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

Final Report Draft

To

Florida Stormwater Association Educational Foundation (FSAEF)

University of Florida (UF)
Department of Environmental Engineering Sciences (UF-EES)
Gainesville, Florida 32611 USA

Christian Berretta, UF
Saurabh Raje, UF
John J. Sansalone, UF

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EXECUTIVE SUMMARY

Day-to-day maintenance of urban stormwater (rainfall-runoff) management systems can significantly reduce pollutant load discharges that contribute to the impairment of urban receiving waters. In short, maintenance matters and quantifying the load recovery from maintenance activities is beneficial for all stakeholders. The hypothesis that maintenance matters and is also quantifiable is central for the implementation of the knowledge developed in this study and presented in this document. While this knowledge may not be revolutionary in that the results presented 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 largely gross solids, particulate matter (PM) and associated pollutants (such as nutrients) from the urban inventory of PM that are transported through and stored in stormwater management systems. With respect to this study, this PM contains 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, time, labor and materials. For 11 of the 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 each of eleven (11) of these MS4s twenty seven (27) samples from a series of three hydrologic functional units (HFU) were obtained. These HFUs consisted 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 category of this sampling matrix, three independent locations were utilized for sampling. In the remaining three MS4s, the same matrix of 27 samples was also taken as well as 27 paired samples from inside urban areas where reclaimed water was used. In total, four hundred and fifty nine (459) samples were recovered, delivered and analyzed.

Knowledge from this effort is categorized in terms of HFU and land use for nitrogen (N, as TN) and phosphorus (P, as TP). This study was designed to create a Florida-based metric for TN and TP and a sub-objective was to initially 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 BMP manufacturers promote differences between BMPs the reality is that such treatment differences are rarely if ever significant given a lack of BMP maintenance. While the Florida-based results indicate that there are differences between HFUs and differences between land uses, the analysis consistently indicates that the resulting set of metrics for TN and TP are log-normally distributed. This observation is critical to the allocation

of load credits because the results are not represented by a singular concentration [mg/kg] but by log-normal distributions of concentration 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 the results leads to the use of the median (50th percentile) concentration 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. 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 should not 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 with a maintenance practice.

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

Results in this study further indicate that reclaimed wastewater irrigation does add N and P loads to the urban environs as determined for 3 MS4s utilizing reclaimed wastewater. The effect of this additional nutrient load is somewhat muted in the resulting distributions from this study for several reasons. HFUs such as structural BMPs and catch basins do not capture dissolved and suspended nutrients that dominate the N and P loads of reclaimed wastewater and can represent a significant fraction of source area stormwater loads. However, results demonstrate there is enrichment of the much coarser PM recovered by all HFUs including street sweeping.

In summary, results from this study reinforces the knowledge that source controls, including urban maintenance practices such as street sweeping and catch basin cleaning, can be a very cost effective tool in reducing stormwater pollutant loads. For a large MS4 with potentially thousands of BMPs to be maintained, such controls and practices have been shown to be more economical and environmentally-sustainable than site-based structural BMP systems that are expensive, rarely maintained and of marginal load reduction benefit when unmaintained, as compared to effective source controls, maintenance practices and hydrologic restoration.

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, almost two decades ago Smith et al. (1993) demonstrated that 48% of 410 water chemistry monitoring sites did not meet the widely accepted USEPA level of 0.10 mg/L at that time, as total P (TP). One impact of eutrophication and PM delivery is oxygen depletion (anaerobic conditions) in unmaintained stormwater appurtenances such as catch basins, unmaintained BMPs such as wet detention basins or hydrodynamic separators, 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 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 proposed 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 analysis of the probabilistic distribution) as “box and whisker” plots or for 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 of the report. The path of nutrients transported by 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 storm water system or directly to a receiving water. For perspective, Figure 1 illustrates the major water bodies around Florida. The potential recipients of nutrient loadings from the HFUs of this study are both fresh and saltwater receiving waters down-gradient of storm water 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 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), extractable P, total Kjeldahl nitrogen (TKN), nitrate-nitrogen (NO_3^{-1}-N) and total ammonia nitrogen (TAN). Extractable N includes extractable nitrate and extractable ammonia, which can be determined by same extraction procedure, then determined by different analysis. 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 concentrations (mg per dry kg of PM) similar to studies of other urban constituents (Maestre and Pitt 2005). Results predominately illustrate lognormal distributions for both TN and TP. The lognormal distribution of the results indicates that the representative statistic is the median (the 50^{th} percentile). However, results are also summarized through box plots which provide non-parametric statistical measures for the median, upper (75^{th}) and lower (25^{th}) quartiles and minimum and maximum values for comparisons made within the study program. Given the predominance of the lognormal distributions ($\alpha \leq p = 0.05$), results are predominately compared based on the median of the distribution.

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. Regarding street sweeping no appreciable difference has been observed among different land uses for TP. In this study highways are landscaped and vegetation delivers biogenic material to the impervious areas. In addition P from highways 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.

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 was performed on the regions followed by the Dunn's test for pair-wise comparison. 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 ($p = 0.05$) 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. The City of Tampa does display a considerably 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, the cities of Gainesville and Tampa display higher median values for samples within the reclaimed areas as compared to those outside reclaimed areas. Sarasota County again shows an opposite trend, with its OUT median value being higher than the IN value. It may also be observed that in some cases, the mean values are markedly higher than their corresponding median values. This indicates that in certain cases there are a few individual locations or hot spots that contain considerably higher nutrient content than others.

This shows that the effect of reclaimed water may potentially depend 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 be ruled out given that effluent TN and TP form POTWs are typically on the order of 2 to 10 mg/L without advanced nutrient treatment**.** This study was not primarily designed to study how the individual POTW reclaimed water influences TP and TN loads their respective discharge areas, but simply to observe the potential effects of reclaimed water usage on PM-based nutrient loads in comparison to loads from areas without reclaimed water usage.

Nutrients removal cost using non structural solutions

The costs of PM and nutrients removal through street sweeping or catch basin cleaning is compared with structural solutions like BMPs. A number of MS4s have provided information on the amount of PM swept in regular cleaning procedures and the values range from 20.8 to 1210 kg of PM/mile swept (clearly there is potential error associated with this wide range of results provided by the MS4s), with mean and median of 266 and 144 kg PM/mile swept (Figure 37). From the findings of this study it is possible to associate a mass of P and N to the PM swept. In particular for TP the mean and median concentration values are respectively 513 and 361 mg of TP/kg of PM for sample collected through street sweeping and 552 and 417 mg of TP/kg of PM for sample collected in catch basins. As regard TN, the mean and median values are respectively 1012 and 563 mg of TN/kg of PM for sample collected through street sweeping and 1729 and 679 for sample collected in catch basins. In these calculations the median values are used.

The cost of street sweeping activities vary depending on several factor such as the sweeper type, mechanical or vacuum assisted, that have different purchase costs, lifetime and operation and maintenance, but also the cleaning frequency affect the costs (Finley, 1996; SWRPC, 1991; Satterfield, 1996; USEPA, 1999). An early published costs for street cleaning was $68 per curb mile and approximately 11 curb miles per day were swept (Ferguson et al., 1997). 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 – 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 costs of street sweeping by subcontractors is considered in order to not take into account the sweeper purchase expense and maintenance. A cost of $30.14 per curb mile was contracted between Florida Department of Transportation (FDOT) and a street sweeping company as reported in a City Commission Agenda Item Report no. 9 of January 9th 2011 of the City of Oakland Park, Florida. This cost is used in the calculations.

With respect to CB cleaning costs, the 2010 cost data from St. Petersburg, FL is $38.20 to $45 per catch basin. These costs are based on one operator for 10-12 basins/day (10 hr work day) and a truck. Truck cost = $50.00/day, labor = $280/day (which includes benefits) and disposal = $90/day. These costs do not include solid waste landfill disposal (on the order of $25 to $35/ton). Based on this information Table 8 and Table 9 provide the costs for PM and nutrient control through structural and non-structural solutions as a function of PM removed based on the information provided by eight MS4. The lowest costs to remove mass of N and P are clearly associated with street sweeping and CB cleaning as compared to the use of structural BMPs. The costs do not include solid waste landfill disposal, which ranges from $21 to $48 per tons of dry solid waste in Florida, and if a BMP is maintained this cost category also applies for the BMP.

As an example the procedure to calculate nutrient removed by street sweeping is shown for TP:

1) Measure the PM mass removed through sweeping and convert to a dry weight based on measurement of moisture content. As an example the value from Jacksonville residential areas recovered through sweeping was 468 kg of PM/mile swept.
2) Calculate the TP associated to the PM recovered by using the median value in Table 2 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. By multiplying this value by the conversion factor 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, 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 increasing the frequency of street sweeping practices. Not only can the frequency increase, but a flexible sweeping schedule depending on rain events, especially for Florida during the dry season, can improve the recovery efficiency. The same calculations can be performed for catch basin cleaning or BMP maintenance.

CONCLUSIONS

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.

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

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 is significantly lower than current structural BMPs, assuming such BMPs are maintained. While the essence of the study is summarized in the above table the study was not designed to compare MS4 to MS4, BMP to BMP or between BMP classes. Any result utilized from this study must be referenced back to this study report to provide a foundation for the result.

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Table 1 List of Types of BMPs and their locations

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 analysed

BMP Classification	**IN**	**OUT**
Pond (Basin)	10	11
Baffle Box	1	27
Swale, Ditch or Sediment Accumulation	11	35
Manufactured BMP	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 Particulate matter phosphorus concentration mean, median and standard deviation values for each HFUs and for different 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 Particulate matter nitrogen concentration mean, median and standard deviation values for each HFUs and for different land uses.

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

Table 7 Median PM-bound TP and TN concentrations per each MS4 independently of the land use or HFU.

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

Separation or Recovery Method	Cost ($/lb)		
	TN	TP	PM
BMP Treatment Train[a]	935	32,600	26
Street Sweeping	170	264	1
Catch Basin Cleaning*	563	917	1

[a]Wet basin sedimentation followed by filtration

*Based on 100 lb PM recovery

Table 9 PM and nutrients removal costs for street sweeping practices based on the information provided by 8 MS4 on PM recovered per mile swept.

PM recovered through sweeping (kg/mile)		Cost ($/lb)		
		TN	TP	PM
Minimum	40.8	594.8	927.7	0.3
25th percentile	113.4	214.1	334.0	0.1
Median	143.6	169.1	263.8	0.1
75th percentile	279.9	86.7	135.3	<0.1
Maximum	1210.3	20.1	31.3	<0.1

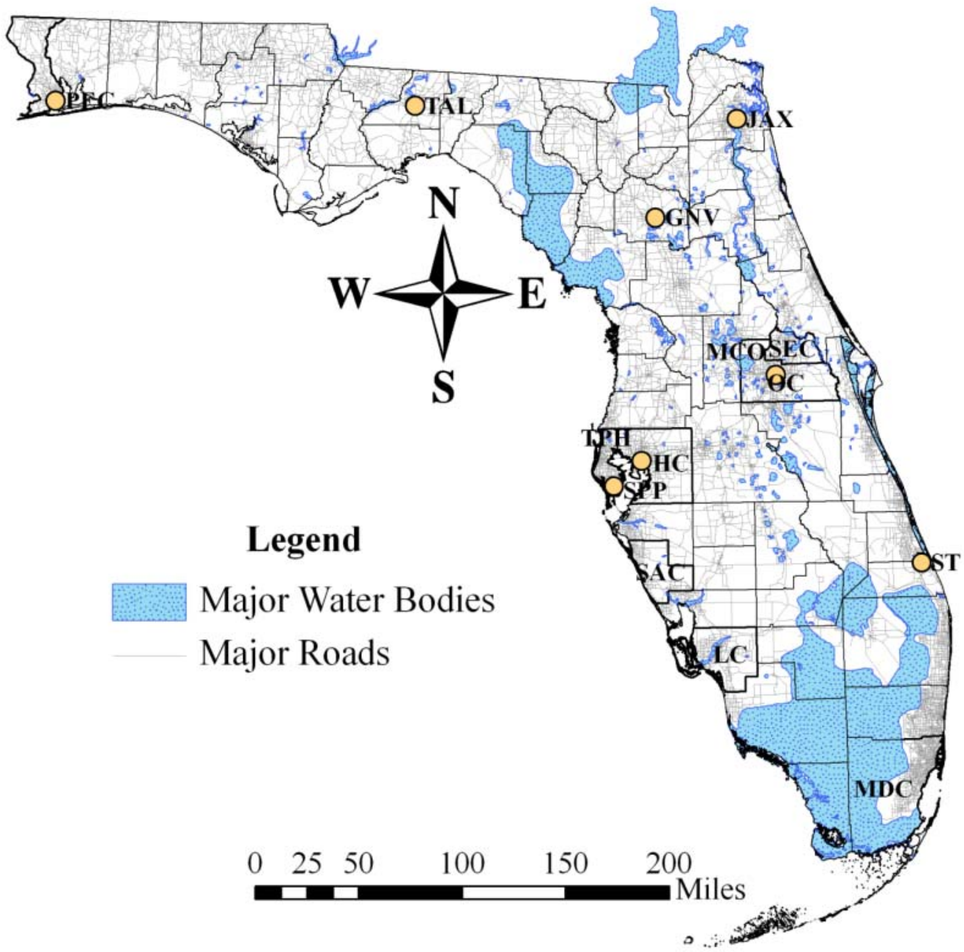

Figure 1 Water Bodies and Major Roads across Florida

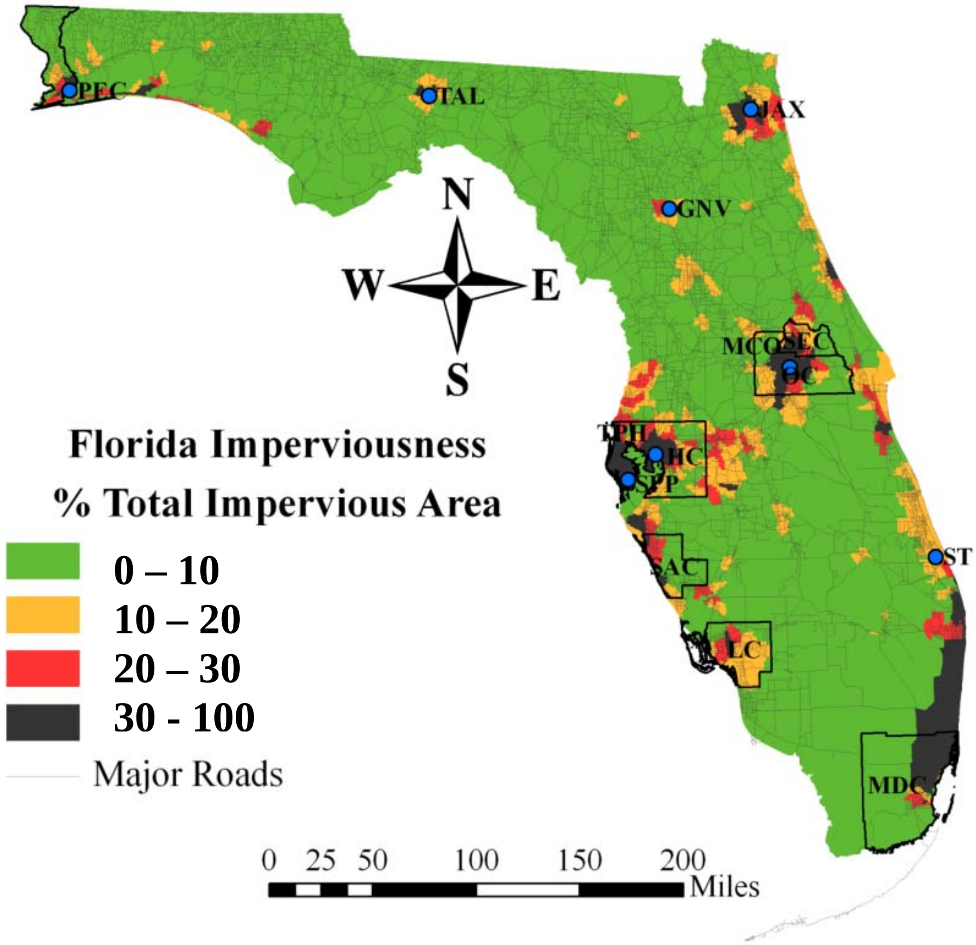

Figure 2 % Total Impervious Area for the State of Florida

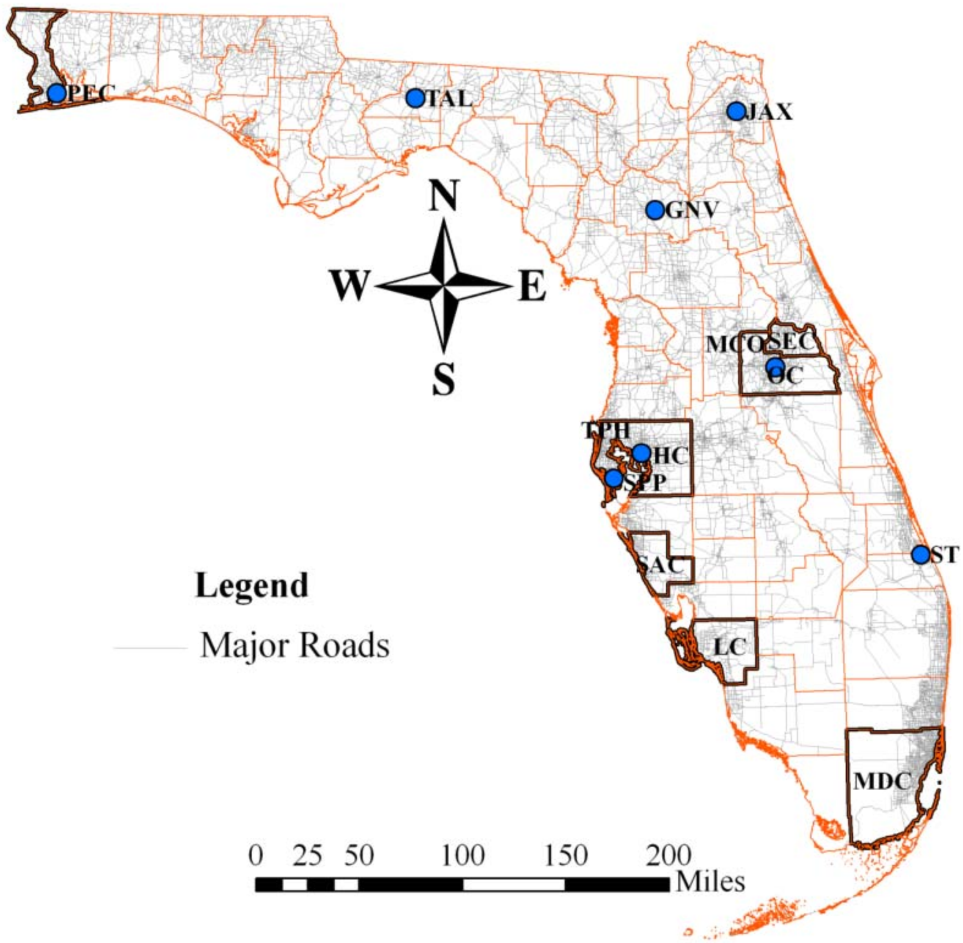

Figure 3 State-wide Distribution of MS4 Sampling Locations

Figure 4 Cleaning of a street sweeper prior to sampling

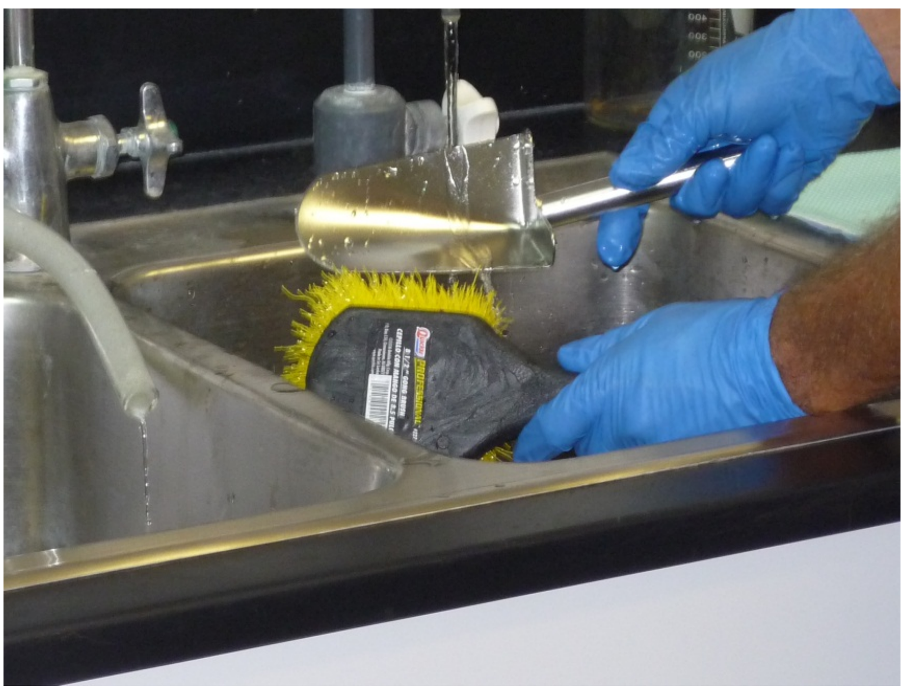

Figure 5 Cleaning of sampling equipment

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

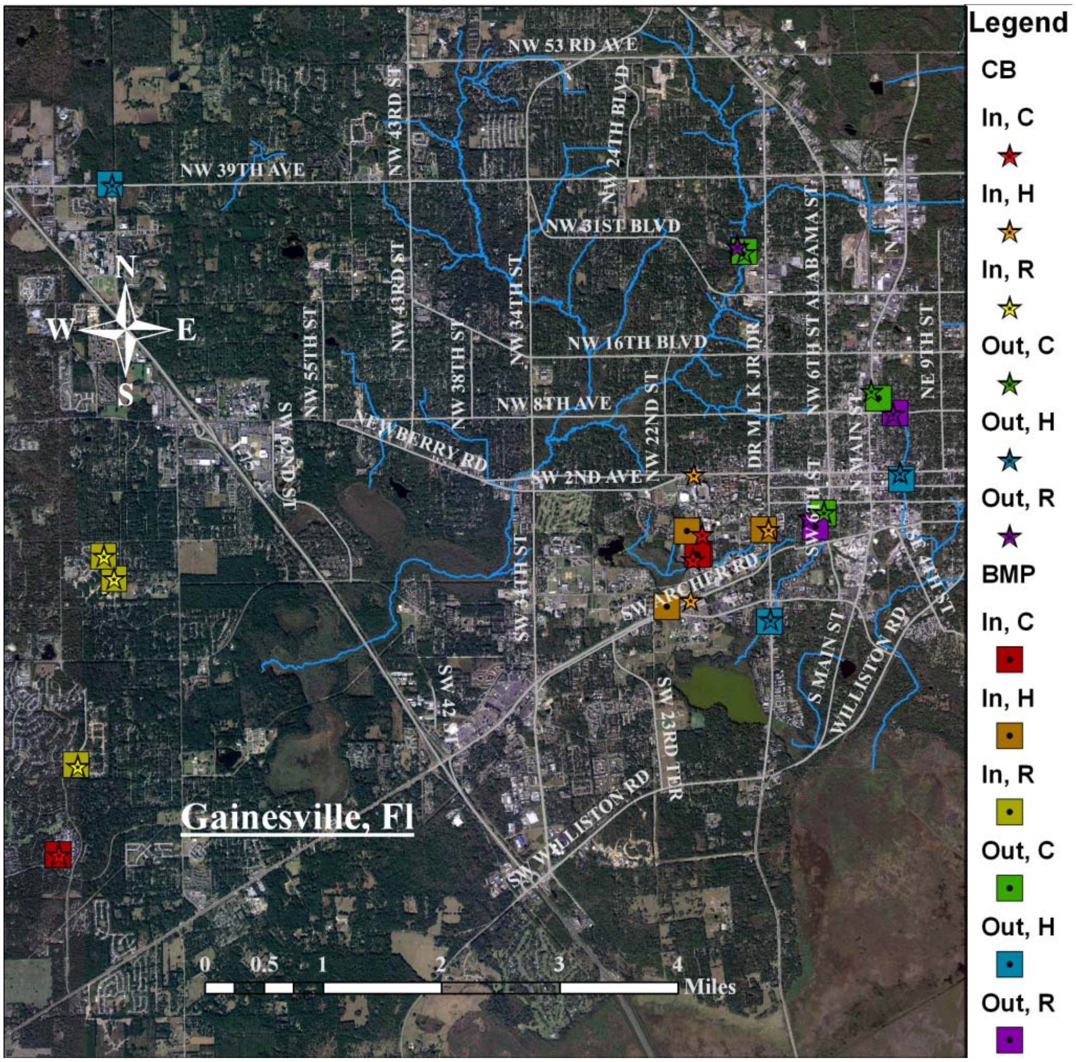

Figure 10 Spatial Information Example - Gainesville BMP and CB Locations

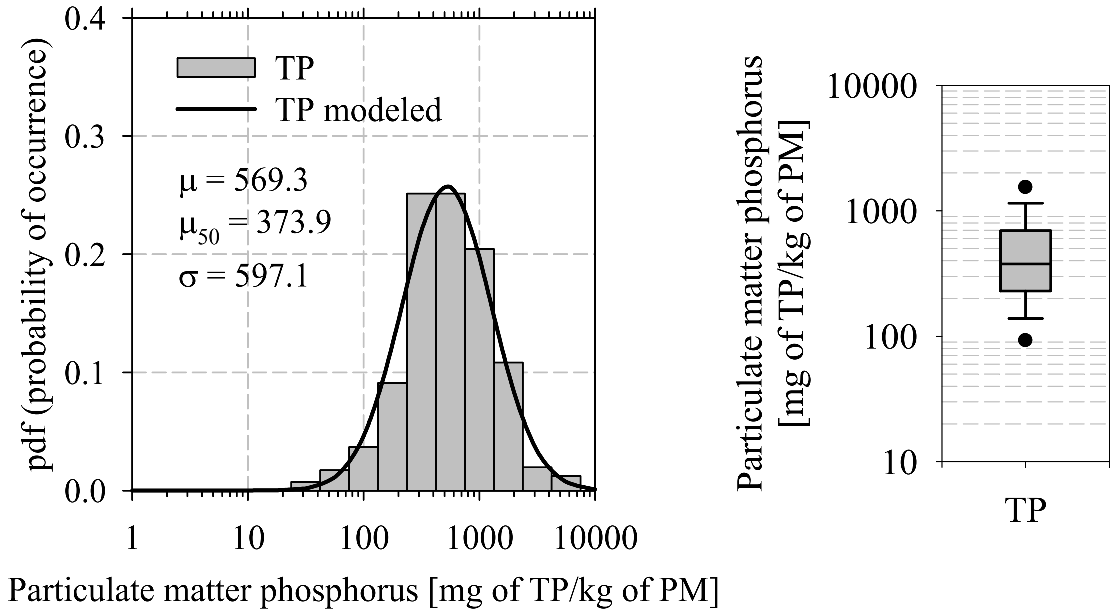

Figure 11 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter phosphorus data and box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values across the whole monitoring program. The mean (μ),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

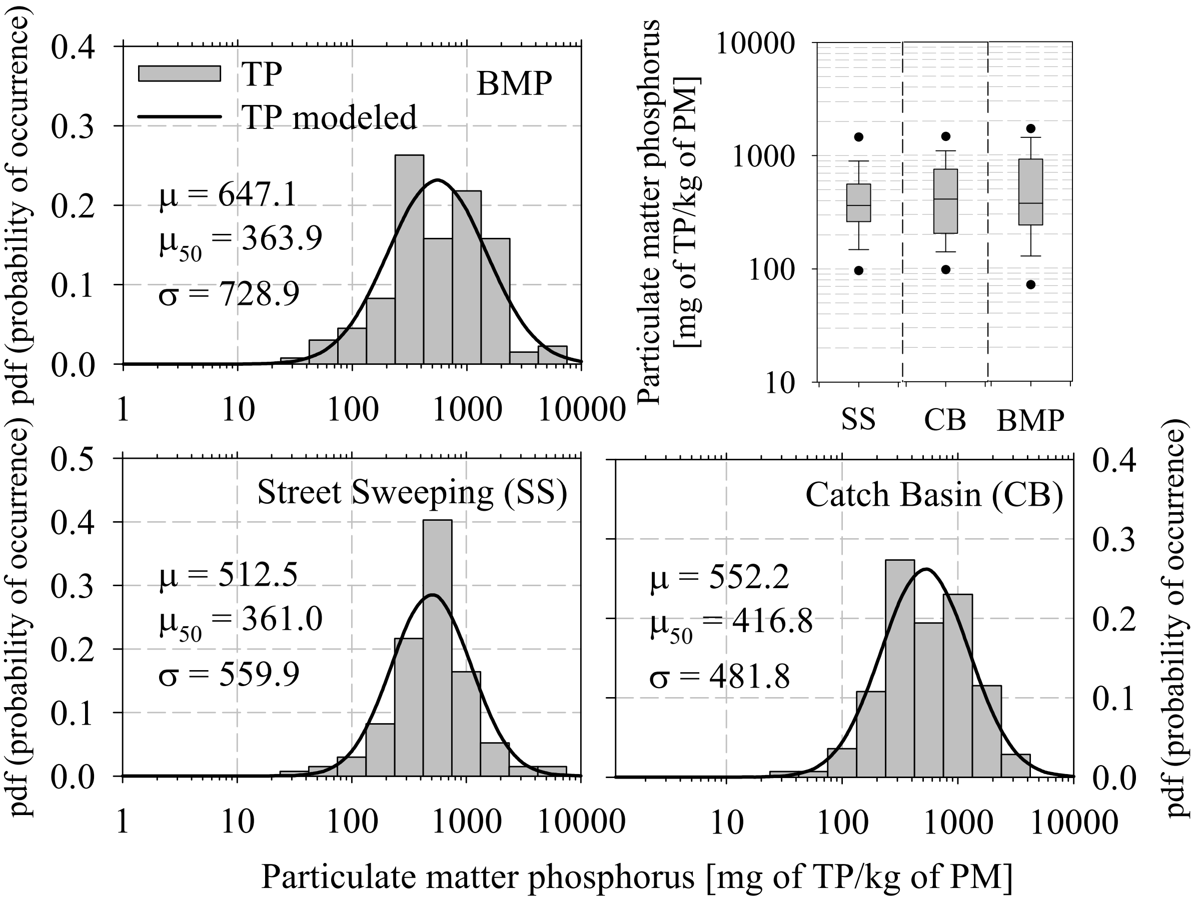

Figure 12 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter phosphorus data and box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values across the whole monitoring program for different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

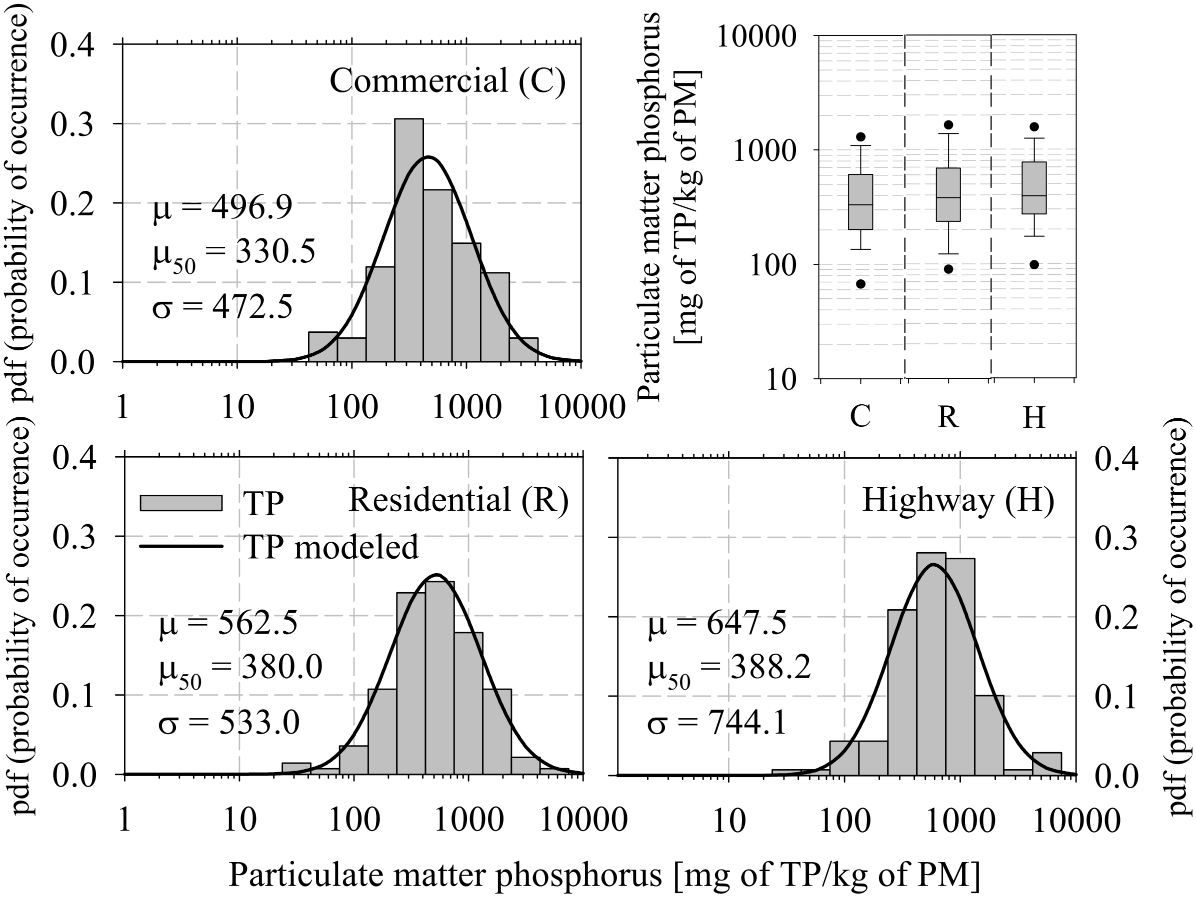

Figure 13 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter phosphorus data and box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values across the whole monitoring program for different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

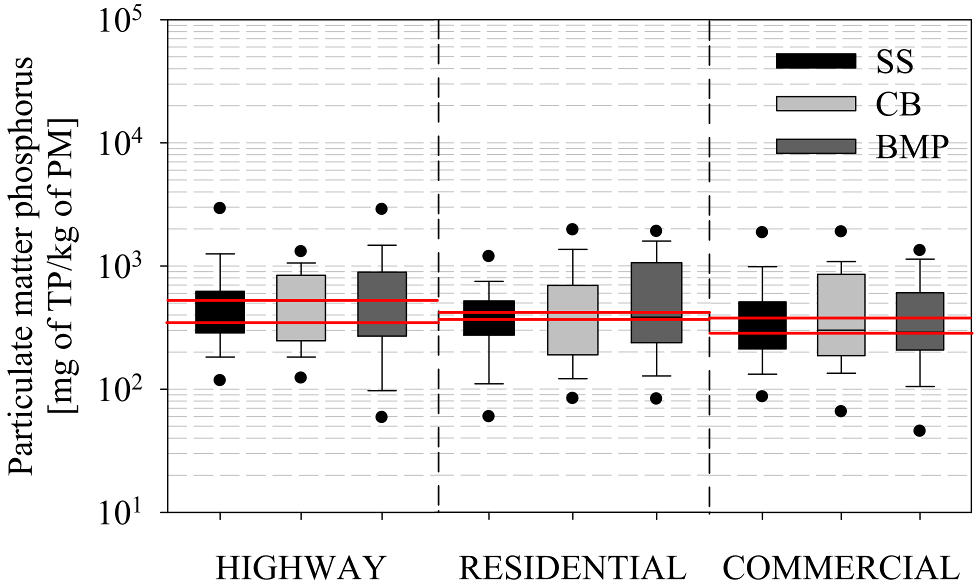

Figure 14 Box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values of the particulate matter phosphorus data across the whole monitoring program for each HFU and within areas characterized by different land uses. The range of variation of the median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

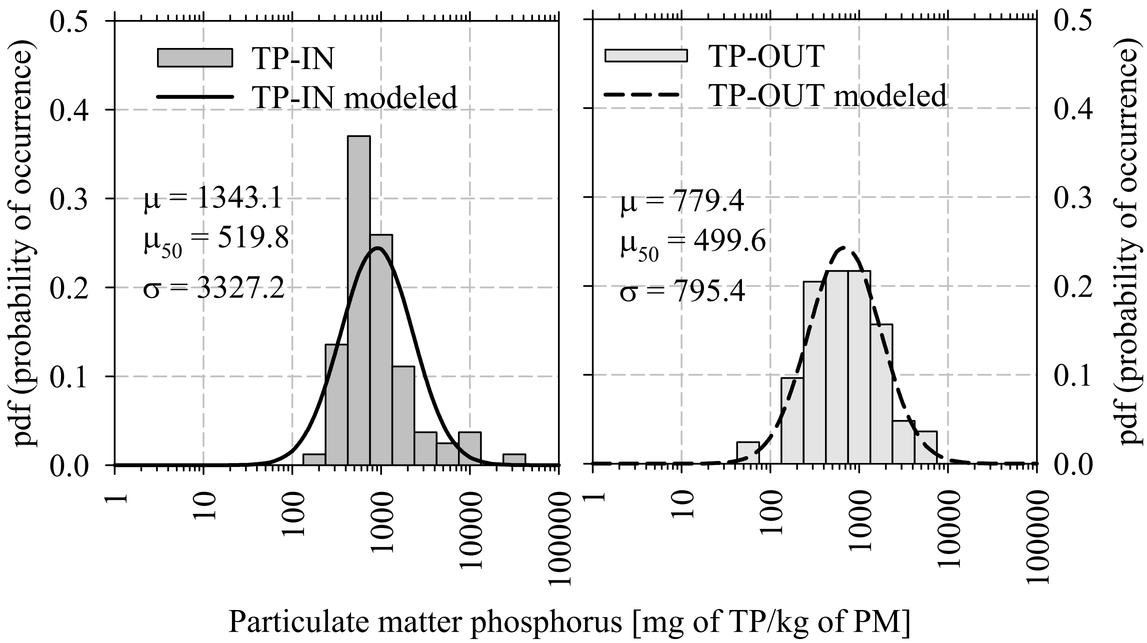

Figure 15 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter phosphorus data for samples collected inside and outside reclaimed areas. The mean (μ), median (μ_{50}) and standard deviation (σ) are also reported.

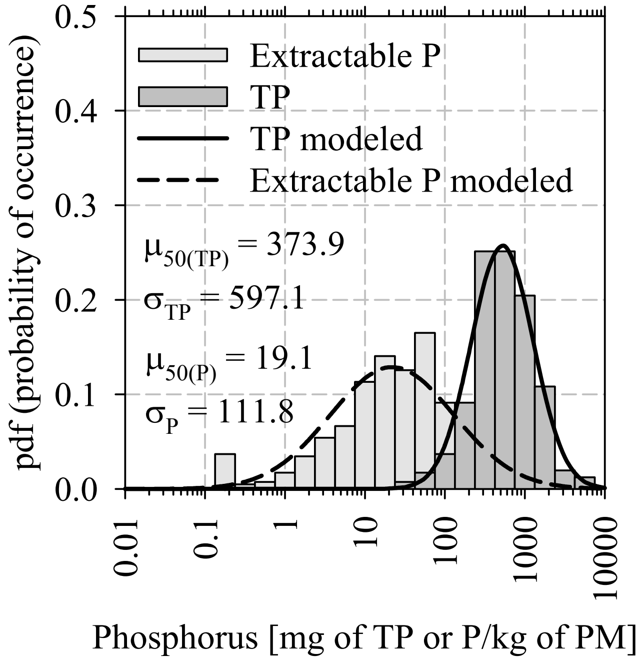

Figure 16 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter total phosphorus (TP) and extractable phosphorus (P) data across the whole monitoring program. The mean (μ) and standard deviation (σ) are also reported.

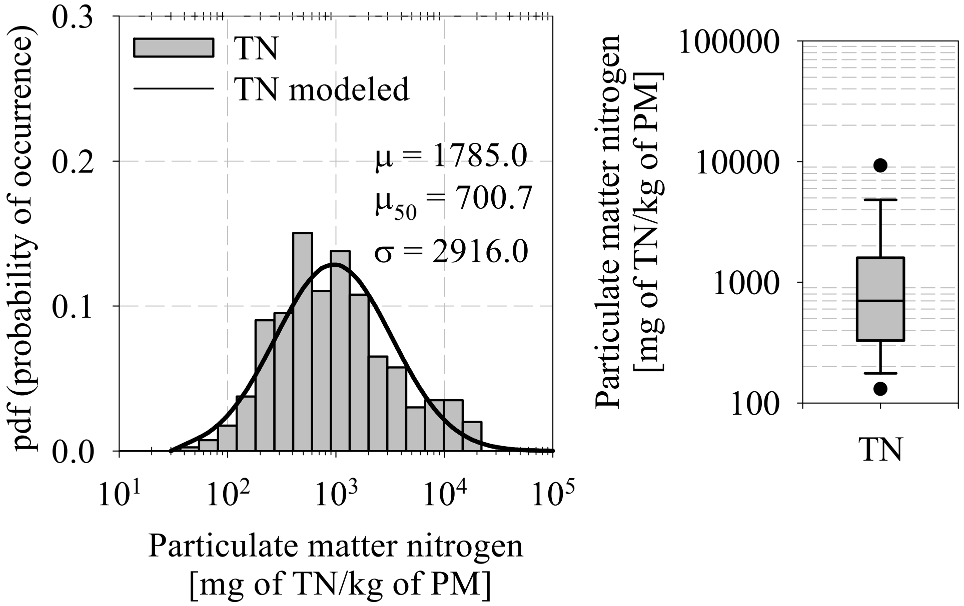

Figure 17 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter nitrogen data and box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values across the whole monitoring program. The mean (μ),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

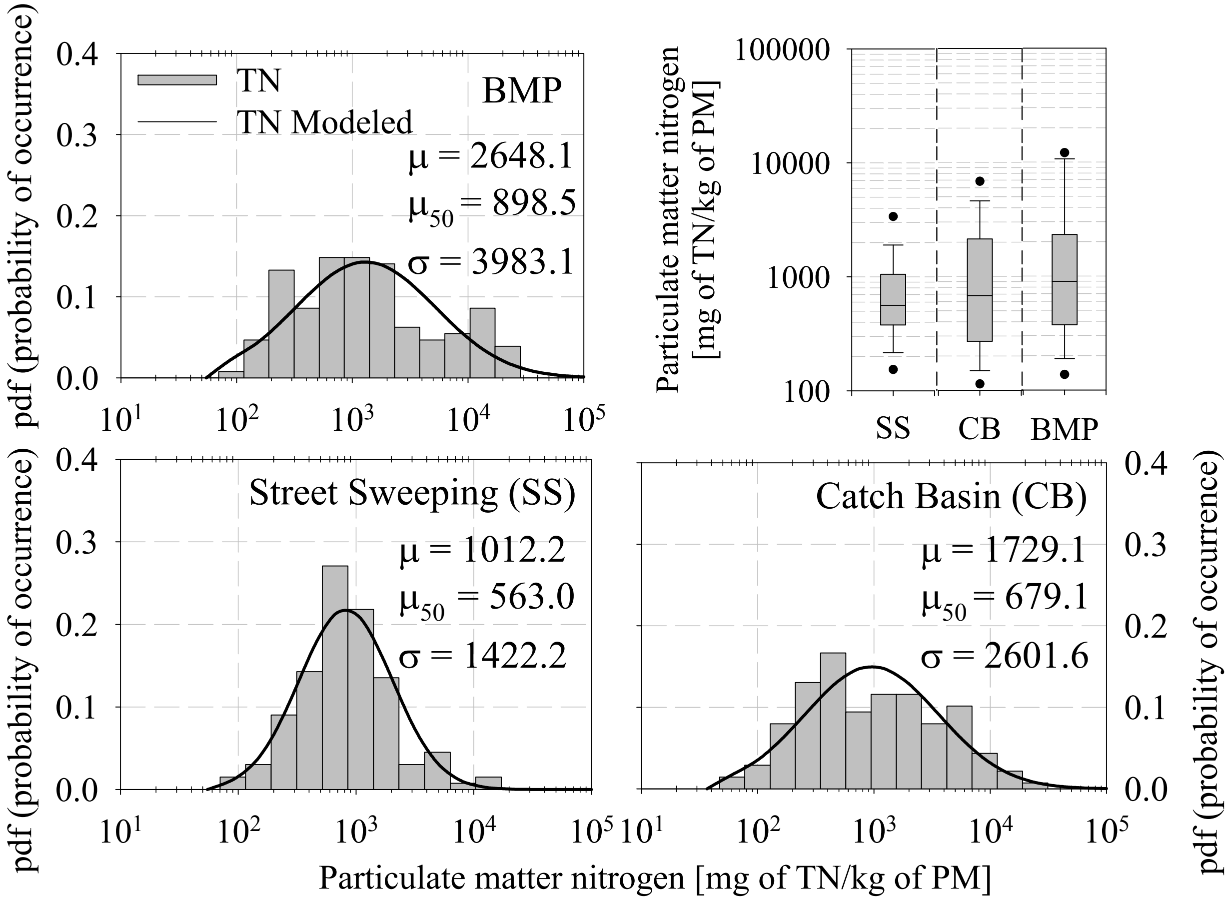

Figure 18 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter nitrogen data and box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values across the whole monitoring program for different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

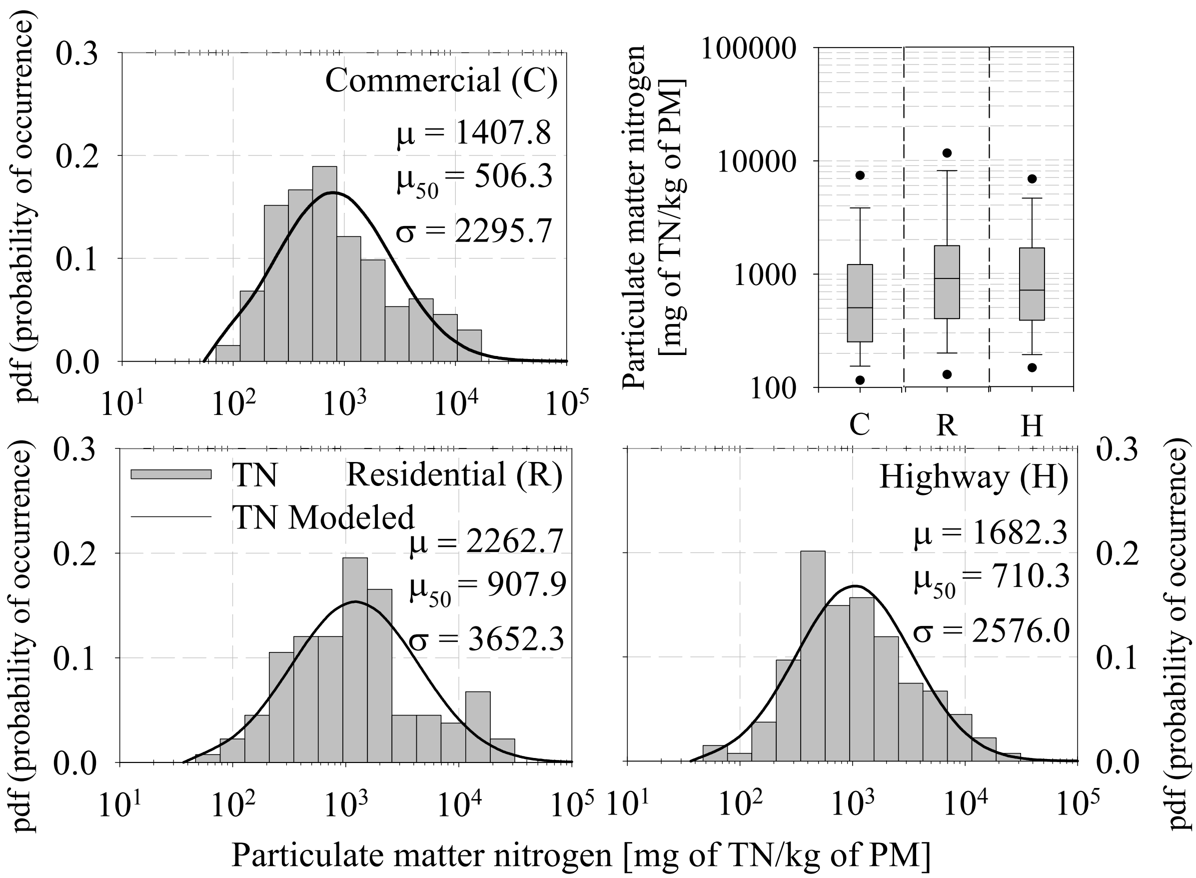

Figure 19 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter nitrogen data and box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values across the whole monitoring program for different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

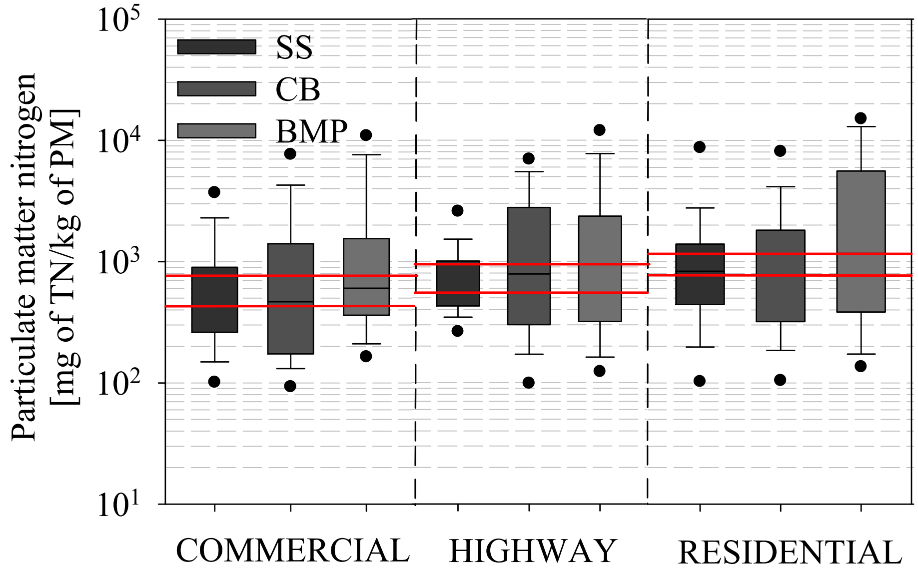

Figure 20 Box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values of the particulate matter nitrogen data across the whole monitoring program for each HFU and within areas characterized by different land uses. The range of variation of the median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

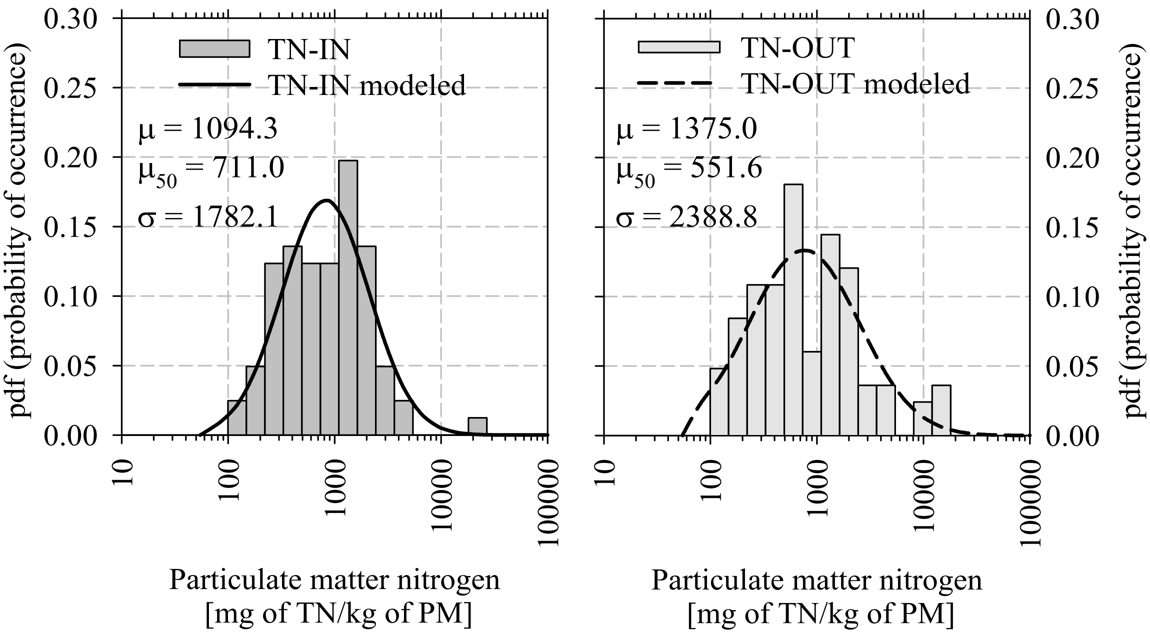

Figure 21 Probability density function curves (pdf) expressing the probability of occurrence of the particulate matter nitrogen data for samples collected inside and outside reclaimed areas. The mean (μ), median (μ_{50}) and standard deviation (σ) are also reported.

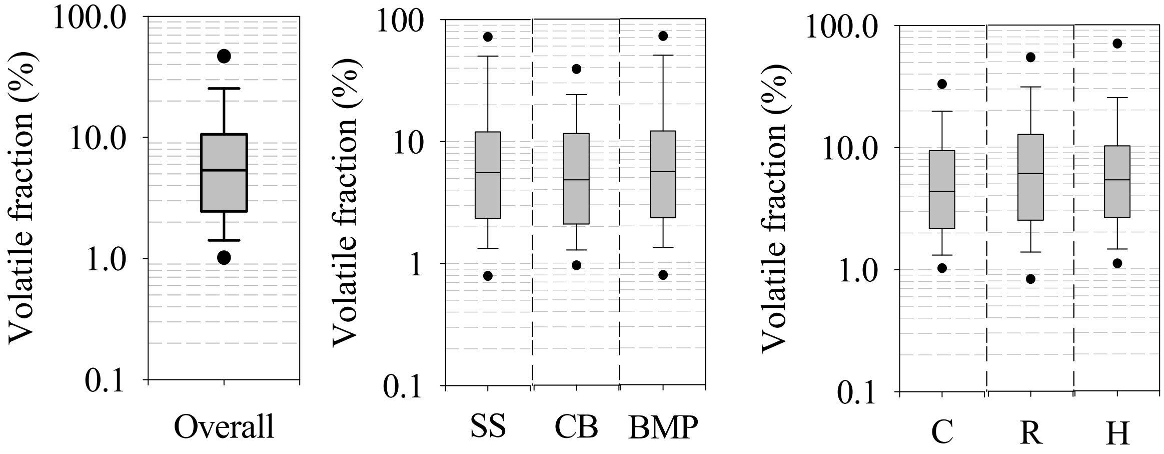

Figure 22 Box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values of the volatile fraction across the whole monitoring program, for different HFUs and within areas characterized by different land uses.

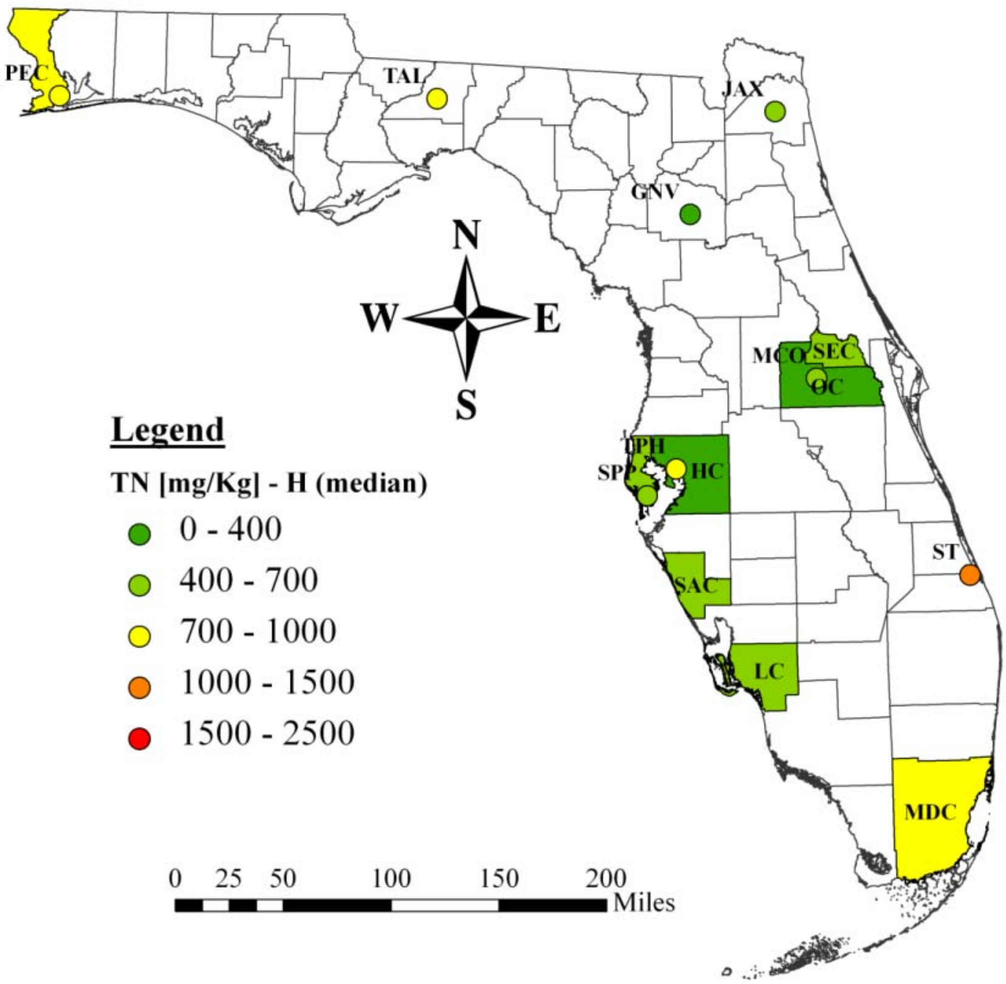

Figure 23 State-wide distribution of TN for Highway land use

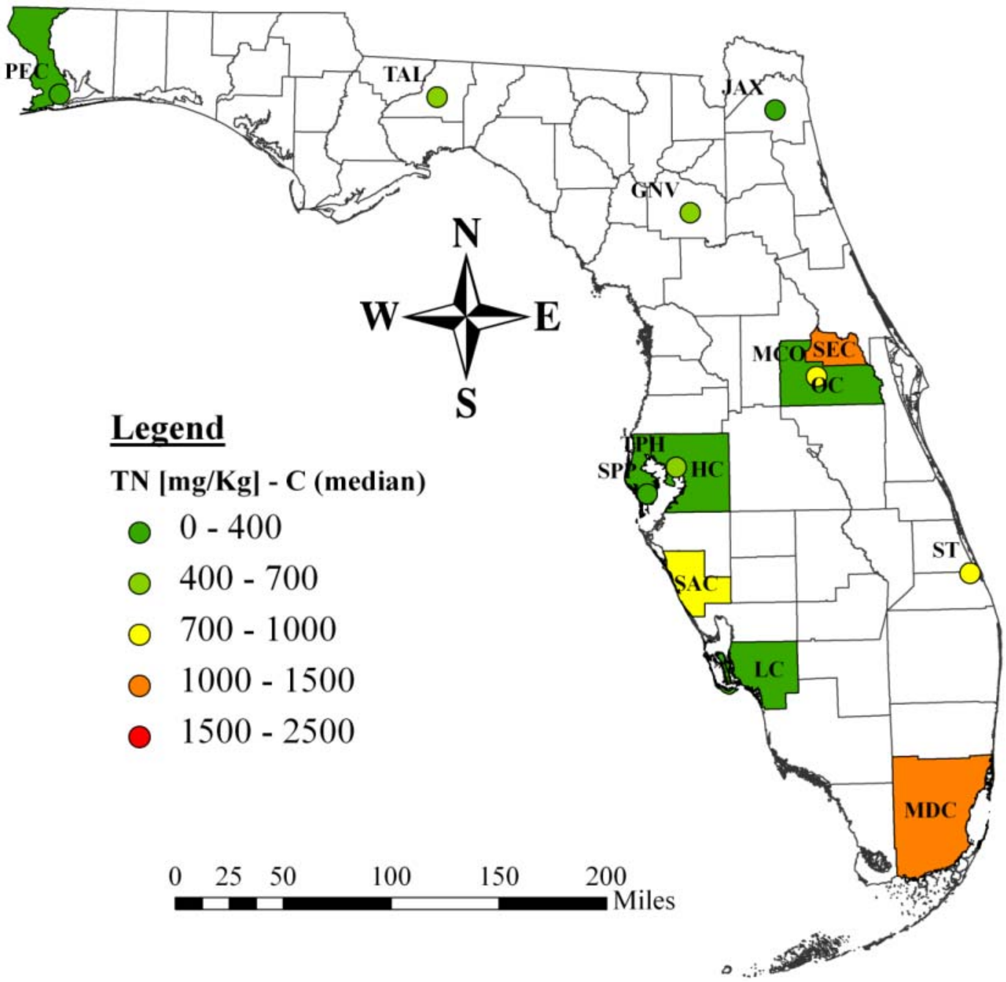

Figure 24 State-wide distribution of TN for Commercial land use

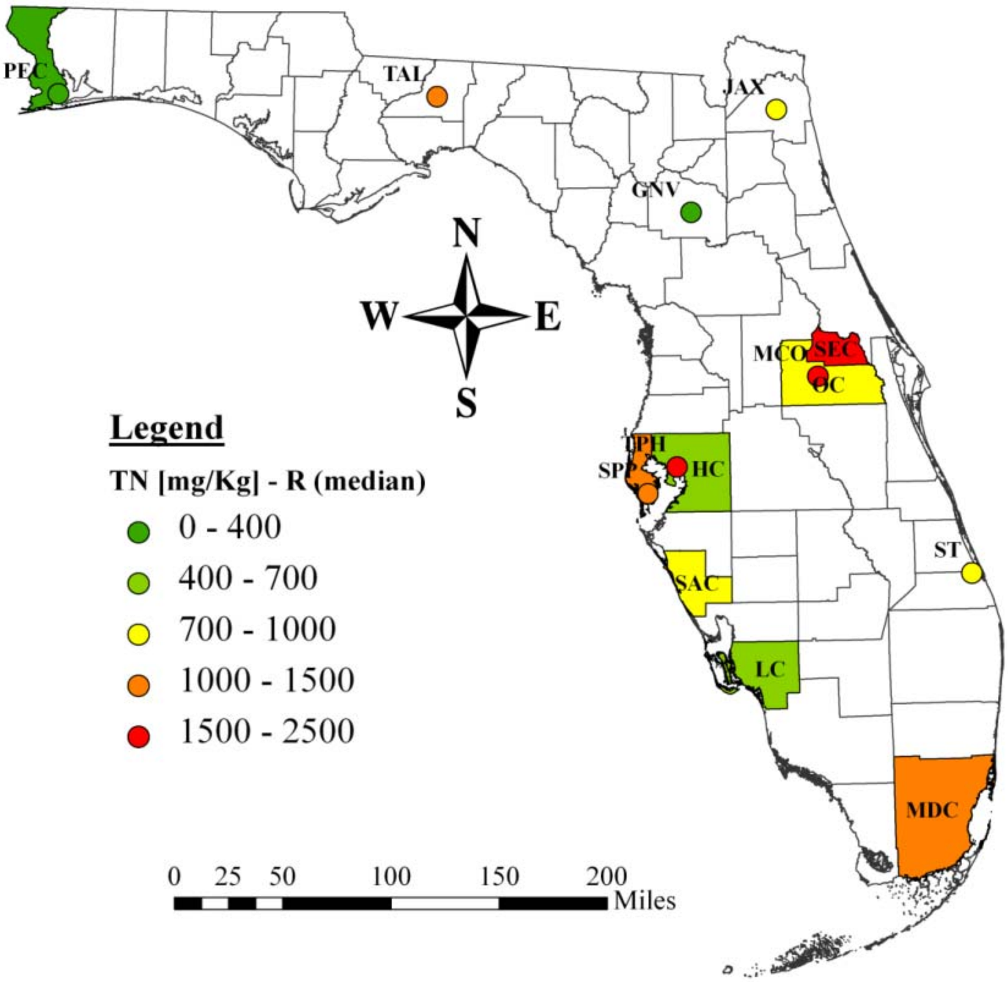

Figure 25 State-wide distribution of TN for Residential land use

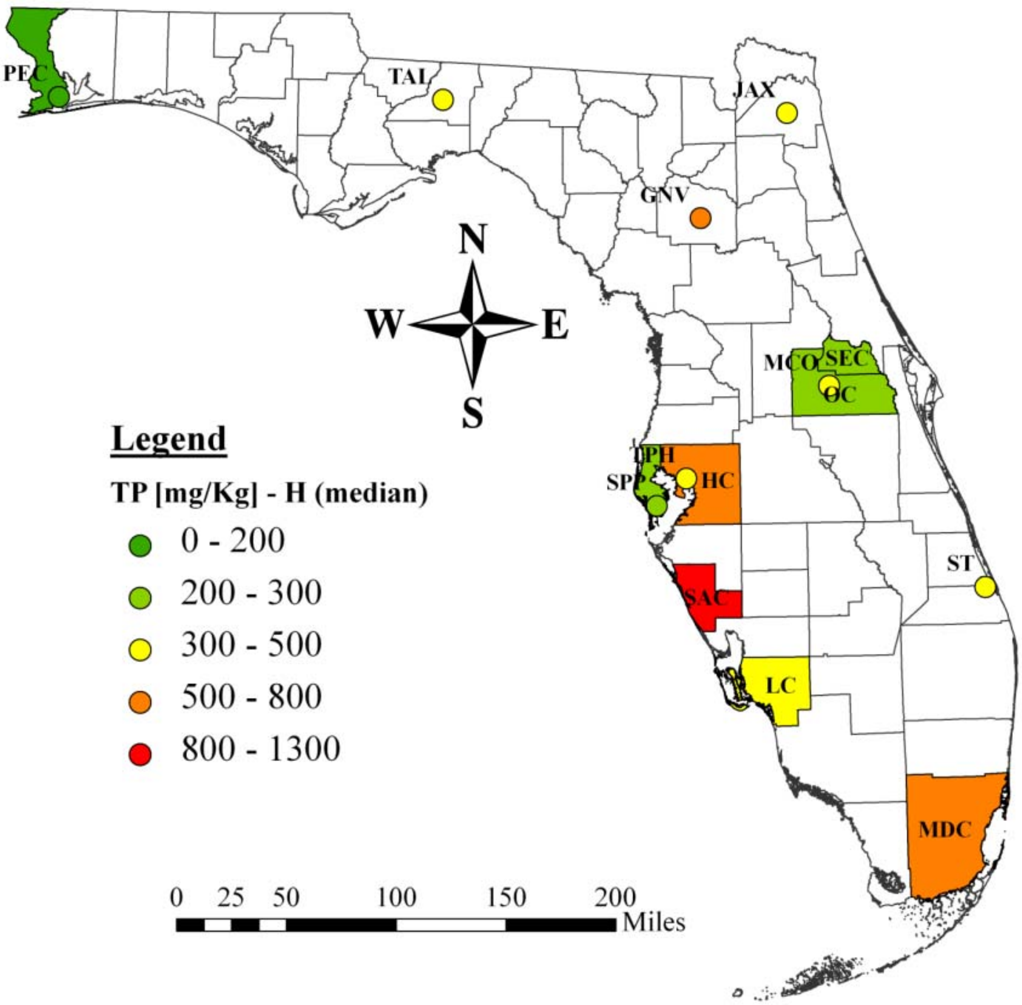

Figure 26 State-wide distribution of TP for Highway land use

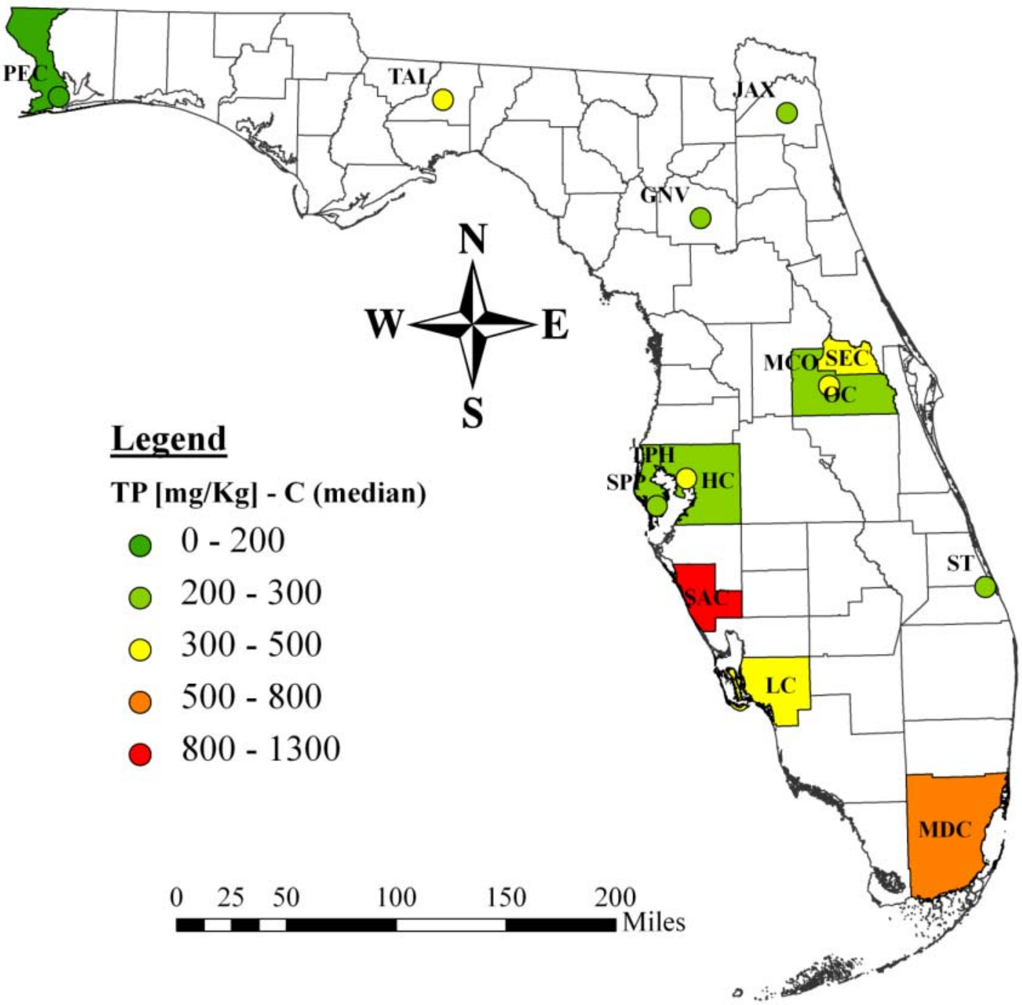

Figure 27 State-wide distribution of TP for Commercial land use

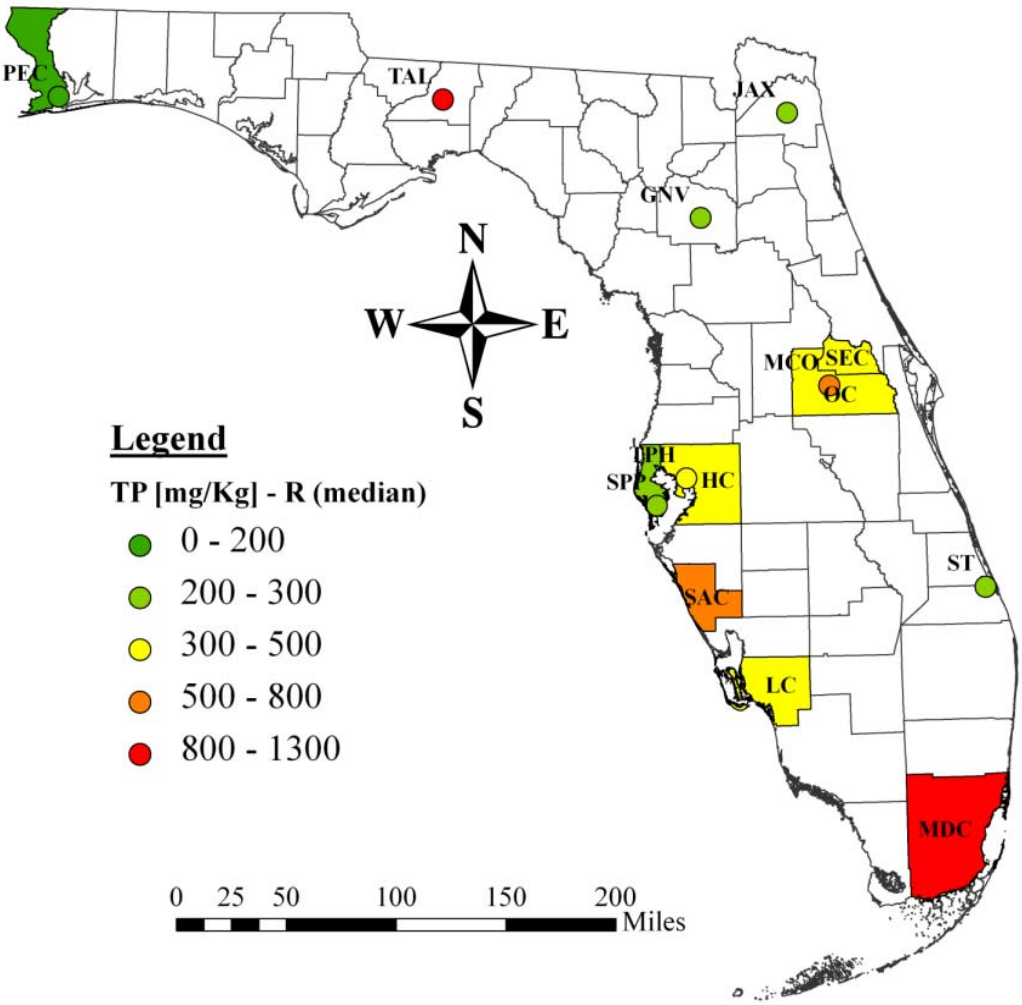

Figure 28 State-wide distribution of TP for Residential land use

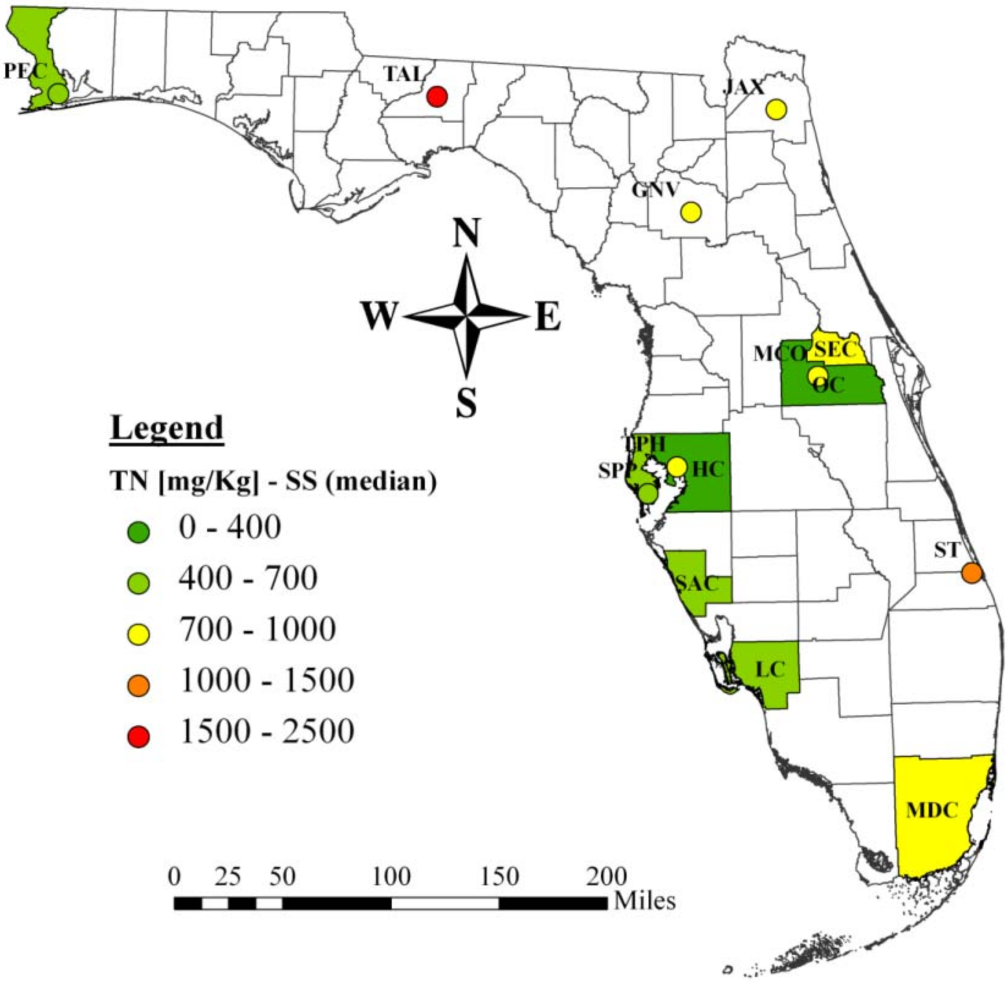

Figure 29 State-wide distribution of TN for Street-Sweepings

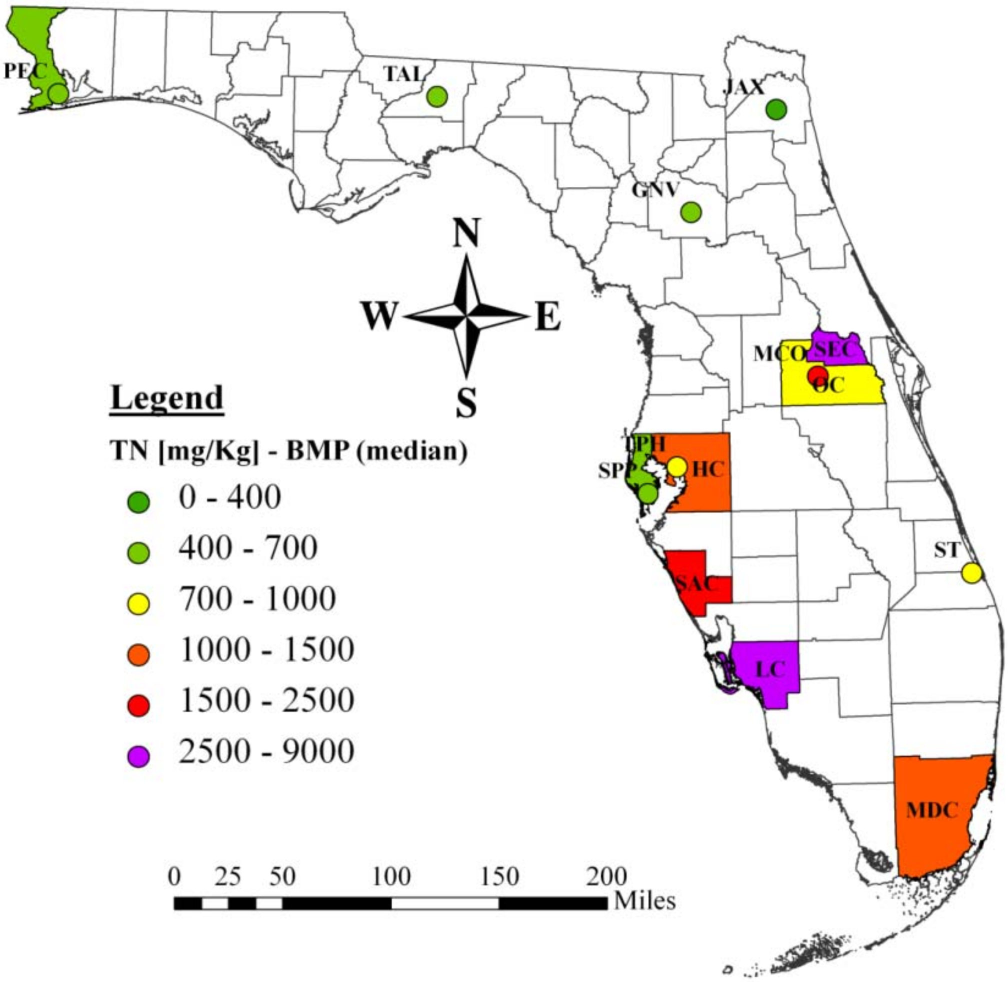

Figure 30 State-wide distribution of TN for Best Management Practices

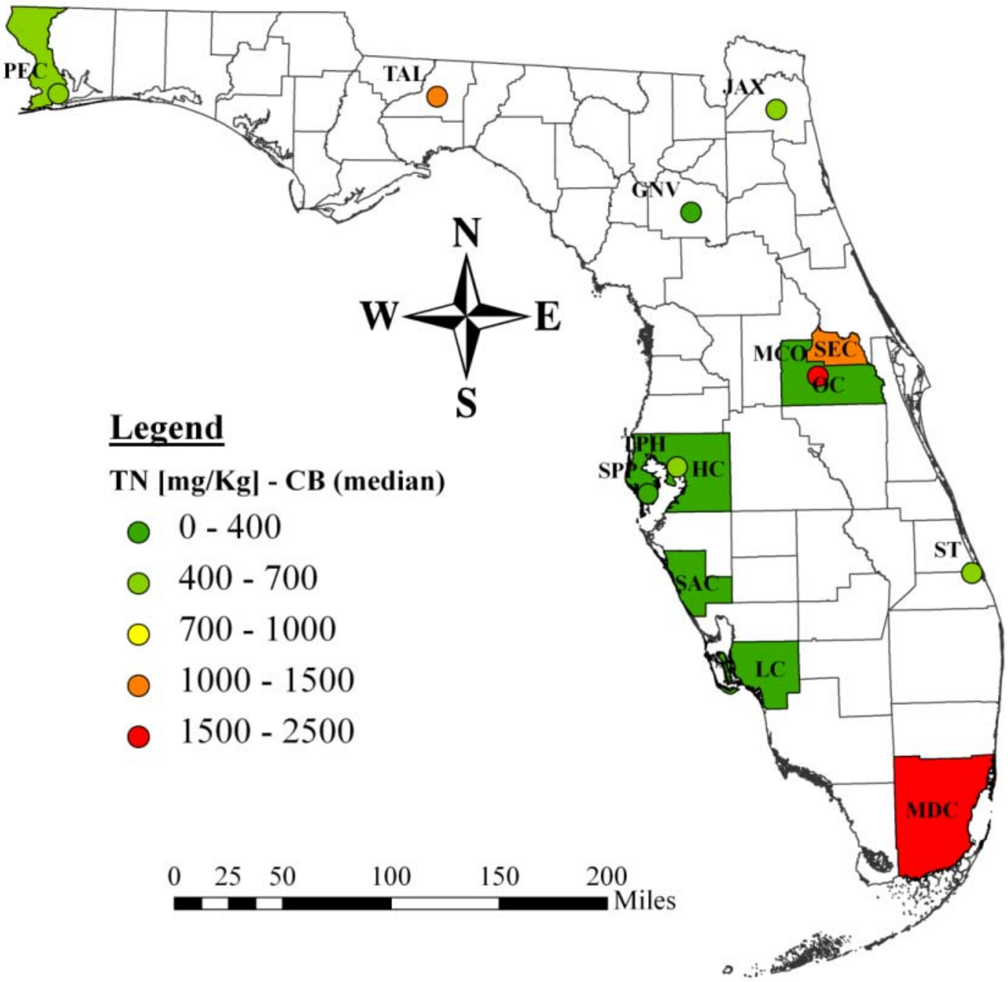

Figure 31 State-wide distribution of TN for Catch-basins

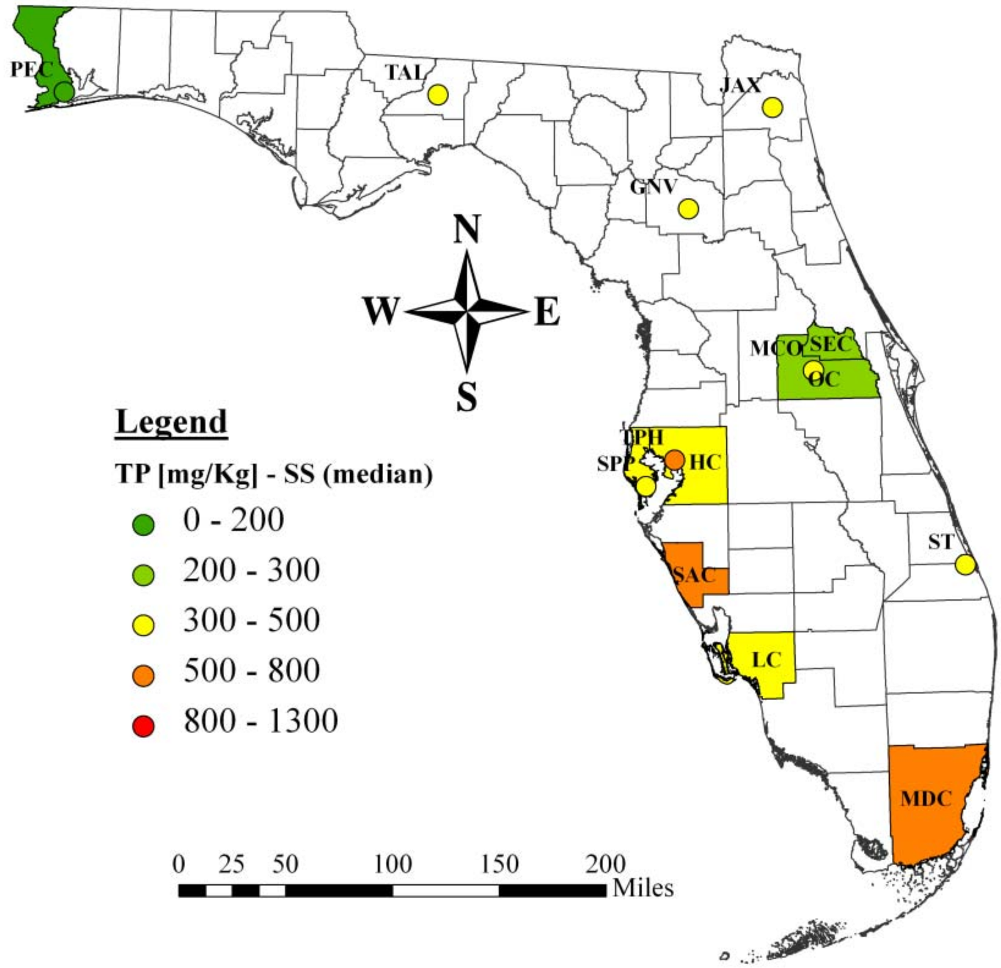

Figure 32 State-wide distribution of TP for Street sweeping

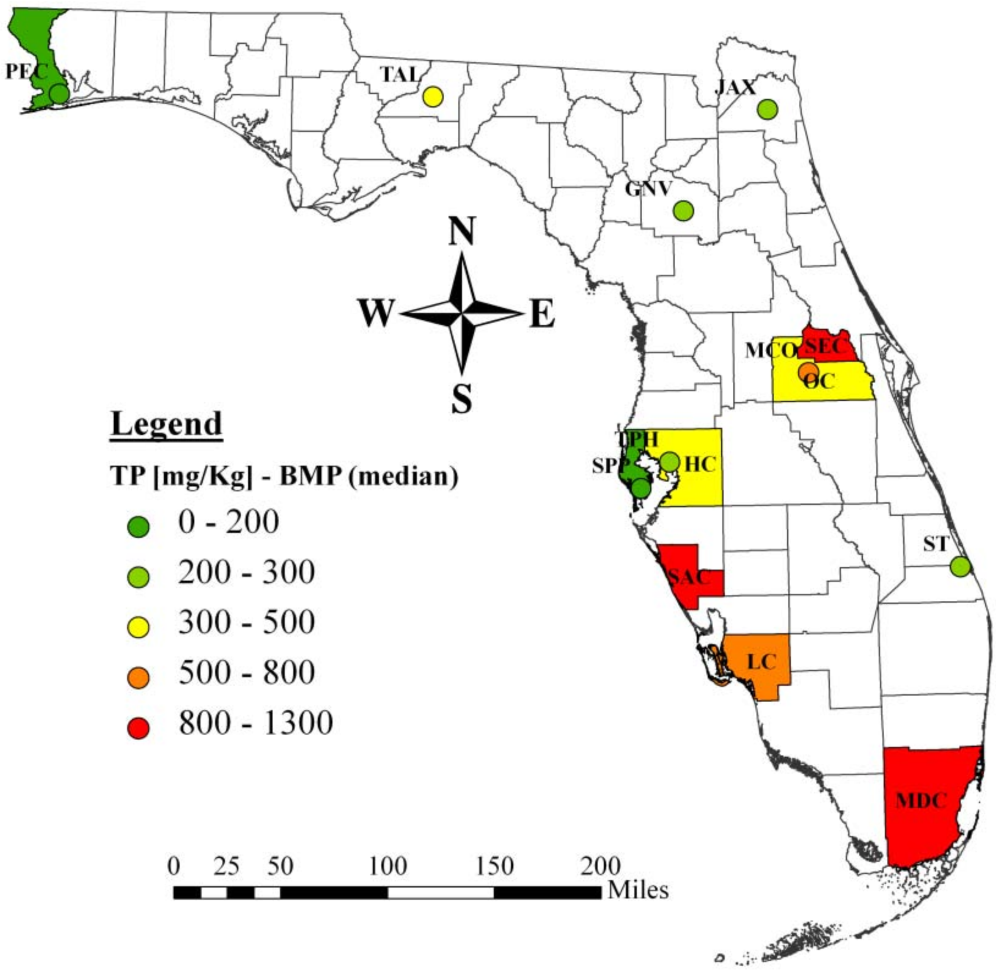

Figure 33 State-wide distribution of TP for Best Management Practices

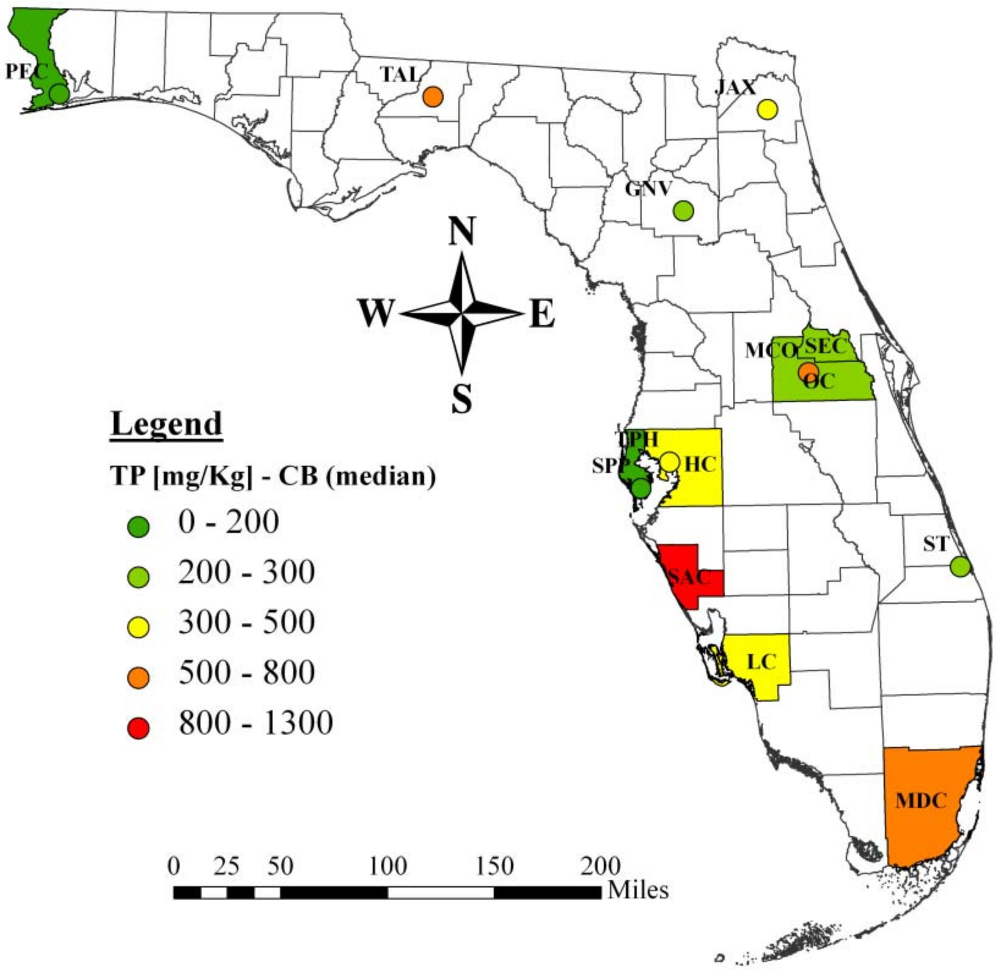

Figure 34 State-wide distribution of TP for Catch Basins

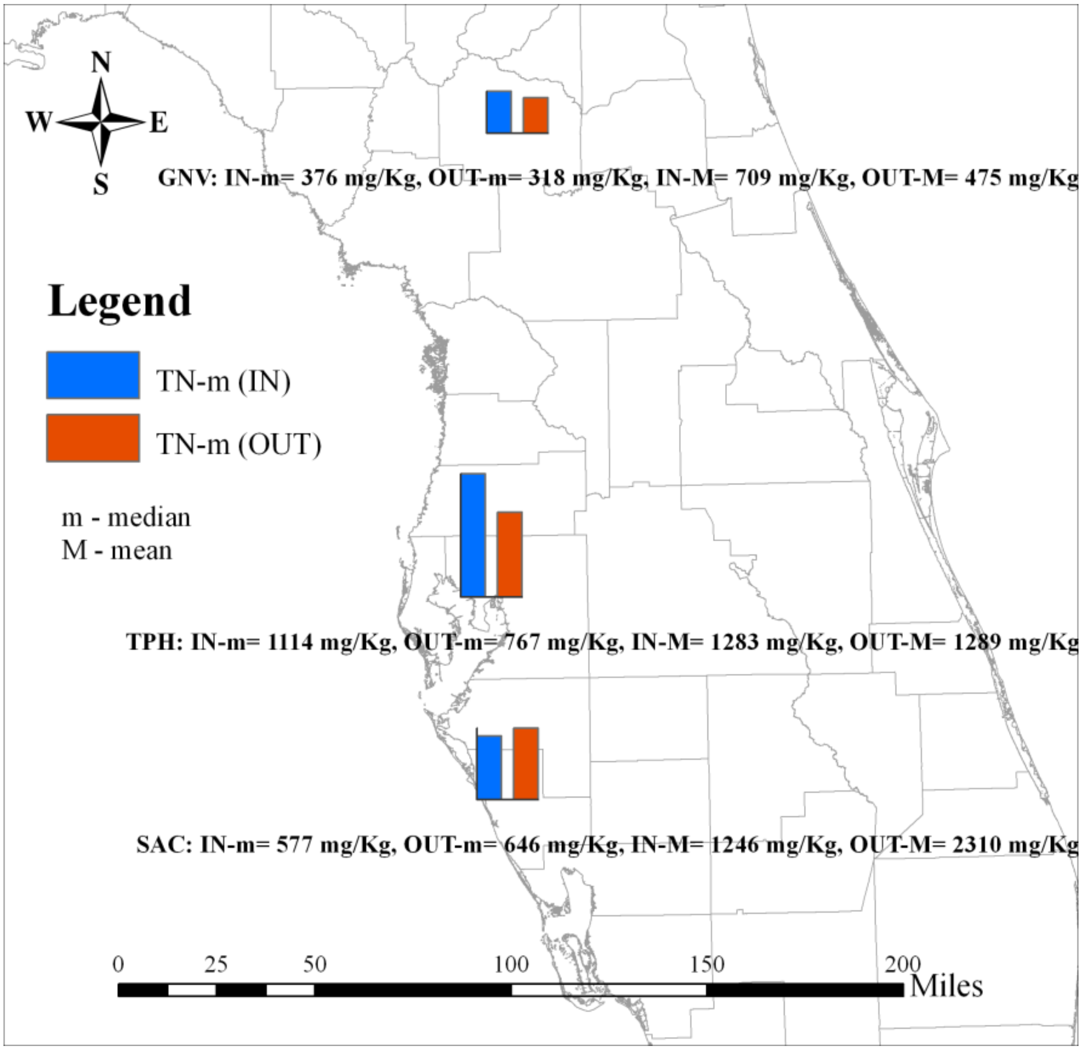

Figure 35 Comparison between TN measurements inside and outside the reclaimed water usage areas

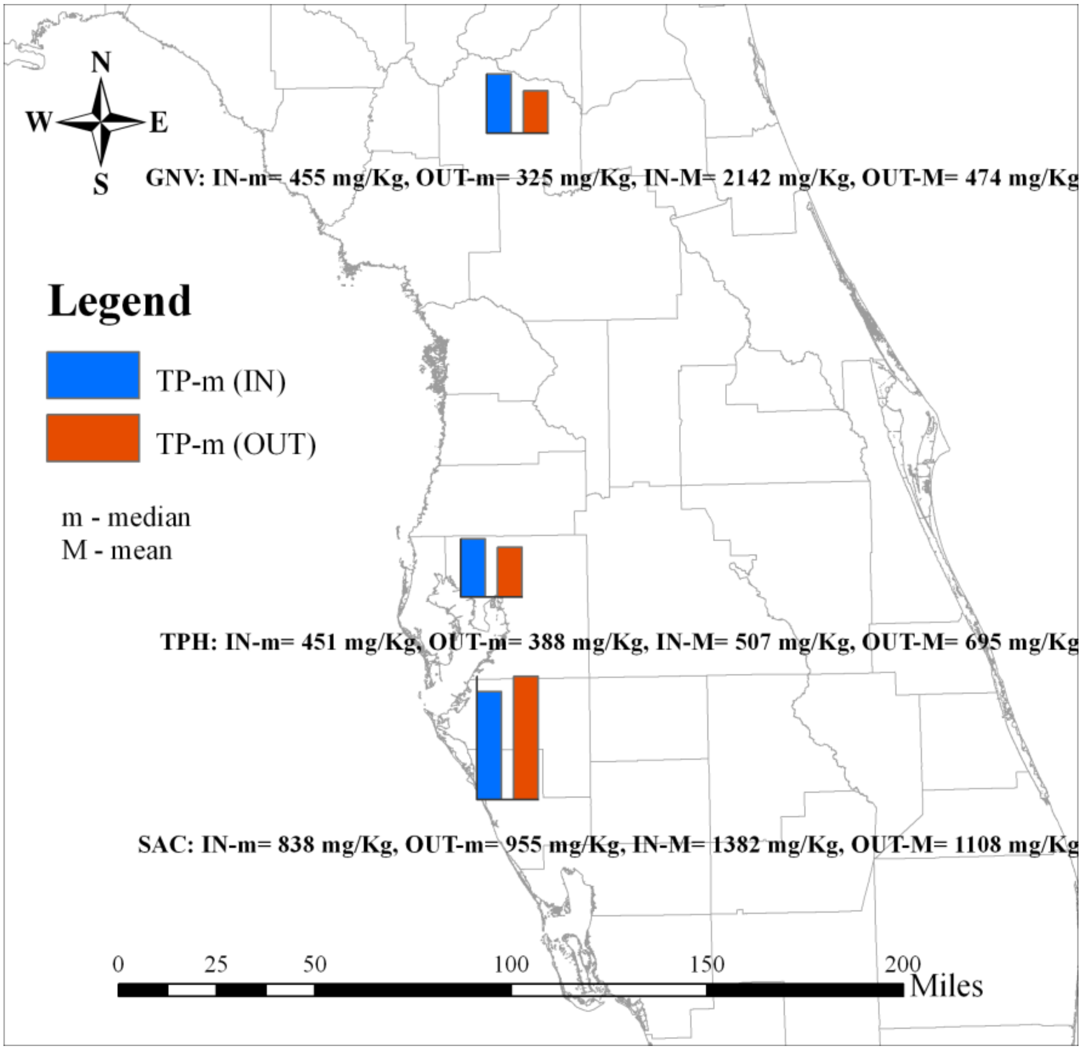

Figure 36 Comparison between TP measurements inside and outside the reclaimed water usage areas

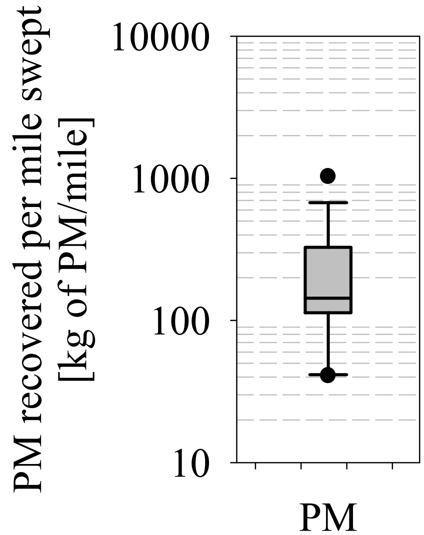

Figure 37 Box plot summarizing the statistical measures of median, upper and lower quartiles and minimum and maximum values of the PM recovered through street sweeping. The dataset consisting of 68 recovered PM masses was created through the information provided by eight MS4 participating in this project.