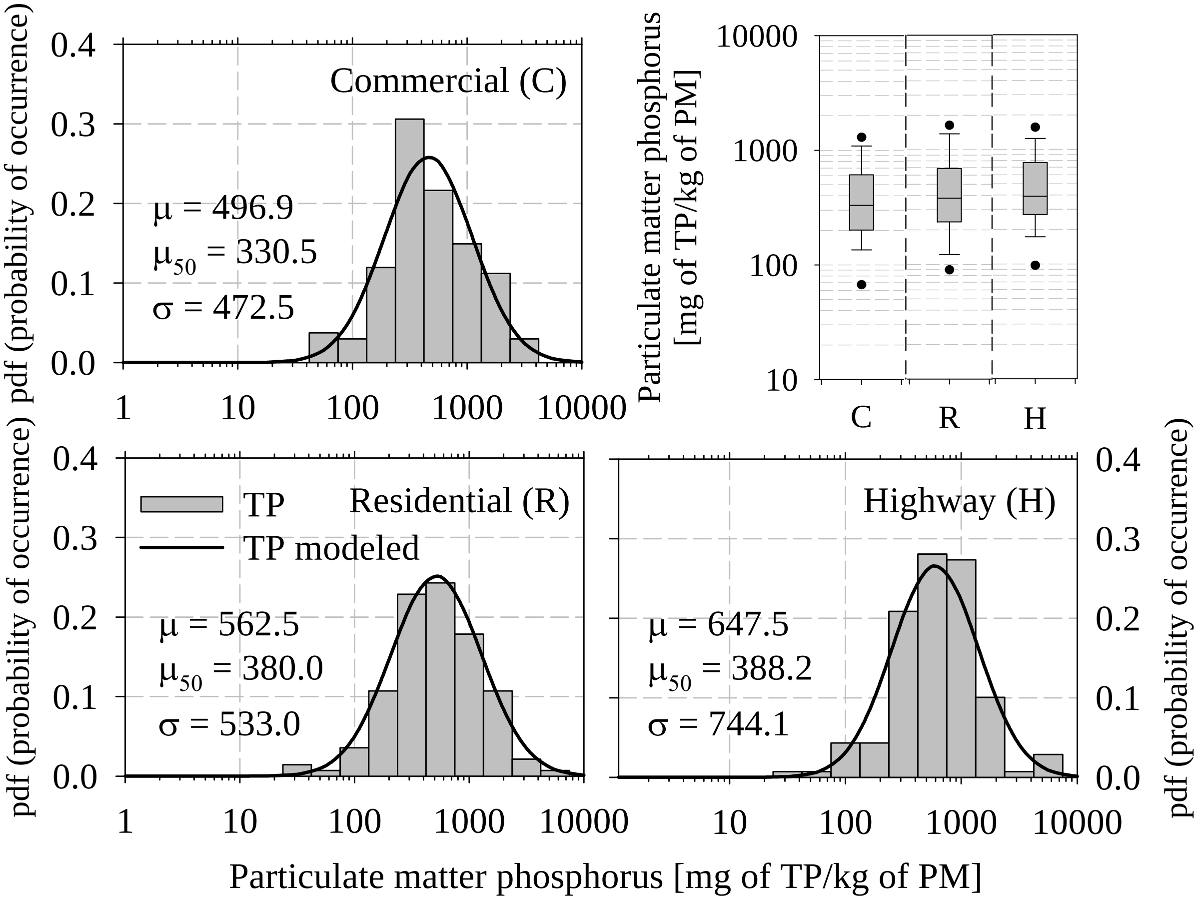

Figure 13 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter phosphorus data and box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values across the whole monitoring program for different land uses. The mean (μ), median (μ_{50}) and standard deviation (σ) are also reported.

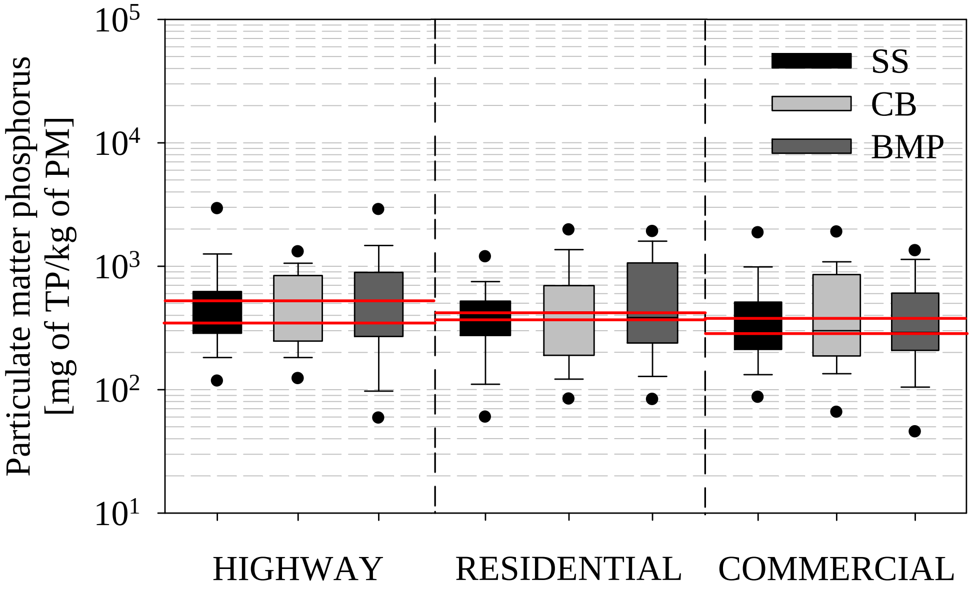

Figure 14 Box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values of the particulate matter phosphorus data across the whole monitoring program for each HFU and within areas characterized by different land uses. The range of variation of the median values per land use is highlighted in red.

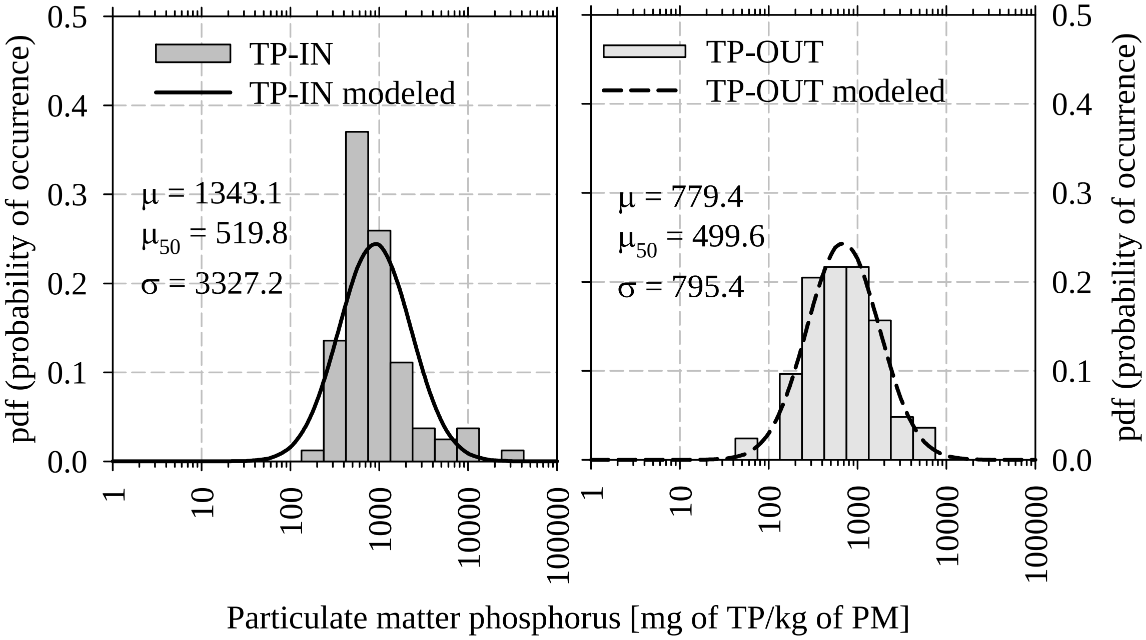

Figure 15 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter phosphorus data for samples collected inside and outside reclaimed areas. The mean (μ), median (μ_{50}) and standard deviation (σ) are also reported.

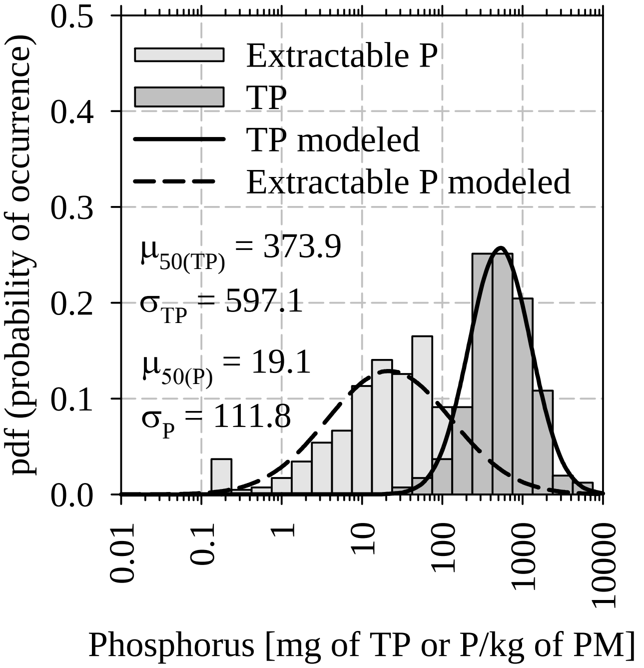

Figure 16 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter total phosphorus (TP) and extractable phosphorus (P) data across the whole monitoring program. The mean (μ) and standard deviation (σ) are also reported.

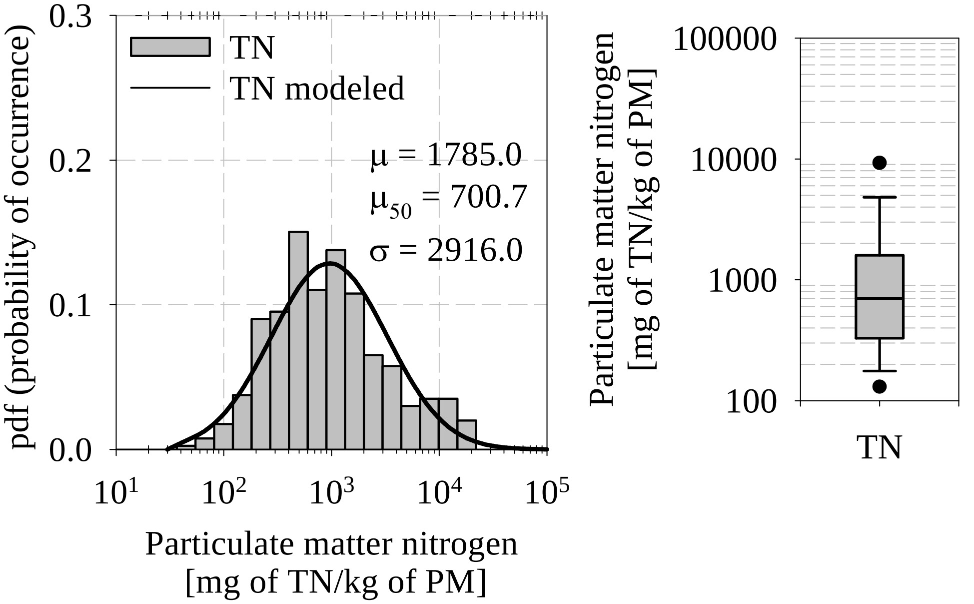

Figure 17 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter nitrogen data and box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values across the whole monitoring program. The mean (μ), median (μ_{50}) and standard deviation (σ) are also reported.

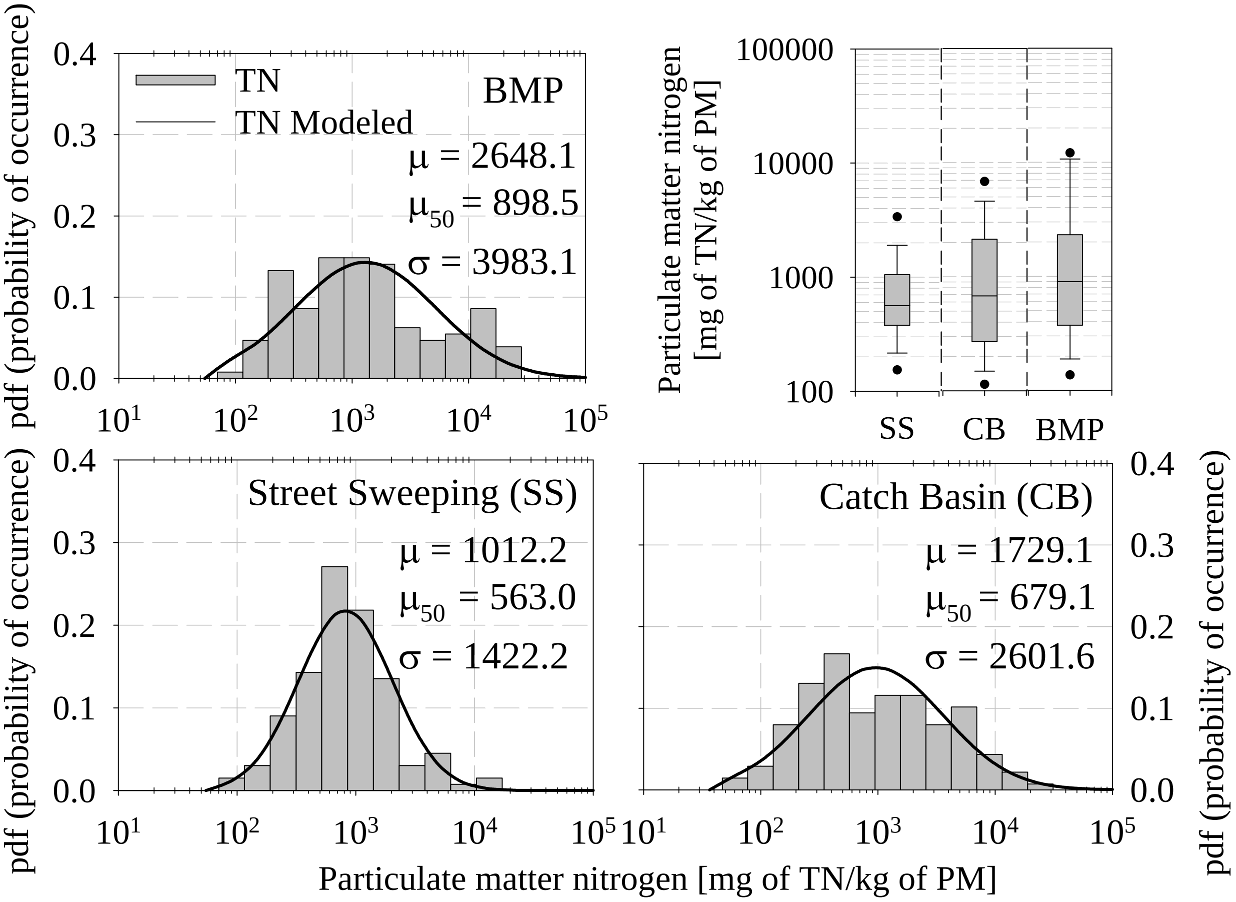

Figure 18 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter nitrogen data and box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values across the whole monitoring program for different HFUs. The mean (μ), median (μ_{50}) and standard deviation (σ) are also reported.

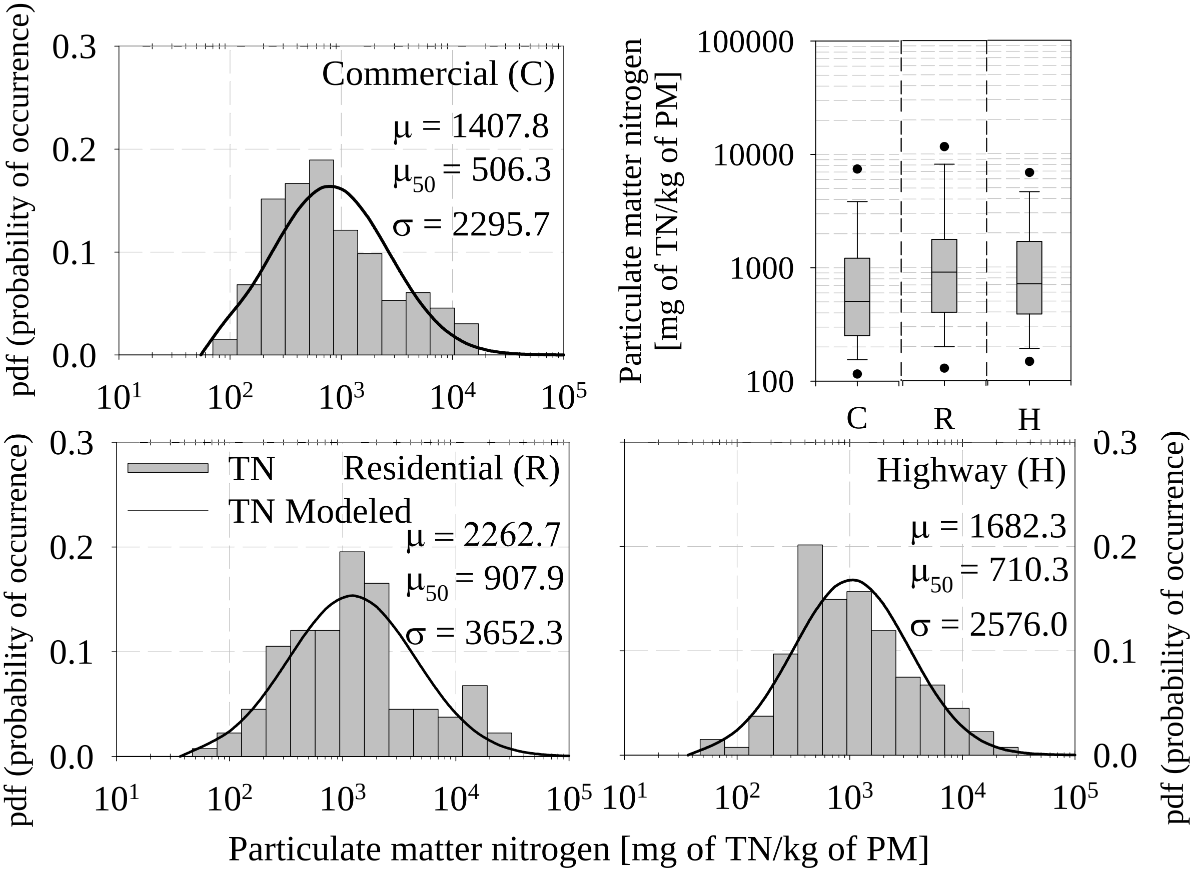

Figure 19 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter nitrogen data and box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values across the whole monitoring program for different land uses. The mean (μ), median (μ_{50}) and standard deviation (σ) are also reported.

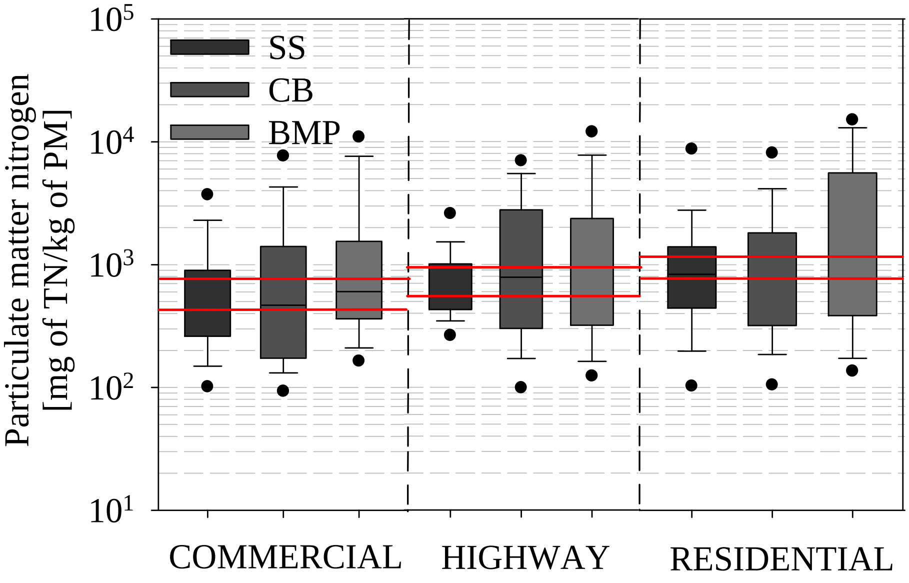

Figure 20 Box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values of the particulate matter nitrogen data across the whole monitoring program for each HFU and within areas characterized by different land uses. The range of variation of the median values per land use is highlighted in red.

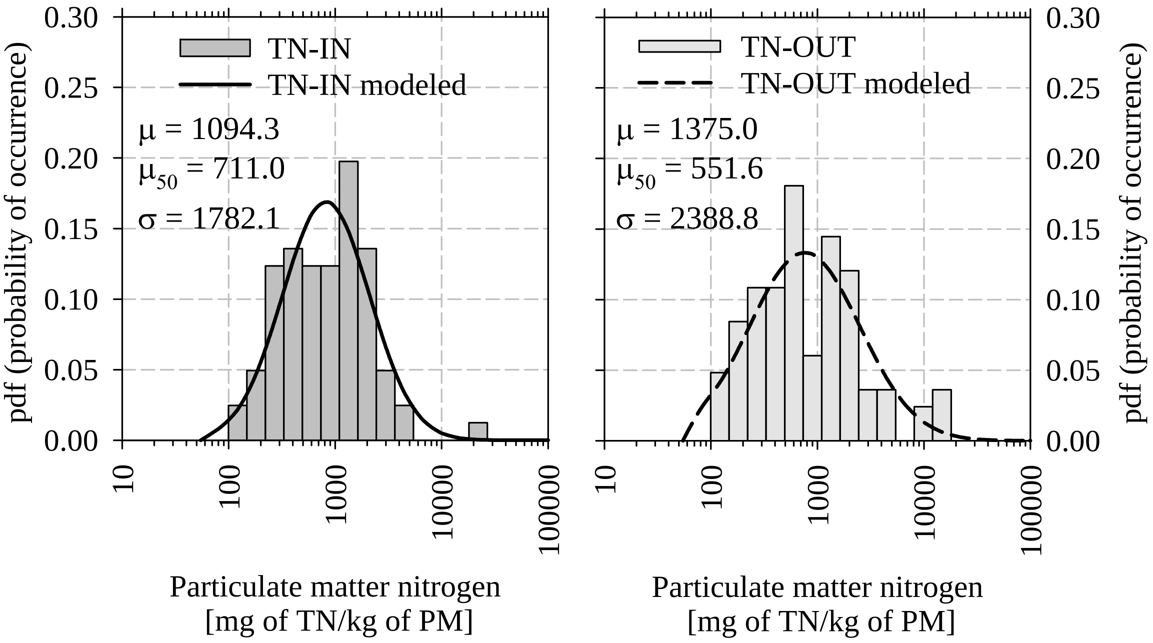

Figure 21 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter nitrogen data for samples collected inside and outside reclaimed areas. The mean (μ), median (μ_{50}) and standard deviation (σ) are also reported.

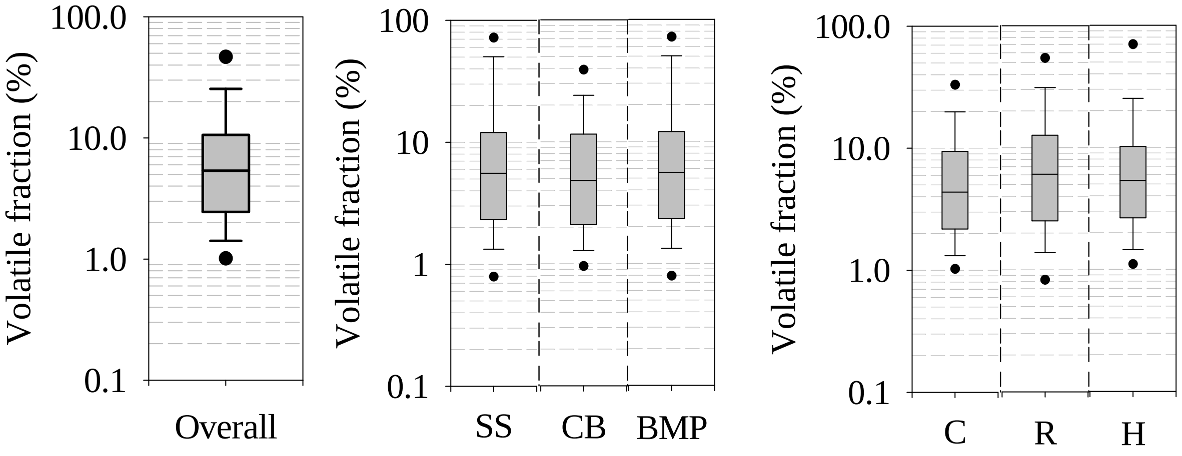

Figure 22 Box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values of the volatile fraction across the whole monitoring program, for different HFUs and within areas characterized by different land uses.

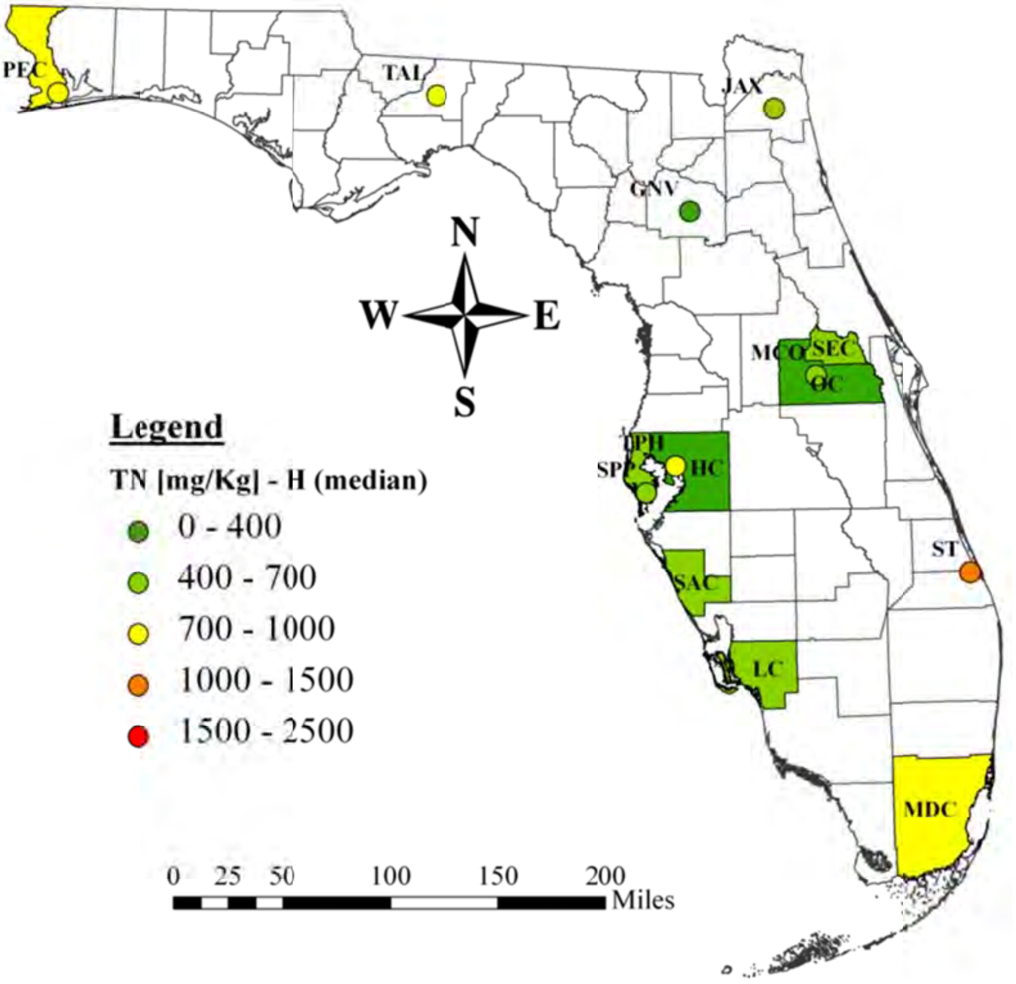

Figure 23 State-wide distribution of TN for highway (H) land use

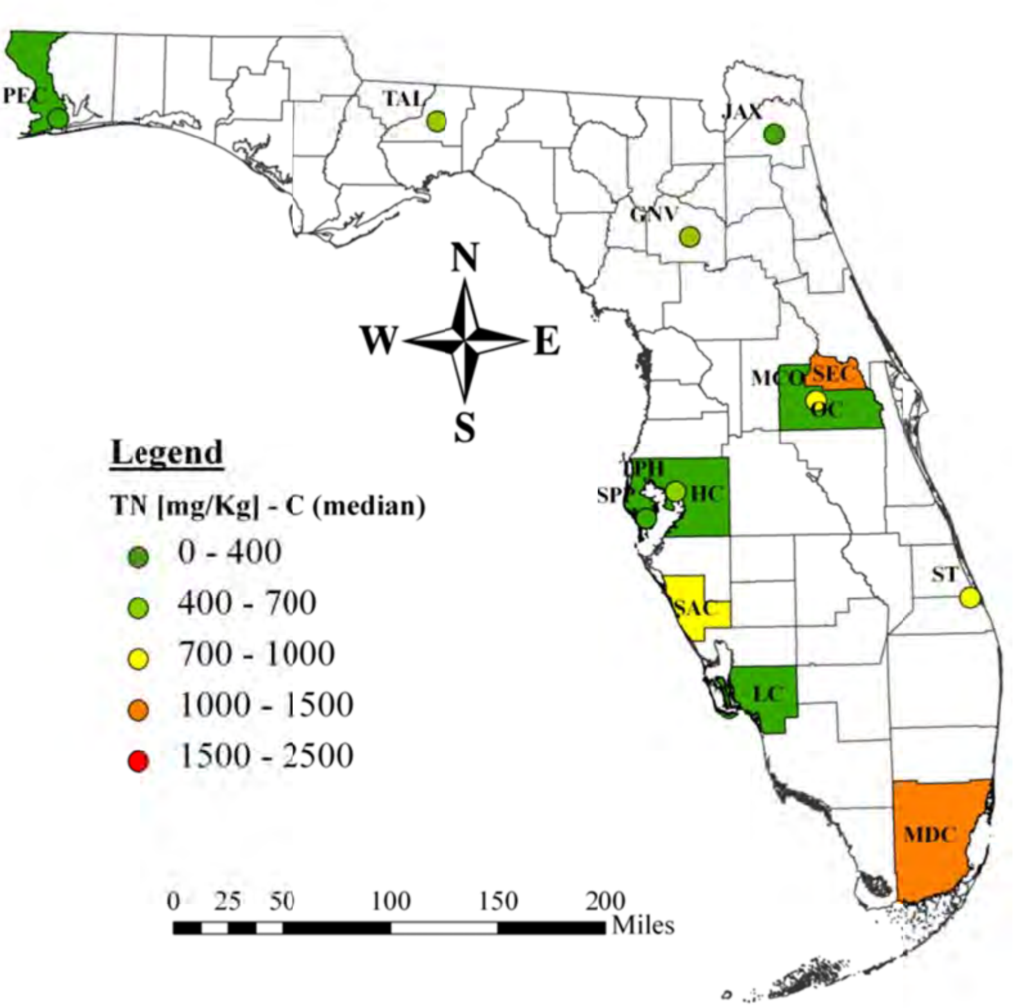

Figure 24 State-wide distribution of TN for commercial (C) land use

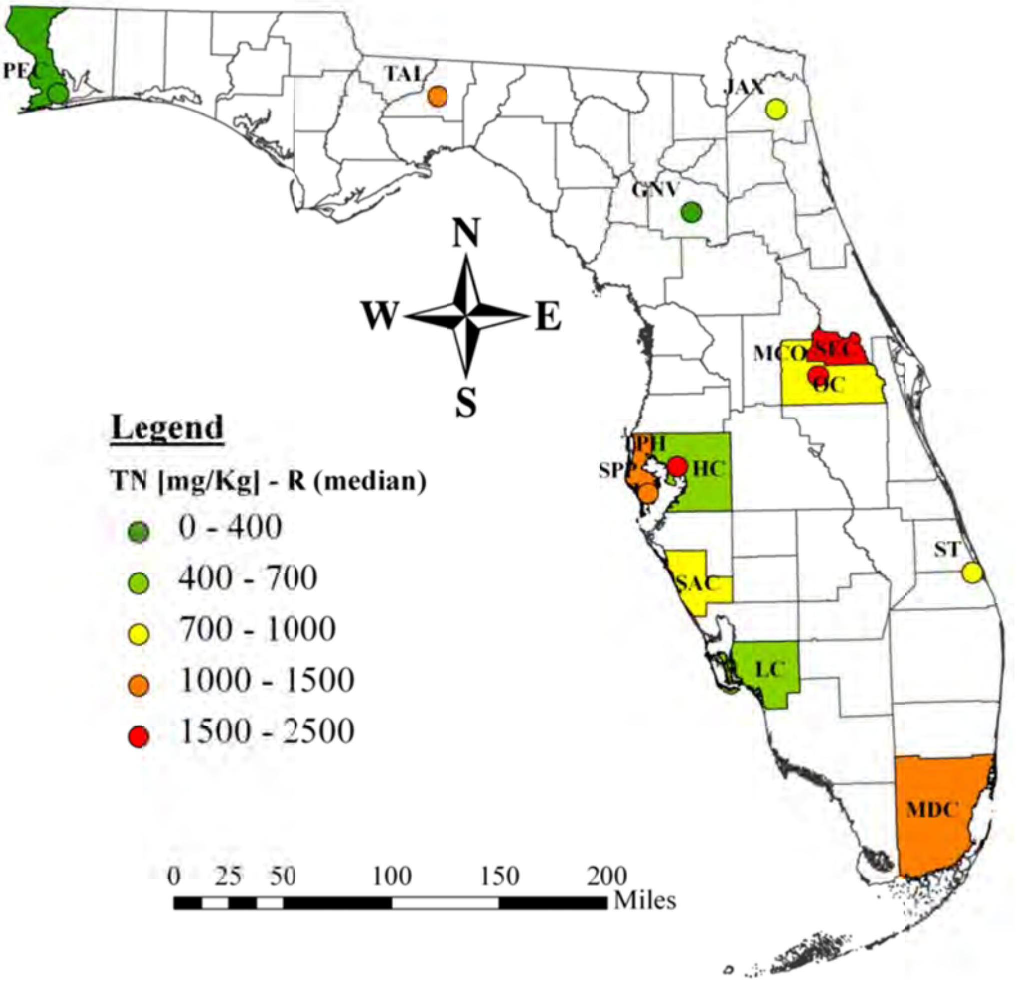

Figure 25 State-wide distribution of TN for residential (R) land use

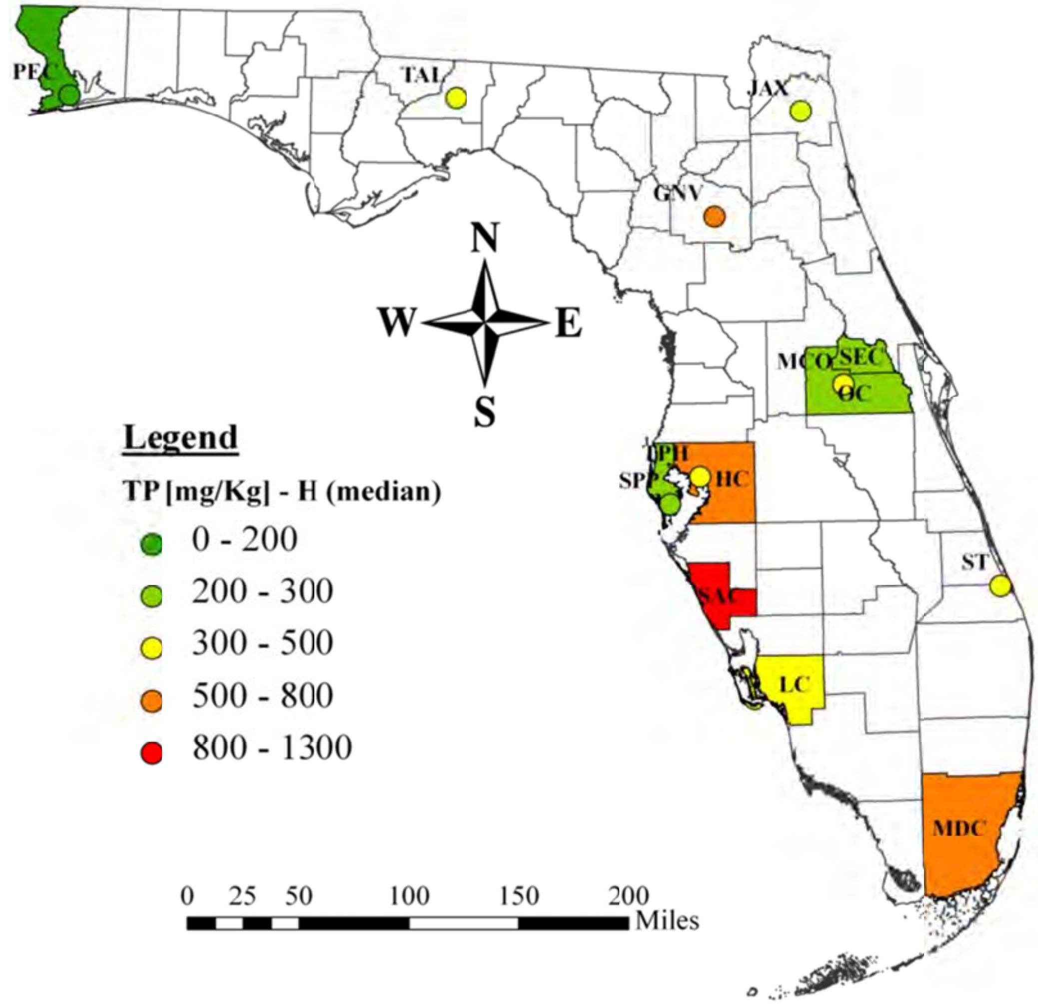

Figure 26 State-wide distribution of TP for highway (H) land use

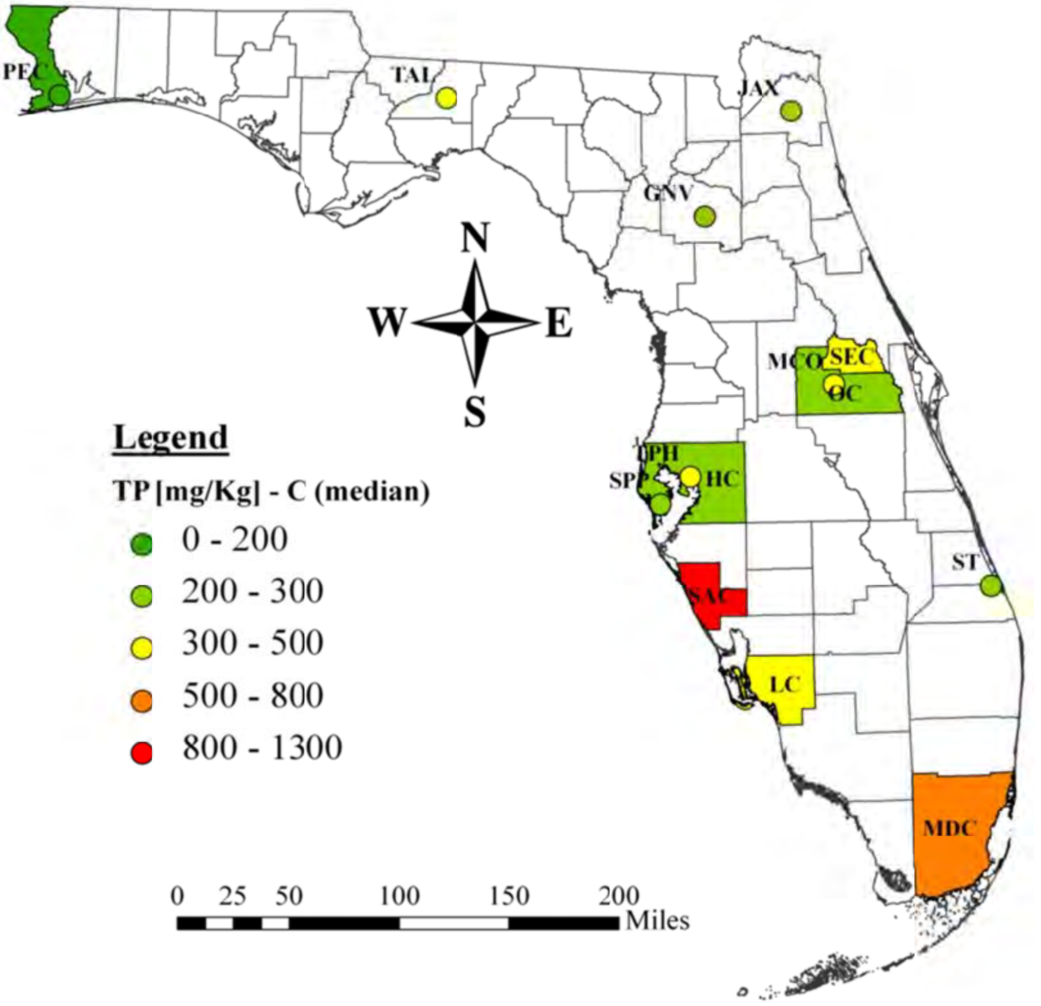

Figure 27 State-wide distribution of TP for commercial (C) land use

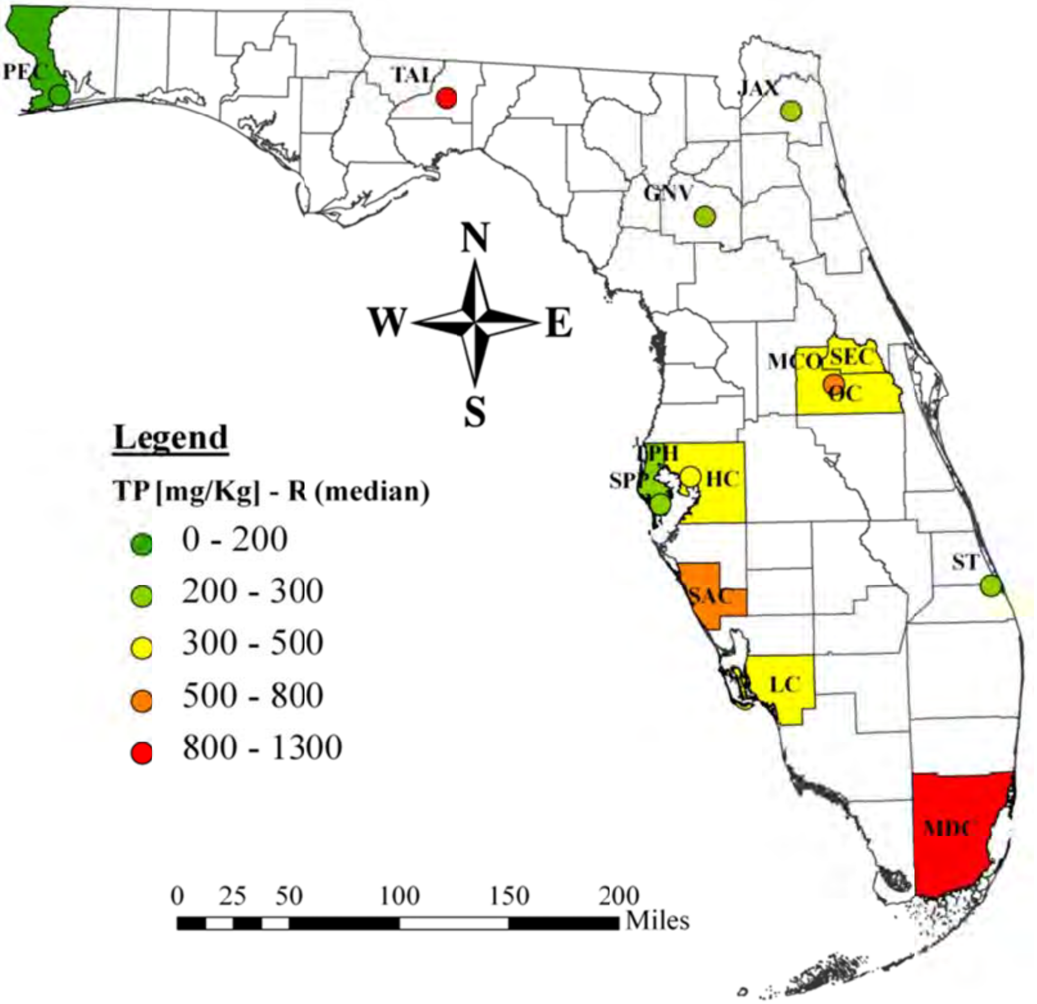

Figure 28 State-wide distribution of TP for residential (R) land use

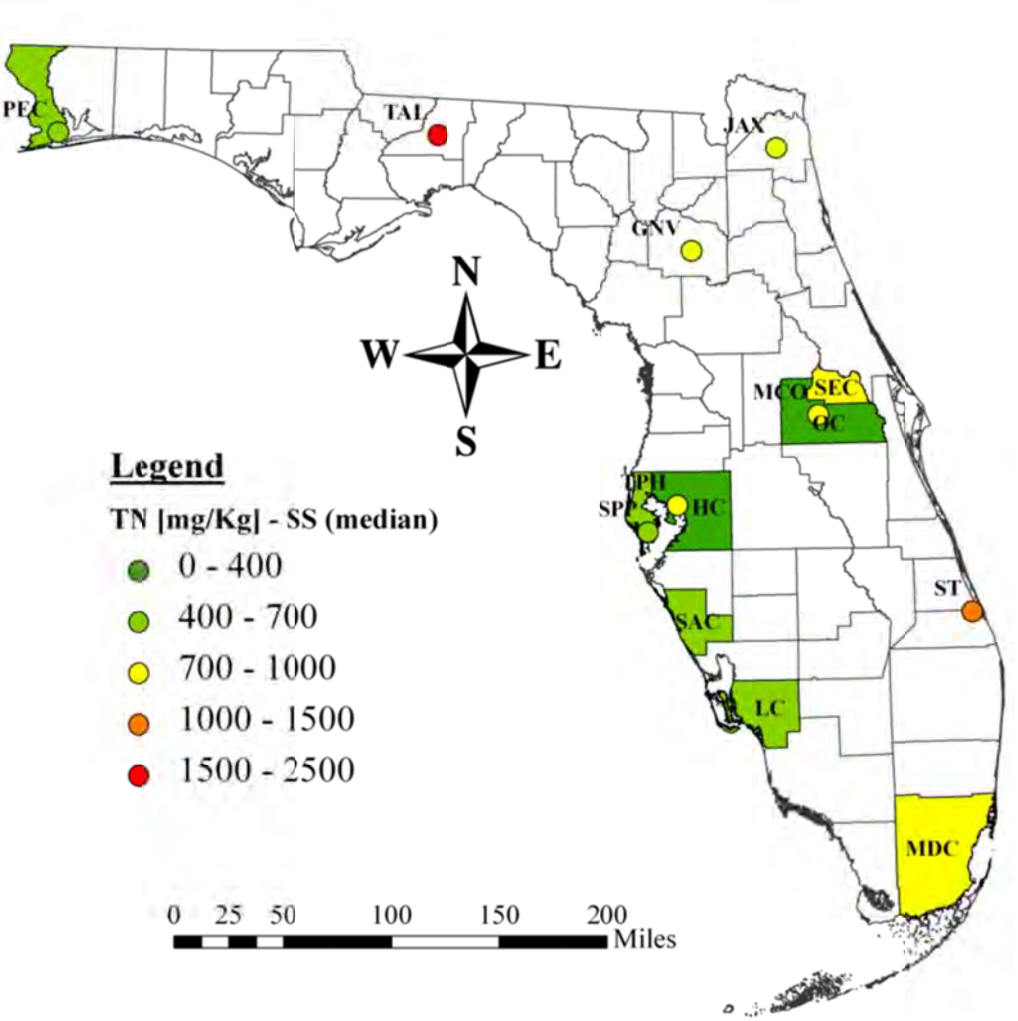

Figure 29 State-wide distribution of TN for street-sweepings

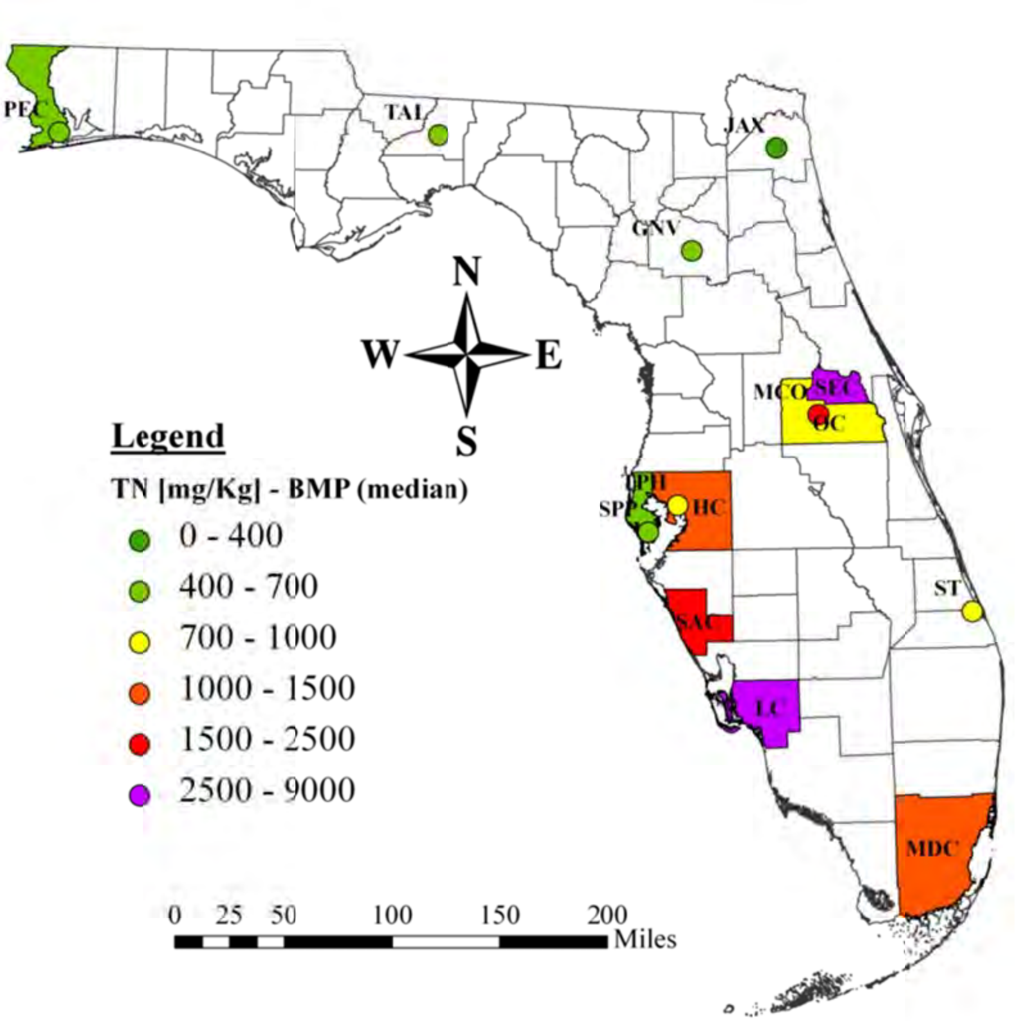

Figure 30 State-wide distribution of TN for best management practices (BMP)

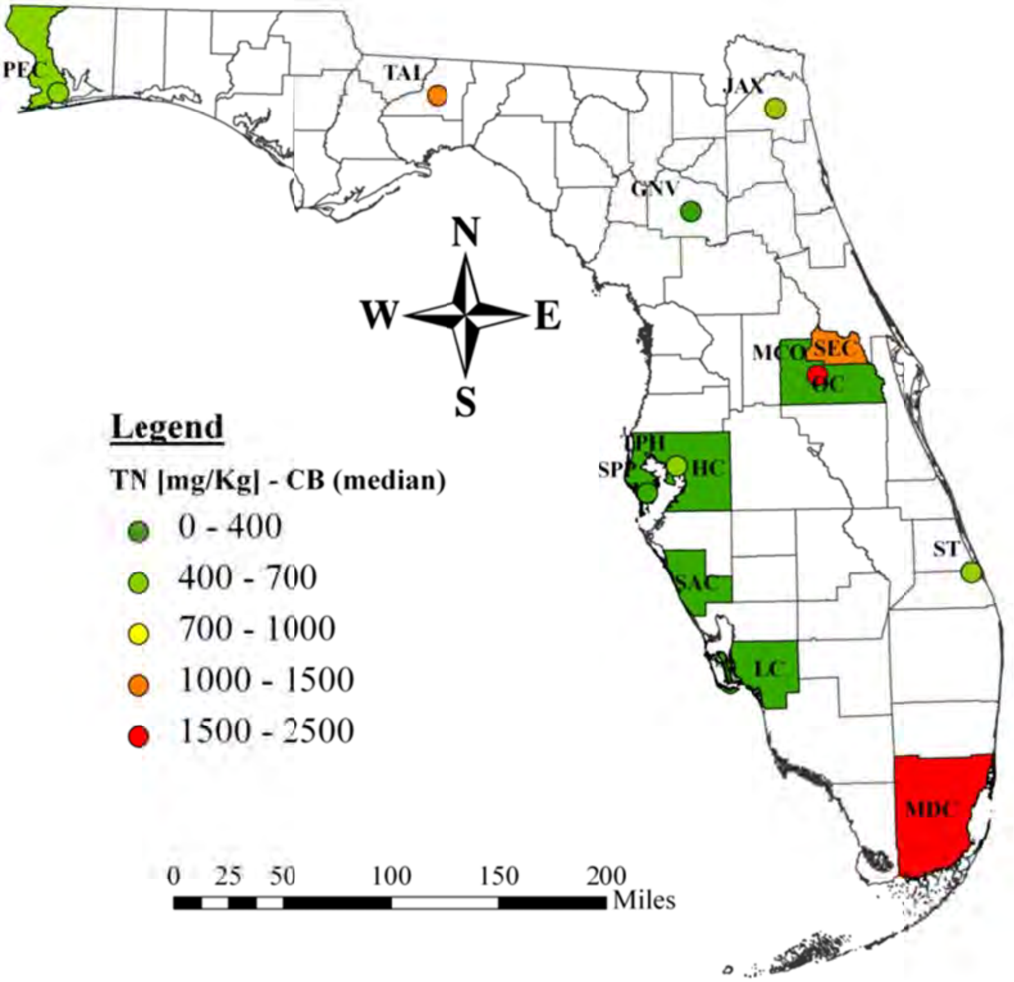

Figure 31 State-wide distribution of TN for catch-basins (CB)

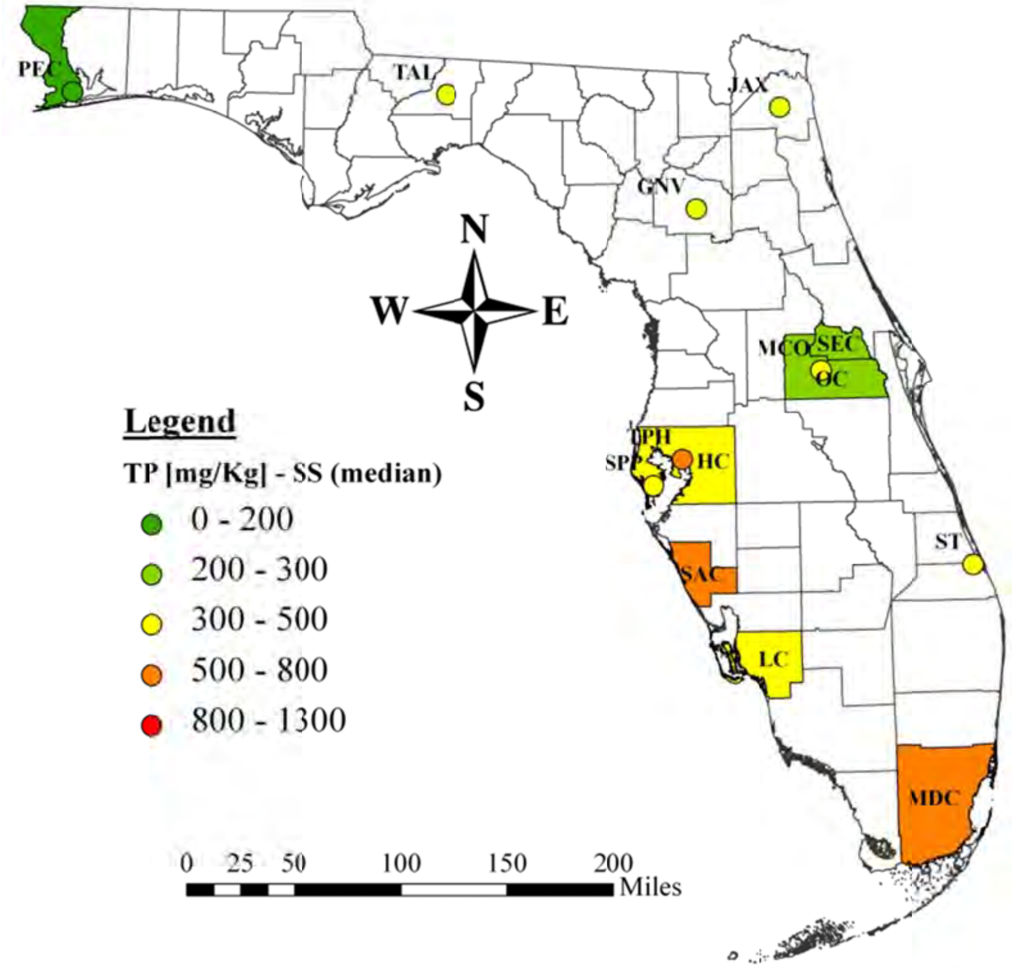

Figure 32 State-wide distribution of TP for street sweeping

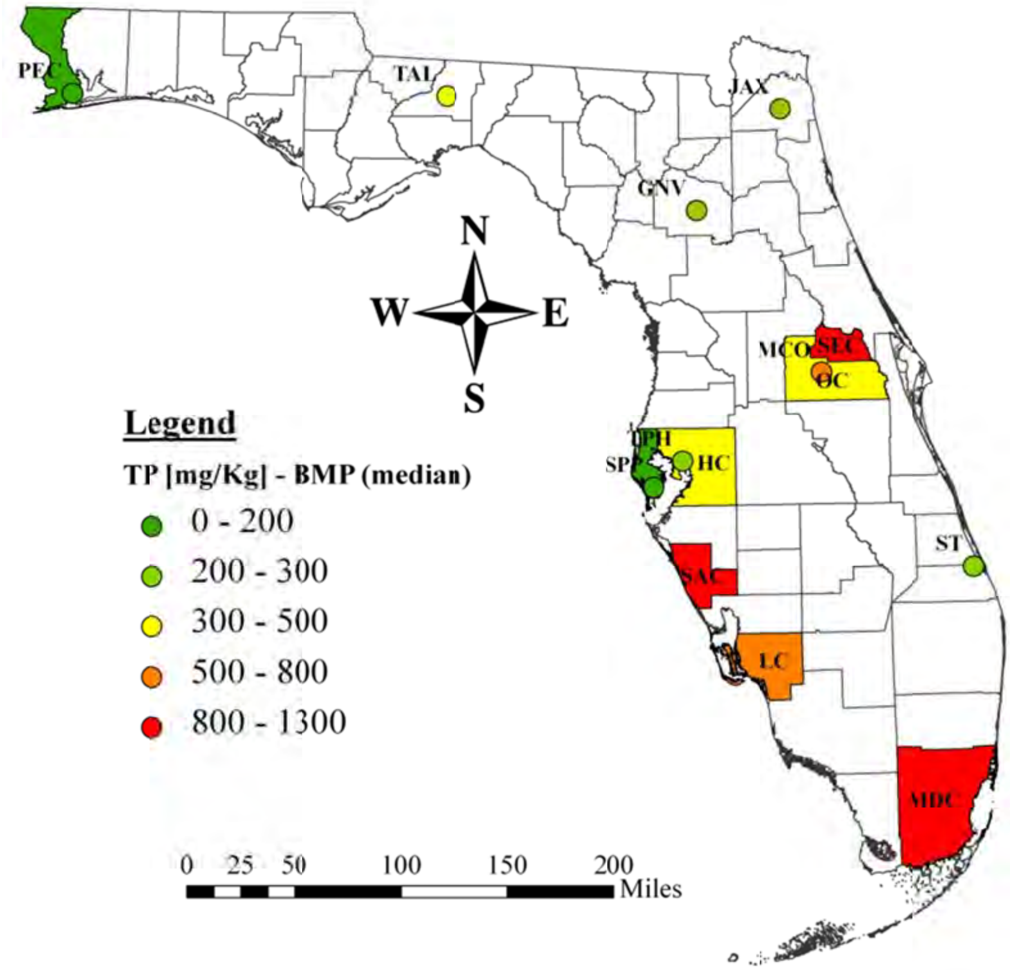

Figure 33 State-wide distribution of TP for best management practices (BMP)

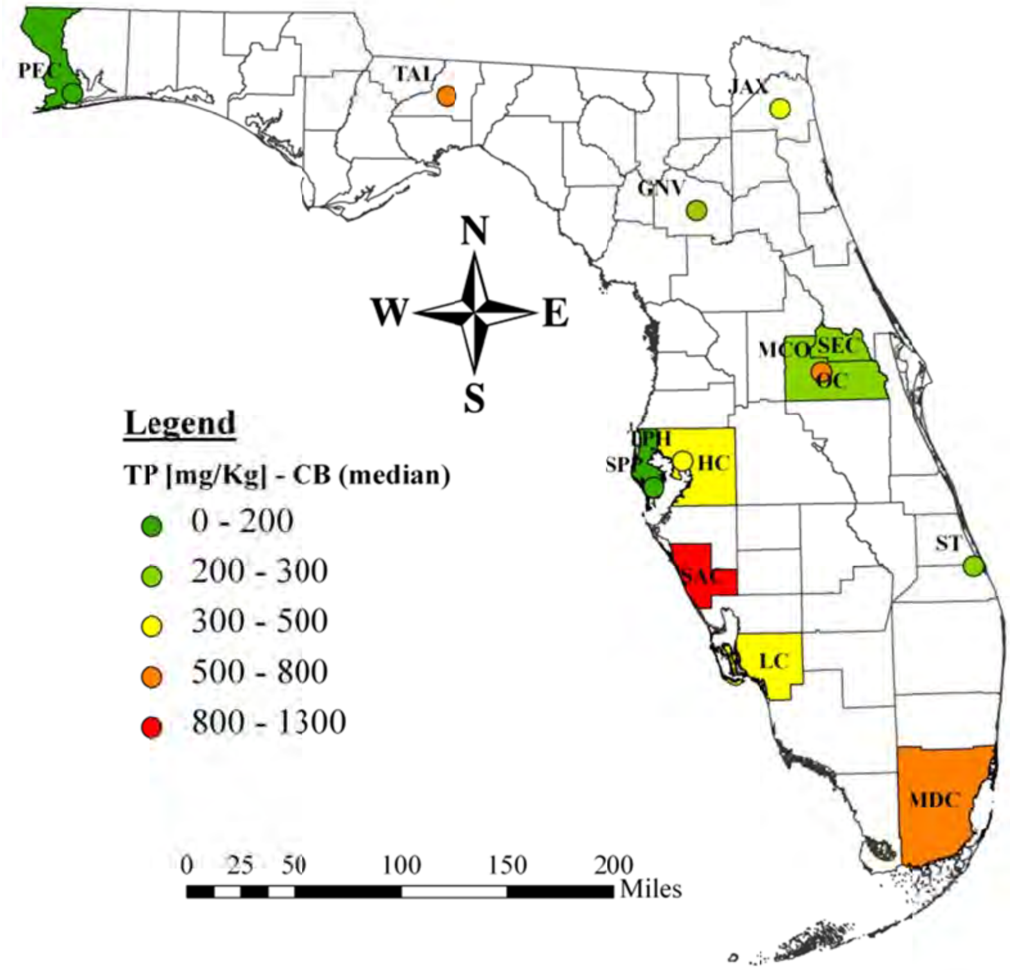

Figure 34 State-wide distribution of TP for catch-basins (CB)

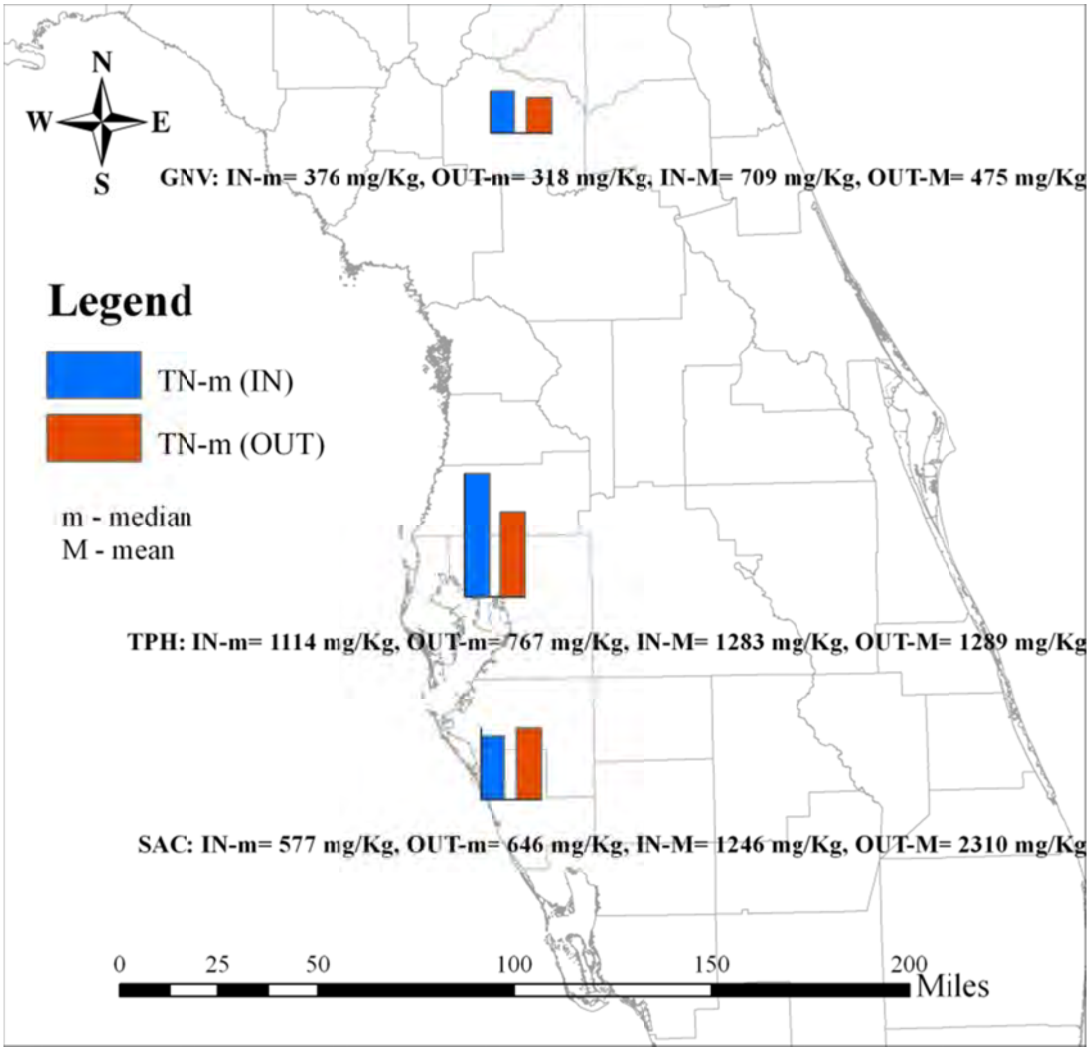

Figure 35 Comparison between TN measurements inside and outside the reclaimed water usage areas

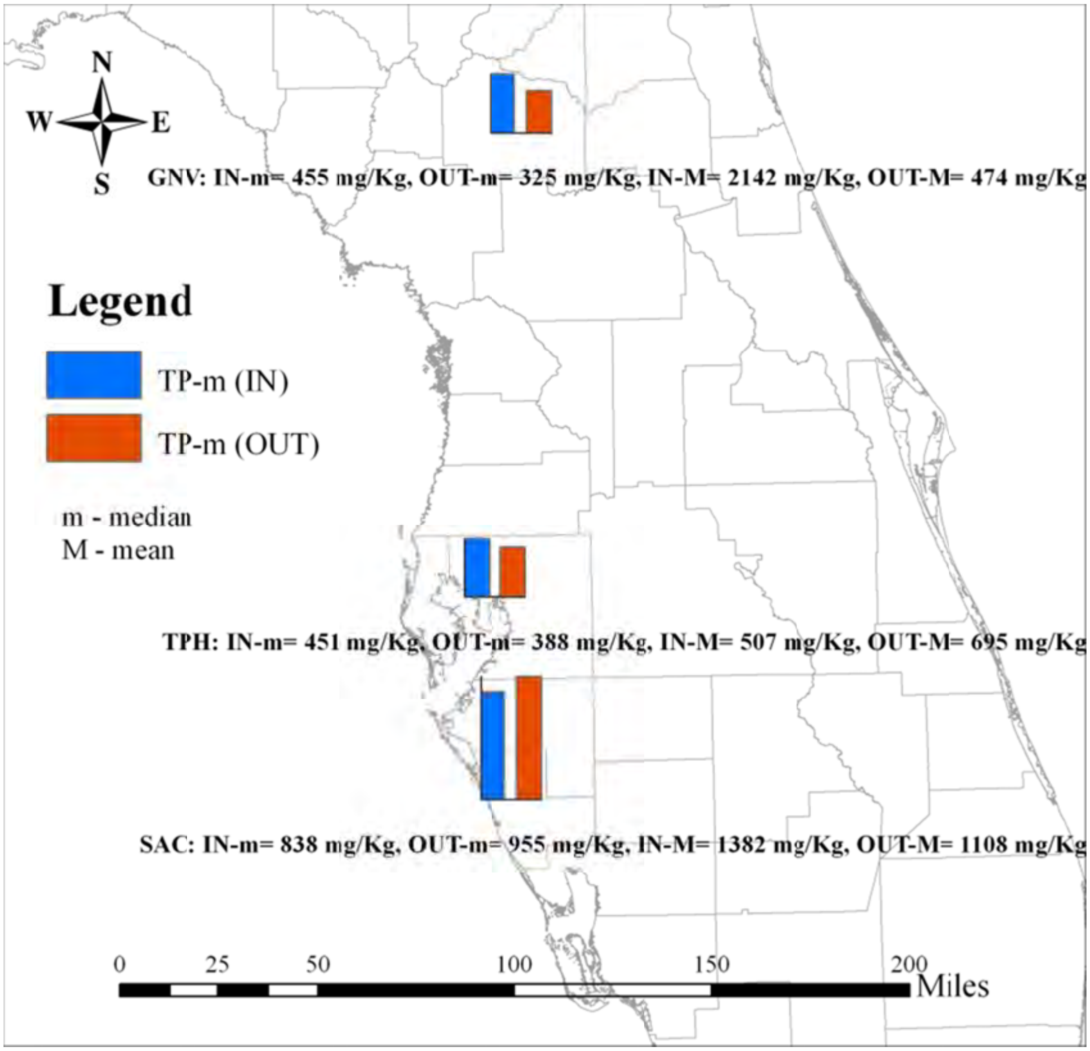

Figure 36 Comparison between TP measurements inside and outside the reclaimed water usage areas

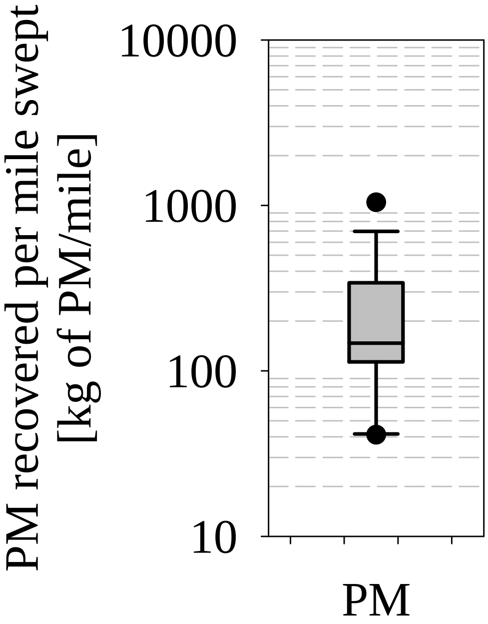

Figure 37 Box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values of the PM recovered through street sweeping. The dataset consisting of 67 recovered PM masses was created through the information provided by ten MS4 participating in this project.