Florida Stormwater Association

USE OF THE FSA MS4 ASSESSMENT TOOL

July 20, 2012

10:30 AM EST

www.florida-stormwater.org

AppliedSciences

NPDES, TMDL & BMAP Support

Watershed Studies

Neighborhood Flood Control

Low Impact Development (LID)

Stormwater Utility/Rate Studies

Surface Water Monitoring

Operation & Maintenance

If you want it done right,
with integrity,
let's talk.

Florida Stormwater Association

Upcoming Events

September Seminar
Local Stormwater Practices: Enhancing New ERP Policies and BMP Maintenance Techniques
September 14, 2012
Hilton Garden Inn, Lake Buena Vista

Winter Conference and Exhibits
December 5-7, 2012
Hyatt Regency, Tampa

www.florida-stormwater.org

Meet the Presenters

Michael Bateman

John Sansalone

Eric Livingston

MS4s Responsibility

- Federal Law: 40 CFR 122.26 Reduce Pollutants to the Maximum Extent Practicable (MEP)
- Result: MS4s must Implement Effective Pollution Load Reduction Programs; Also Must Address Specific Impairments
- 40 CFR 122.26(d)(2)(v): MS4 Must Assess Effectiveness of SWMP program for Providing Pollutant Load Reductions
- MS4s Need To quantify the load reduction associated with the SWMP

MS4s Engaged in Various Activities to Remove Pollutants
HOW QUANTIFY?

Assessment Has Proved Difficult

- MS4s Implement Programs that are Holistic; Primarily Consist of “Soft” Management Practices
- Difficult to Assess Effectiveness
- But, should receive due “Credit” for day-to-day Program Activities that result in Pollutant Removals

FSA Helping To Meet The Need – Initiated Development MS4 Assessment Tool

- Focus on Day-to-day Management Practices Required by Permit
- Focus on Measured Materials Removed, on Mass Basis
- Develop Robust Data Set - Assign Appropriate Pollutant Composition Values
- Spreadsheet Calculation of Pollutants Removed

USING THE MS4 TOOL TO OBTAIN LOAD REDUCTION CREDITS

- DEP is partner in the project and has accepted the final report and methodology

- Programs needing load reductions
  - Total Maximum Daily Load implementation
  - Basin Management Action Plans
  - MS4 permit effectiveness

- Use of local data
  - Data collection and analysis must be consistent with methods in FSA MS4 project

FSA Project Summary from 2008-2011 for:

PM and Nutrient Load Recovery, Credits and Costs for MS4 Maintenance Activities

University of Florida, Environmental Engineering Sciences (EES)
Engineering School of Sustainable Infrastructure and Environment (ESSIE) Draft Presentation

John Sansalone (jsansal@ufl.edu) and Saurabh Raje

20 July 2012

Urban Particulate Matter (PM)

- **PM is the predominate sink and source of nutrients (P, N)**
- **Management of PM = Control of chemical (nutrient) load, [C]**
- Myths regarding PM is a function of how we sample and analyze
  - *samplers are designed for steady wastewater flows and organic PM*
  - *analysis based on sub-aliquot methods (TSS) without particle size data*
- Particle size distributions (PSD), particle number density PND:
  - *Required for modeling PM, solute and microbiological fate*
  - *Required for load inventories of PM and nutrients, maintenance*
- **The cost of PM and nutrient recovery by maintenance (street, CB cleaning) is much lower than using conventional BMPs**

What Were the Project Objectives and Outcomes ?

The primary project objective is a ***<u>Florida-based</u>*** "yardstick" or metrics allowing an MS4 to quantify nutrient (N and P) loads through ***separation*** then ***recovery*** of ***<u>particulate matter</u>*** (PM) for common urban hydrologic functional units (HFUs):

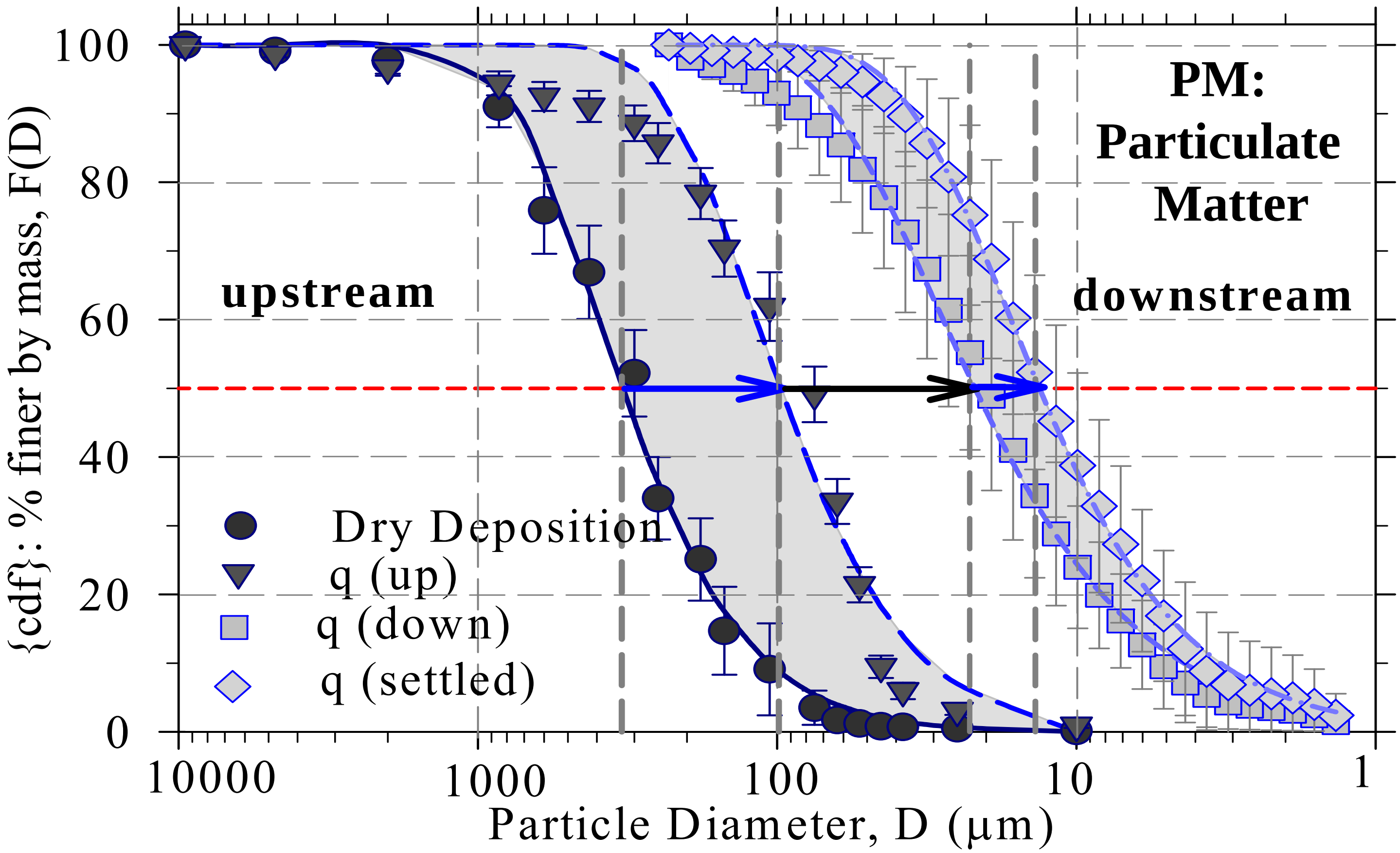
1. Pavement systems cleaning (pavement street sweeping),

2. Catch basins (inlets),

3. "BMP " (the most utilized and cleaned BMPs for an MS4)

- Outcomes are Florida-based metrics (a statistic of the resulting probability distributions: i.e. median) based on 14 MS4s
- Outcomes allow ***<u>dry-equiv.</u>*** load of PM ***separated*** (i.e. a BMP) and then ***recovered*** by maintenance to be converted to N, P loads
- Outcomes quantified by land use or independent of land use
- Outcomes quantified outside or inside wastewater reuse areas

HFUs modify PM: From pavement PM deposition to catch basin PM through conveyance to “BMP” influent and effluent PM



PSD of PM	DD Pavement ***Deposition***	q (up) CB or inlet ***Runoff***	q (down) BMP influent ***Runoff***	q (settled) BMP effluent ***Runoff***
D_{50m}	331 μm	99 μm	23 μm	14 μm

PSD gamma model

$$f(D) = \frac{(D/\beta)^{\gamma-1} e^{(-D/\beta)}}{\beta \cdot \Gamma(\gamma)}$$

$$F(D) = \Gamma_D(\gamma)/\Gamma(\gamma)$$

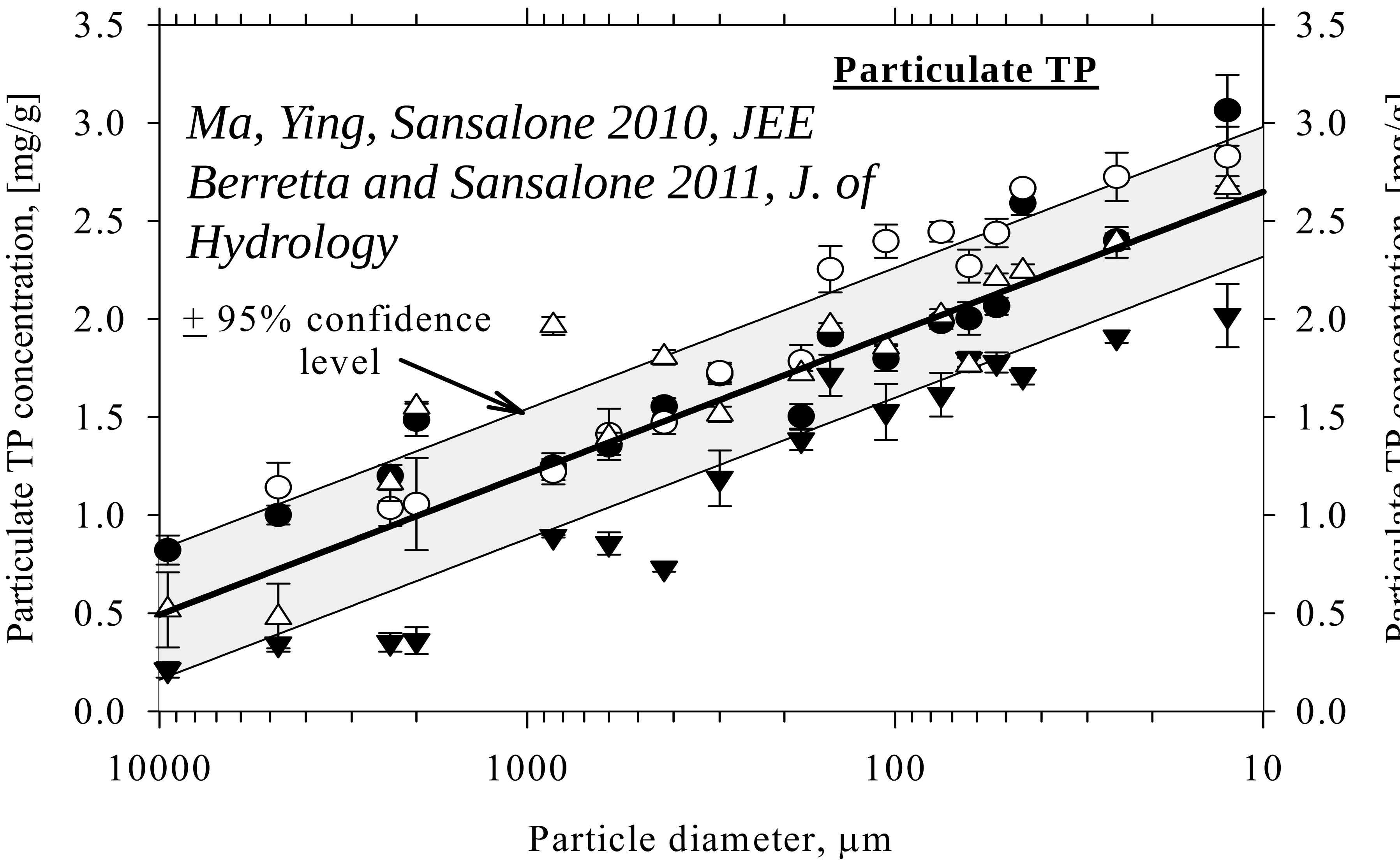
$$\Gamma(\gamma) = \int_0^\infty x^{\gamma-1} e^{(-x)} dx$$

$$\Gamma_D(\gamma) = \int_0^D x^{\gamma-1} e^{(-x)} dx$$

BMP: Clarifier with 1 hr. of quiescent settling

Location	(γ, β)
DD	(2.06, 187.7)
q (up)	(1.90, 61.9)
q (down)	(1.23, 23.6)
q (settled)	(1.51, 11.1)

Relationship between granulometry (PM size) and particulate TP based on University of Florida rainfall-runoff event datasets



Brief Review of Project Methodology

Participating Florida MS4s

1. Gainesville (GNV) ***[IN + OUT]***
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) ***[IN + OUT]***
10. Seminole County (SEC)
11. St. Petersburg/Pinellas County (SPP)
12. Stuart (ST)
13. Tallahassee (TAL)
14. Tampa (TPH) ***[IN + OUT]***

MCO-CB-R-OUT-2

HC-CB-R-OUT-2

JAX-SS-R-OUT-1

TPH-BMP-C-OUT-1

MDC-BMP-C-OUT-9

ST-BMP-C-OUT-1

Project Process Flow

Sampling Process → **UF Lab Analysis** → **Future Application**

1. The objective is to develop a 'yardstick' to quantify the nutrient load recovered through regular maintenance of BMPs, CBs and pavements (street sweeping or cleaning).
2. 14 MS4s, each collected 27 samples with detailed field information for every sample.
3. 3 locations each, in 3 land uses – commercial, highway and residential; for the 3 maintenance practices.
4. 3 MS4s also collected 27 samples from within areas with reclaimed wastewater usage, to compare nutrient loads.

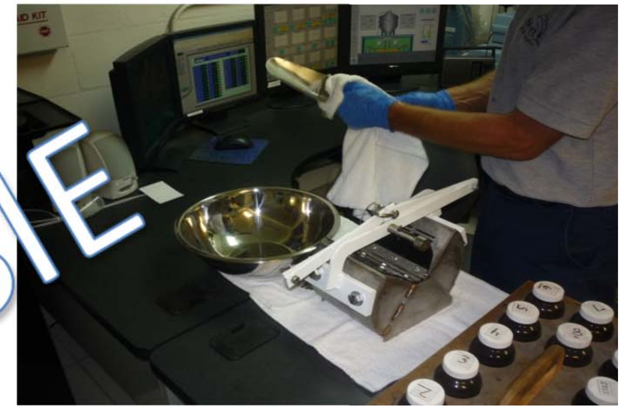
Project sampled a diversity of “BMPs”

(Diversity provided a robust FL-based metric and valuable debate)

BMP Classification	**IN**	**OUT**
Pond (Basin)	10	11
Baffle Box	1	27
Swale, Ditch or Sediment Accumulation	11	35
Manufactured BMP (i.e. hydrodynamic separators)	5	28
Drainage or Sump Box (i.e. “French drains”)	0	23
Total	**27**	**124**

Cleaning, Sampling, Packing, Shipping, Receiving

1. QAPP specifies sampling, site information needed
2. Cleaning of equipment is very important to prevent cross contamination
3. Samples have to be collected in 2 L bottles
4. Samples have to be stored on ice immediately after collection and delivered or shipped to UF within 24 hours along with detailed chain of custody (COC)
5. Samples need to have considerable amount of particulate matter (PM)
6. Study utilized dry/moist samples ***(<u>representative moisture content (MC) is a simple and critical requirement for credits</u>)***



<u>Sample Identification:</u>
City/County Code – HFU – Land use – In/Out of reclaimed water usage area – Dry/Moist/Wet – Sample Location number
i.e. GNV – SS – H – IN – D – 1

Collection of Field Information: 1 Tallahassee Sample

FIELD INFORMATION - TALLAHASSEE (TAL - CB - C - OUT - 1)

Sample identification
- TAL – CB – C – OUT – 1

Jurisdiction
- Tallahassee

Land use zoning

Condition
- Needs maintenance attention

Condition of PM residuals
- Dry

Dimensions and volume

FIELD INFORMATION - TALLAHASSEE (TAL - CB - C - OUT - 1)

Sample identification
- TAL – CB – C – OUT – 1

Jurisdiction
- Tallahassee

Land use zoning
- Commercial, Restaurant, Hotel, Small Businesses

Location
- University; NE Corner of Tennessee and Dewey Streets

Co-ordinates
- 30.44504 N and 84.29451 W

Date and time (with previous dry hours)
- 06/15/2009 11:23 AM

Condition
- Needs maintenance attention

Condition of PM residuals
- Dry

Dimensions and volume
- 25 in (w) x 25 in (d) x 40 in (l)

Description of flow to catch basin
- Direct run-off

Description of sampling method
- Stainless steel scoop

Traffic estimate (ADT)
- 39509

- Anthropogenic

Description of catch basin

Type
- Catch basin

Approximate age
- Older (brick lined)

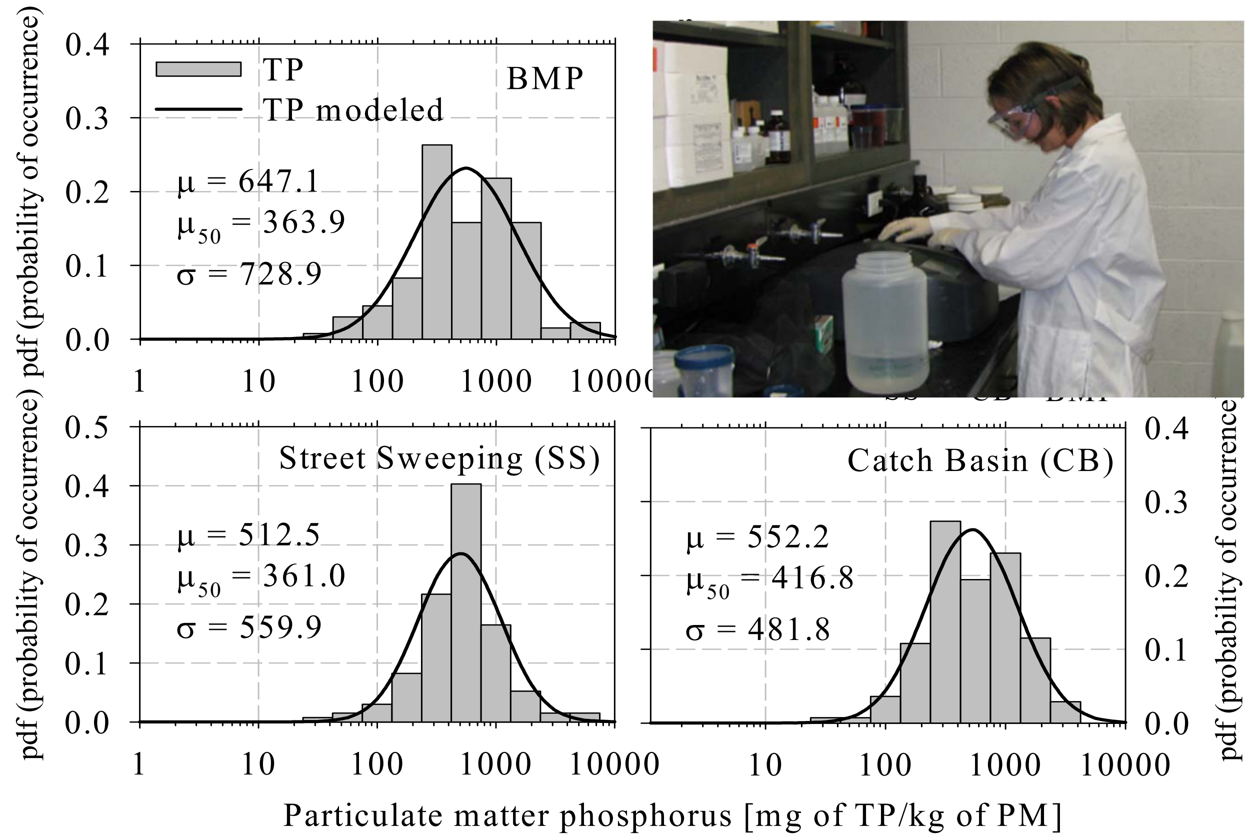
Previous cleaning activity
- Unknown

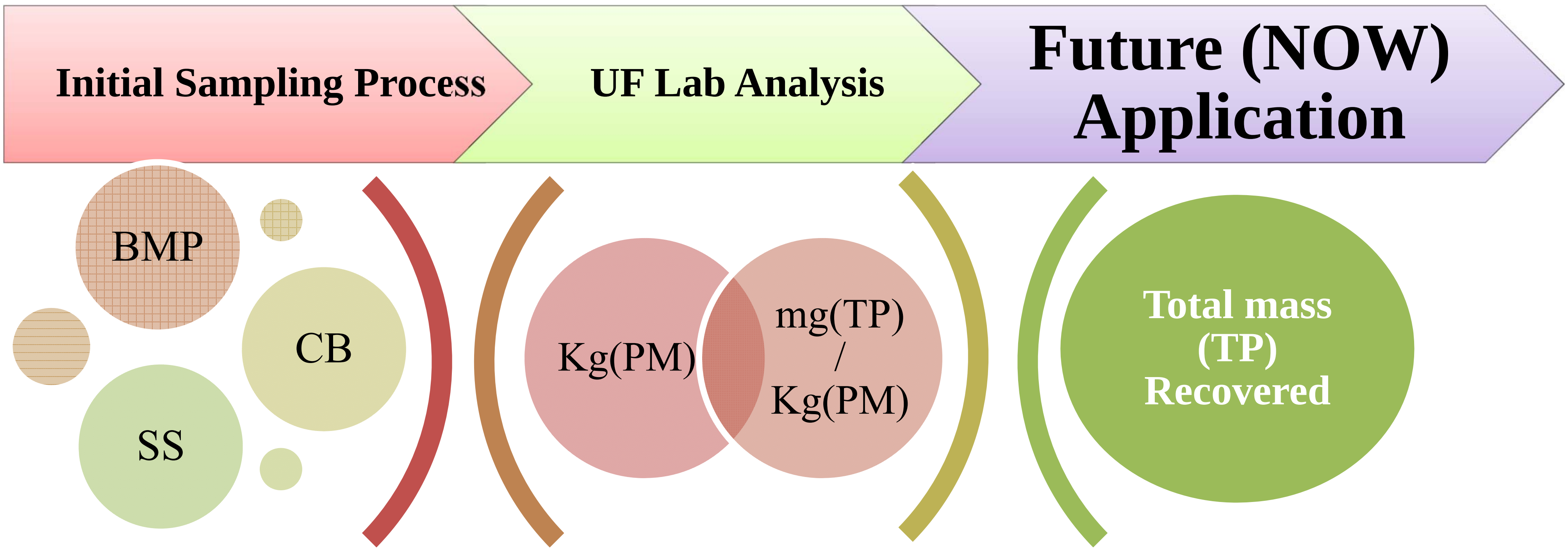
OUT : outside reclaimed water area
R/W : right of way
TAL : Tallahassee

Initial Sampling Process → # UF Lab Analysis → **Future Application**

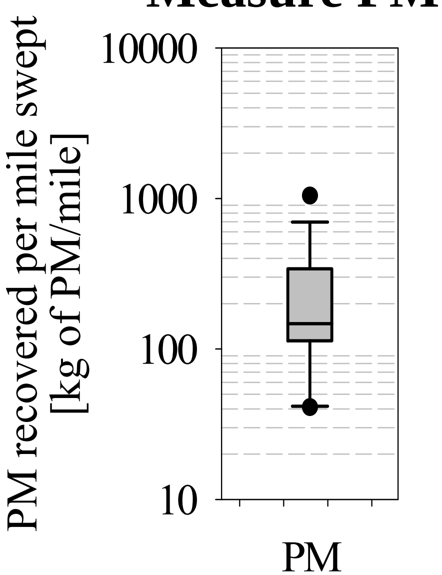
1. U. of Florida analyzed samples for N (as TN) and P (as TP) in NELAC certified labs.
2. TP, TN, and extractable P, moisture content and particle size distribution (PSD) analyses were performed.
3. Based on results, probability distributions (and statistical indices) generated for N, P.
4. Distributions and indices generated on Florida-basis with/without land use, HFU or reclaimed wastewater.

For example, these distribution statistics are in Table 8 of report (and land use results are lumped)

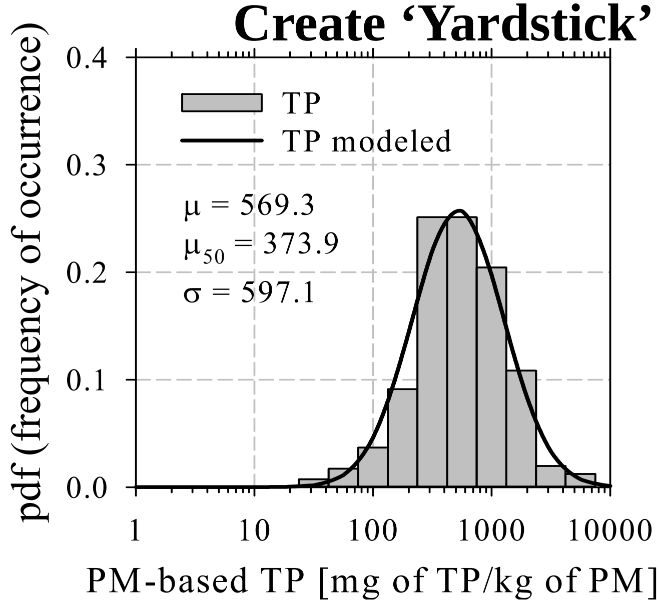




Measure PM



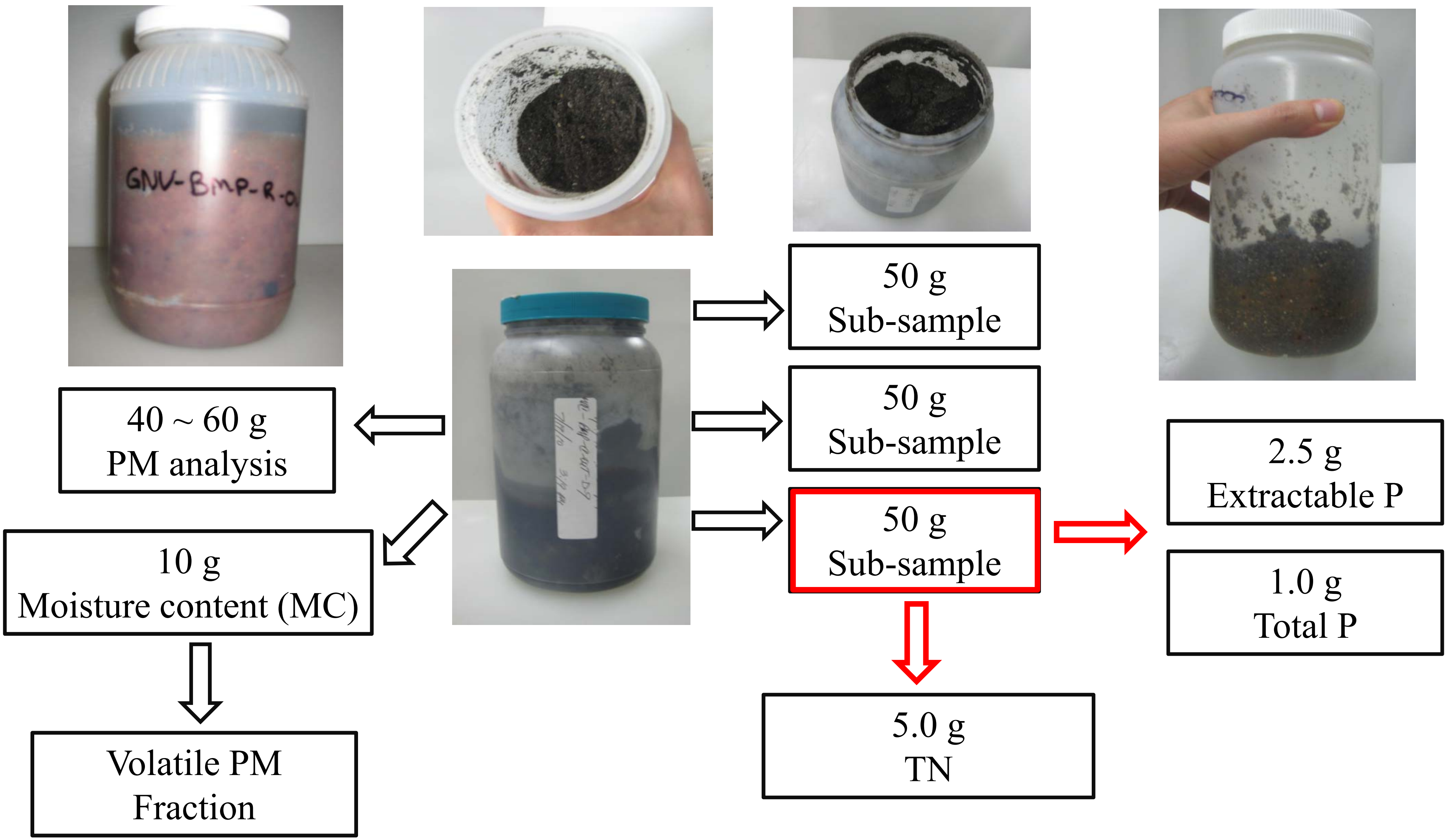
Create 'Yardstick'



Nutrient (N, P) Credit

Documentation and validation reqr. for dry-equivalent PM recovery

Sample Analysis Flow Chart: MC, dry PM, N, P

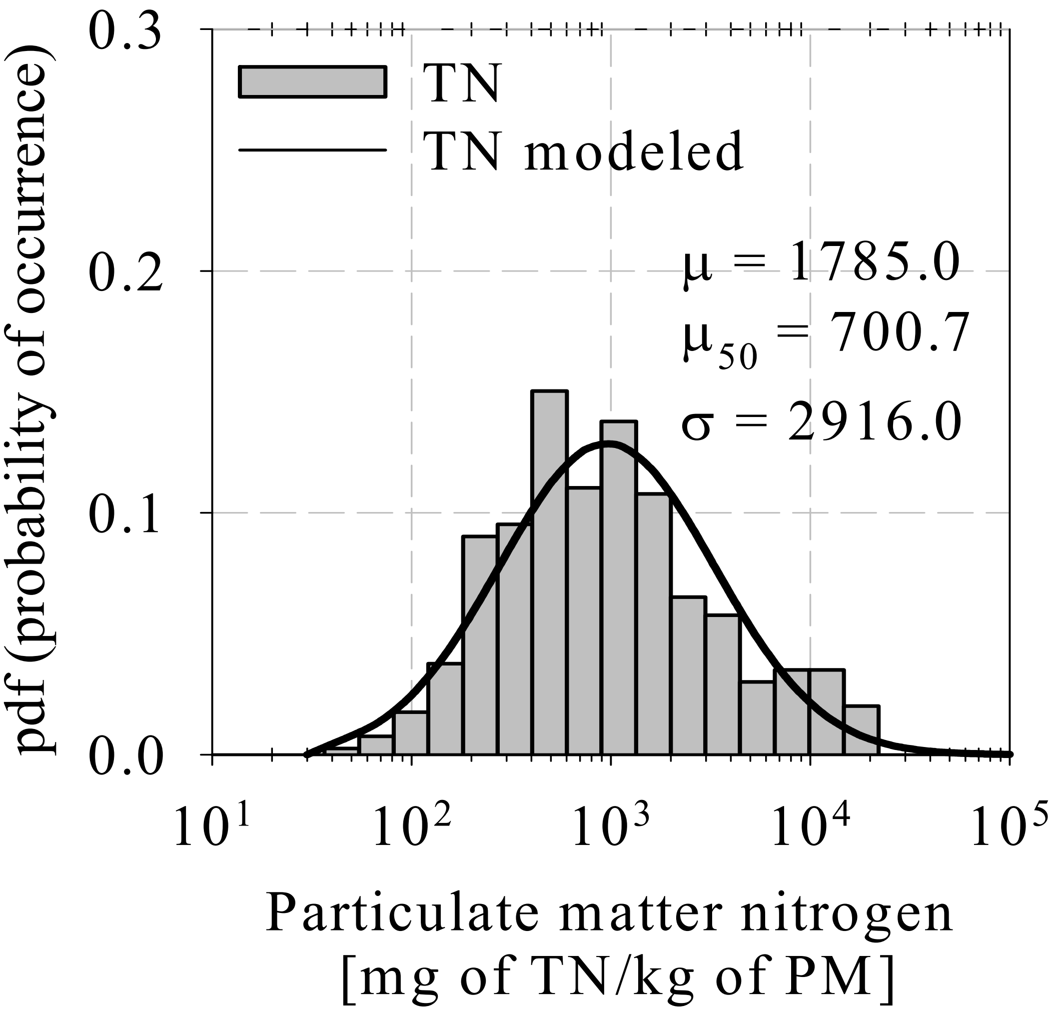


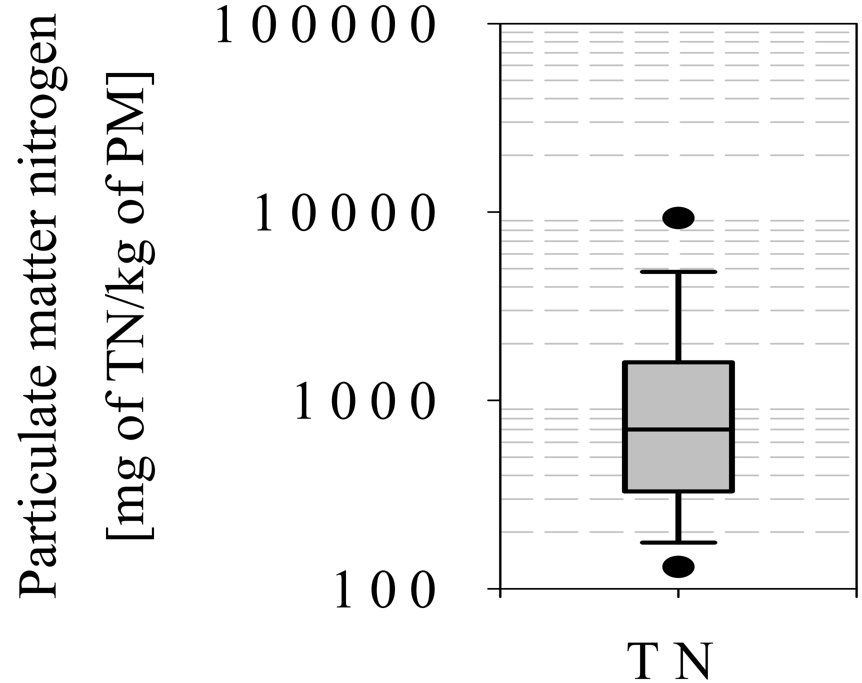
Questions

Review of Primary Project Results

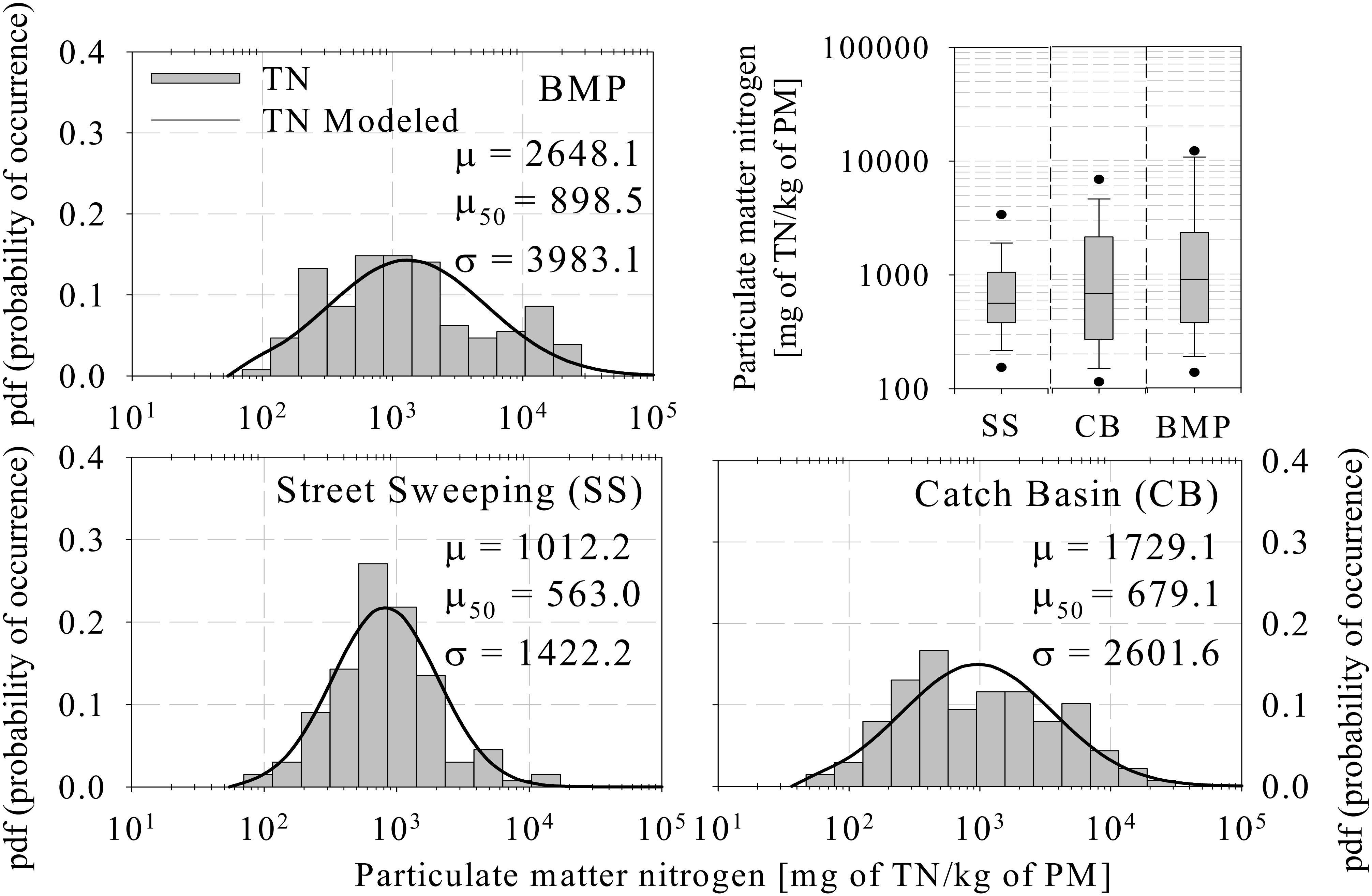
1. Results presented are from outside (OUT) reclaimed wastewater areas, unless inside (IN) reclaimed area results are specifically identified.
2. Results are either composited by combining separate land use results or combining separate HFU results or both, OR results are delineated as a function of land use and HFU
3. Land uses:
   - "Highway" (H) {major transportation R/W}
   - Residential (R)
   - Commercial (C)

Florida-Based Result: Distribution of N (as TN) (Land Uses Composited and HFUs Composited)

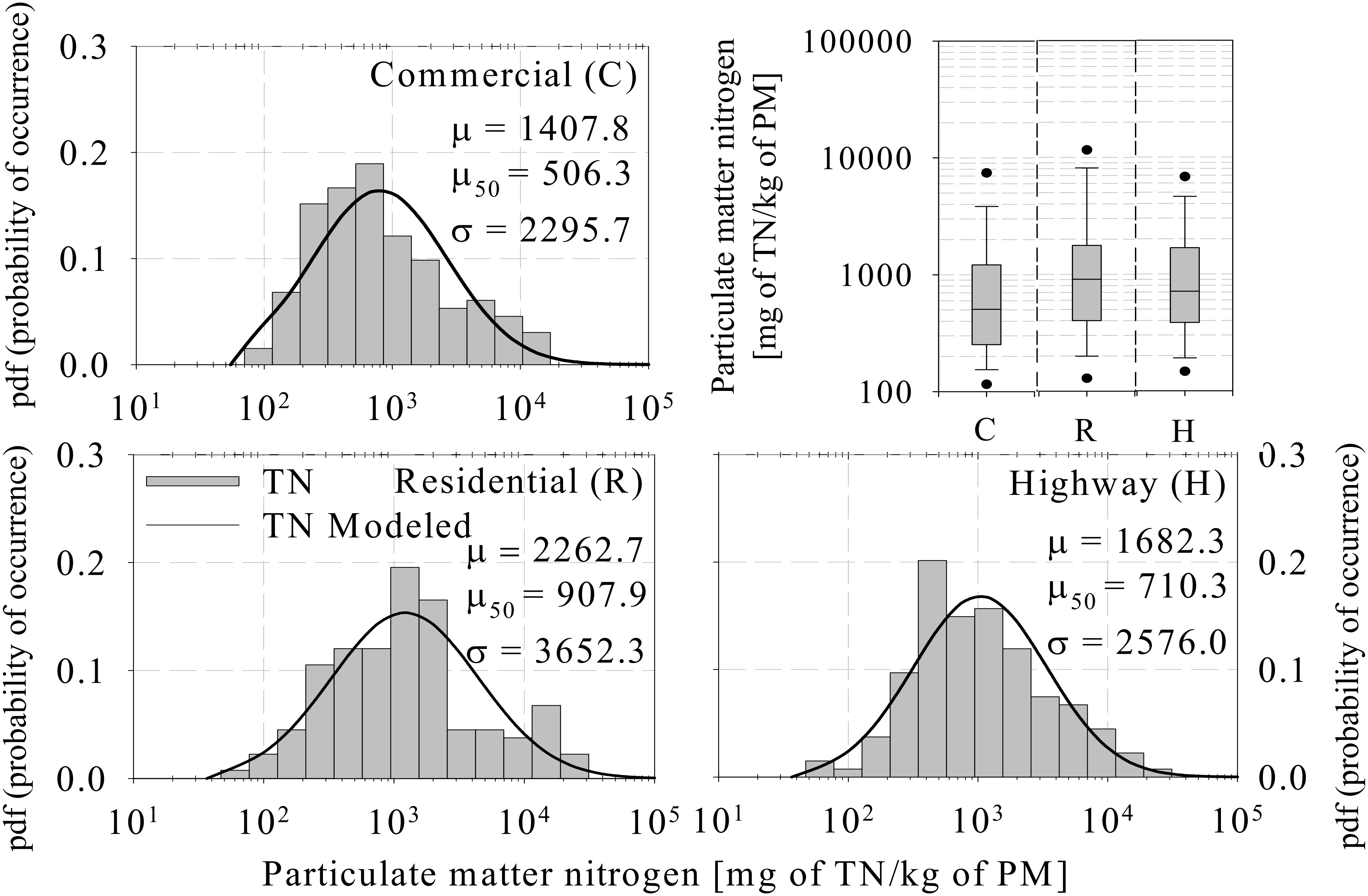




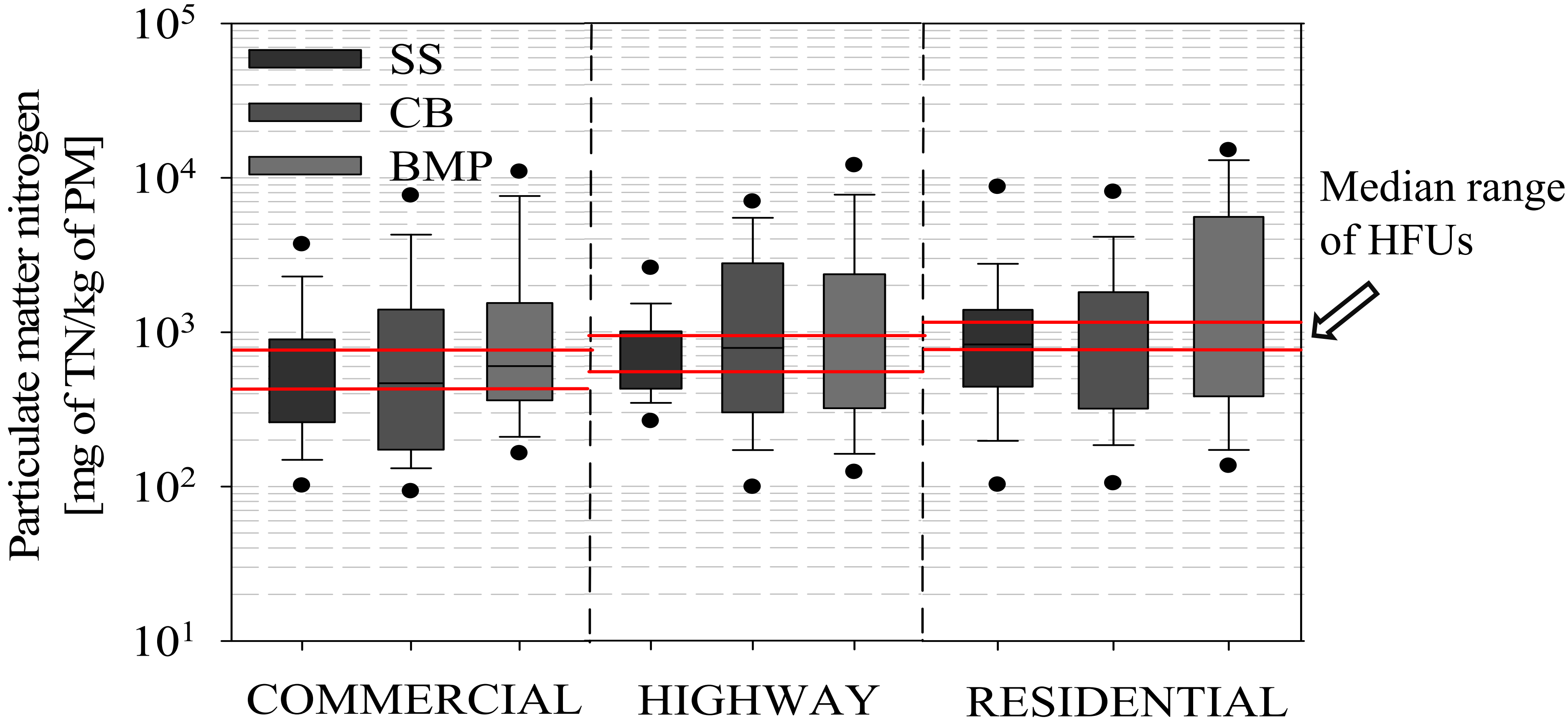
TN Results – Distribution by HFUs



TN Results – Distribution by Land Use



TN Results by Land Use and HFU (Table 6 or S1)

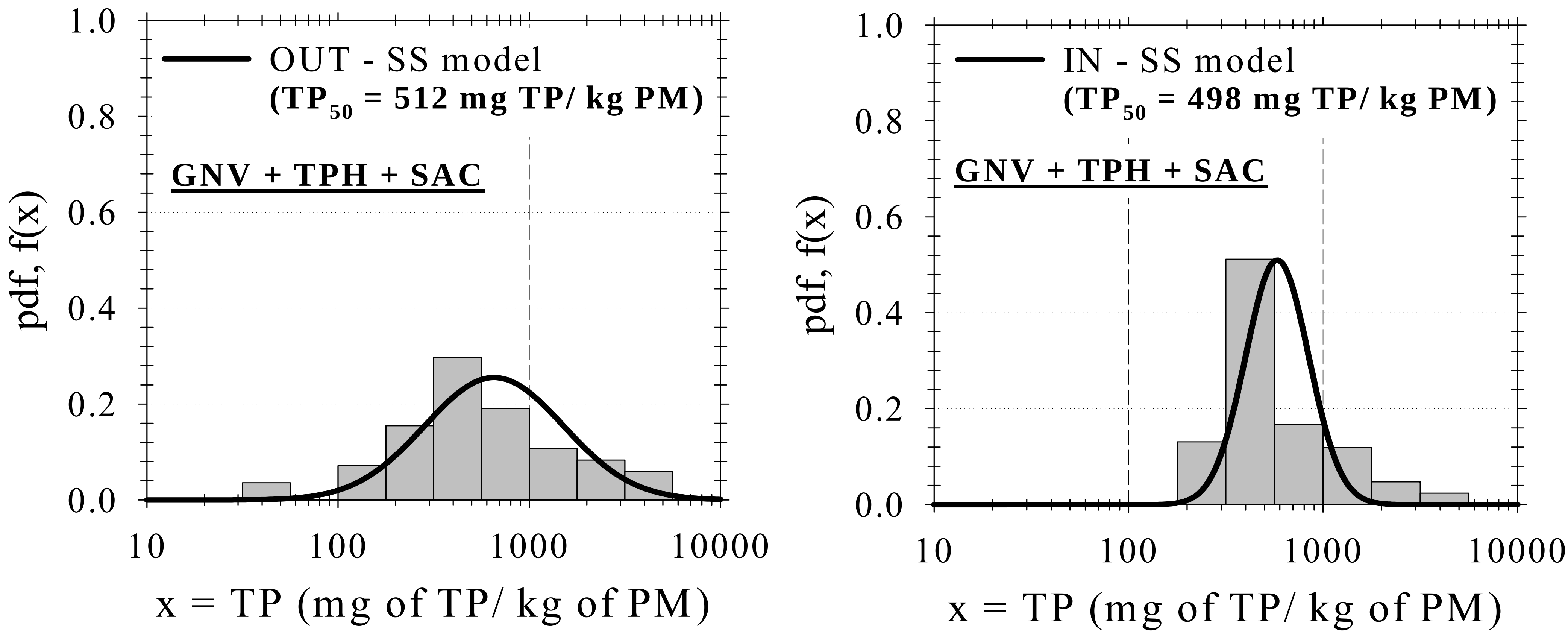


TN [mg/kg]	Street Sweeping (SS)			Catch Basin (CB)			BMP		
	Mean	Median	St. Dev.	Mean	Median	St. Dev.	Mean	Median	St. Dev.
C	789.1	429.6	944.2	1459.7	467.2	2237.8	1999.0	602.1	3104.1
R	1439.0	832.4	2169.9	1803.9	773.8	2955.8	3587.7	1169.0	4991.9
H	826.6	546.4	654.8	1926.3	785.4	2587.8	2342.4	939.2	3496.6

“In” vs. “Out” numerical offset results: N and P load offsets for MS4 areas that irrigate with reclaimed wastewater

Should there be a numerical offset for loads recovered inside reclaimed wastewater irrigation areas of MS4s? (Results have a physical-chemical basis)

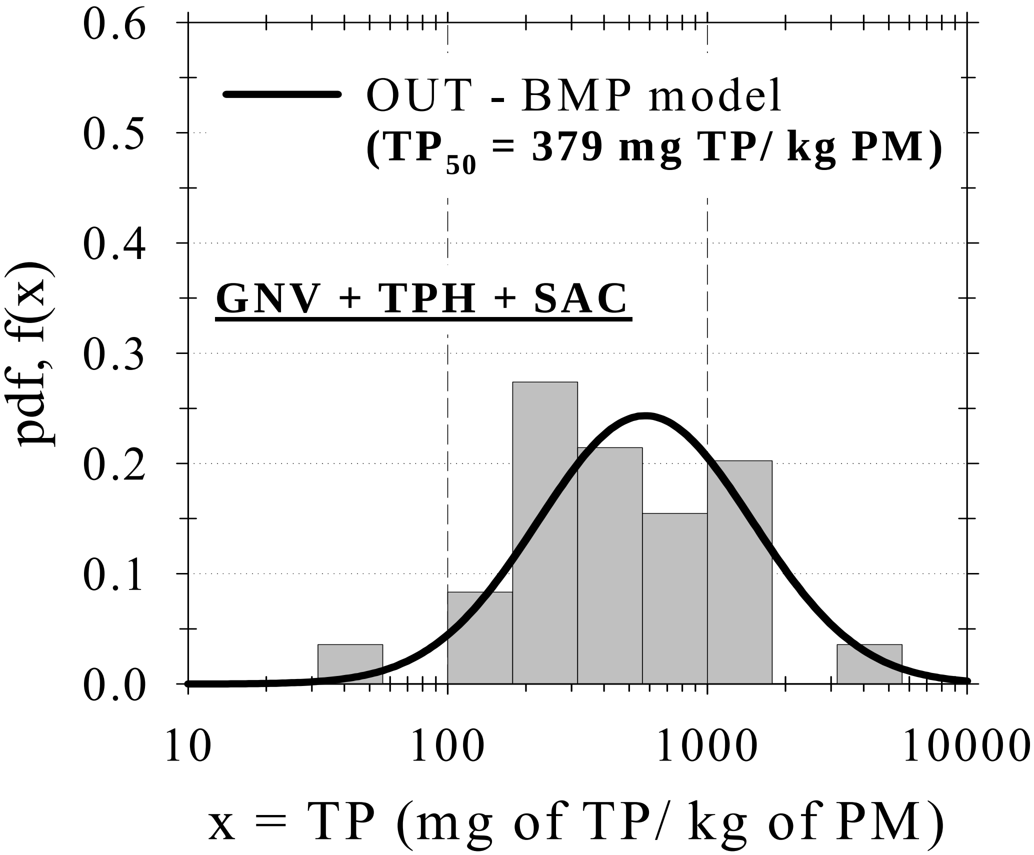
Comparing nutrient loadings inside and outside areas with reclaimed wastewater usage: **TP for SS**

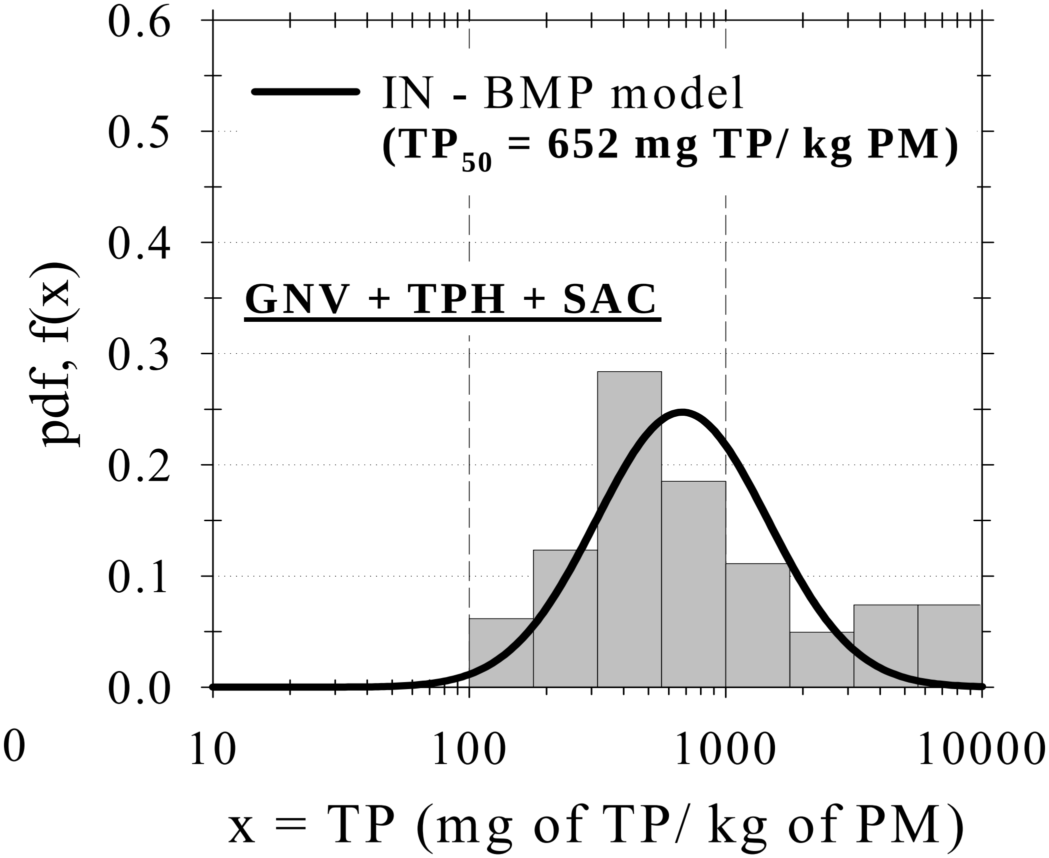


Total Phosphorus (TP) for Street Sweepings (SS)

No statistically significant difference between collected datasets at 95% C.L.

Comparing nutrient loadings inside and outside areas with reclaimed wastewater usage: **TP for BMPs**





Total Phosphorus (TP) for BMPs

Statistically significant difference between collected datasets at 95% C.L.

Moisture Content (MC) and Bulk Density (ρ_b)

<u>Moisture Content</u> (MC):

1. PM recovered in a maintenance operation **<u>is never</u>** dry ("Dry" ≡ 0% MC)
2. MC will be generally lowest for street sweeping PM, and MC will generally be highest for PM recovered from BMPs
3. Project metrics and FDEP credits are based on dry mass of PM; all results (including future) must be on a dry (MC = 0%) basis

<u>Bulk Density</u> (ρ_b):

1. All PM has intra- and inter-particle porosity that is occupied by fluids (gases or liquids) and the ρ_b is a non-linear function of MC, densification, granulometry,…
2. The **<u>preferred method</u>** to generate dry PM mass is gravimetric: to measure moist PM mass and convert the measurement(s) to dry mass with MC measurement(s)
3. Recognizing that PM is often (**<u>and less preferably</u>**) measured volumetrically, the volume of a PM deposit (wet or dry) must be converted to dry PM mass
4. This conversion requires ρ_b (dry mass/volume of a PM deposit)

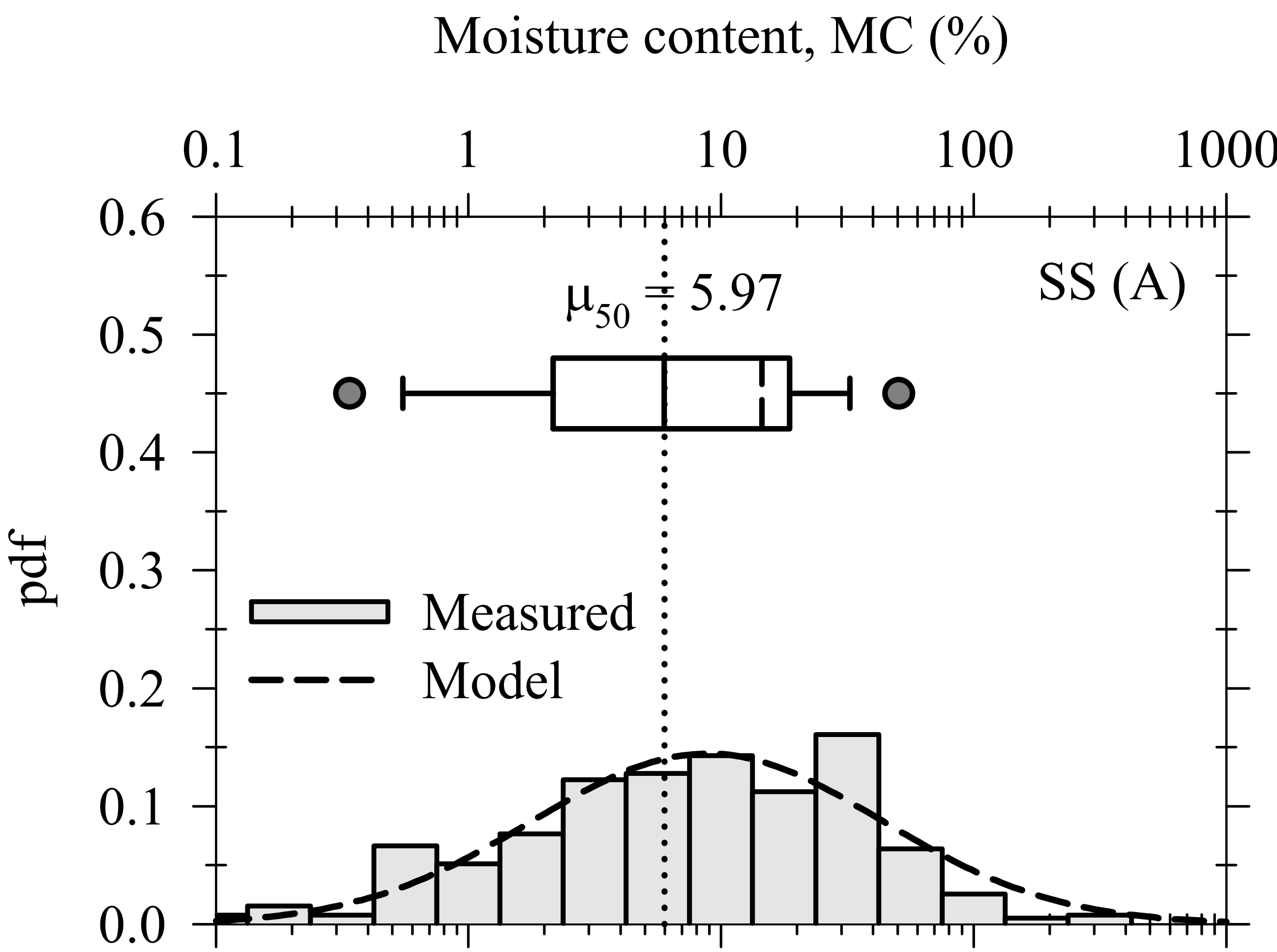
What is a representative moisture content (MC) associated with collected PM deposits ?

Moisture content (%)	Range	Max.	Min.	Median	25%	75%
BMP	768.2	768.3	0.1	34.1	19.2	63.4
CB	759.6	759.9	0.3	26.9	16.3	40.3
SS	314.3	314.3	< 0.1	5.9	2.2	18.7

- Representative nutrient load credit requires MC of PM: measured and eventually modeled *(Recall that the study samples were sampled as moist)*
  - BMPs have highest MC: BMPs predominately have wet sumps
  - CBs have an intermediate MC: CBs by design should be free-draining
  - SS have the lowest MC: SS are in equilibrium with atmospheric MC

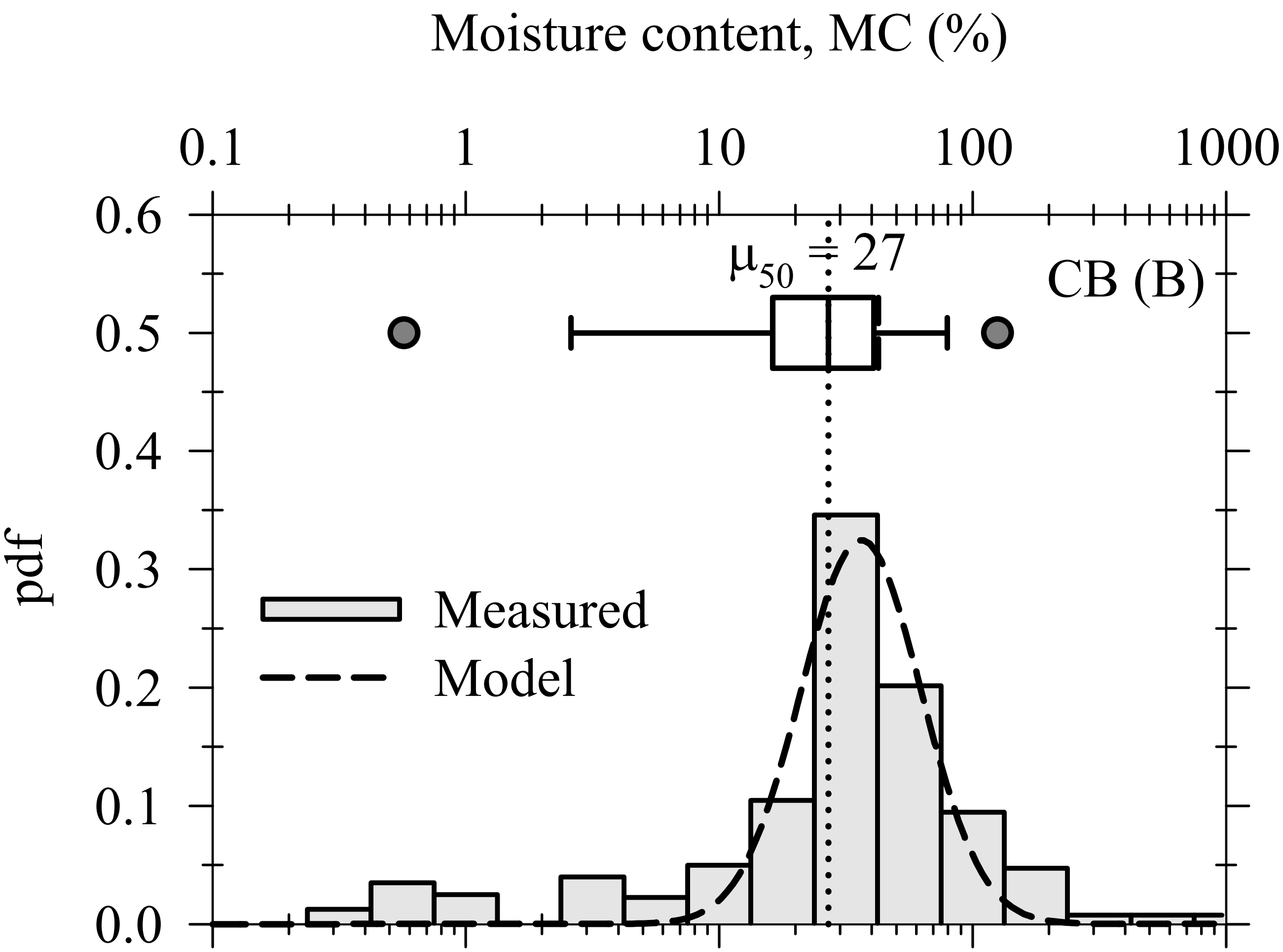
For the first year that each MS4 is involved in the load credit process, each MS4 requesting credit will provide to FDEP supporting MC and ρ_b data in a physically and statistically defensible manner as part of their verification process for load credits.

Florida-based results: A representative moisture content (MC) associated with street sweeping (SS) PM



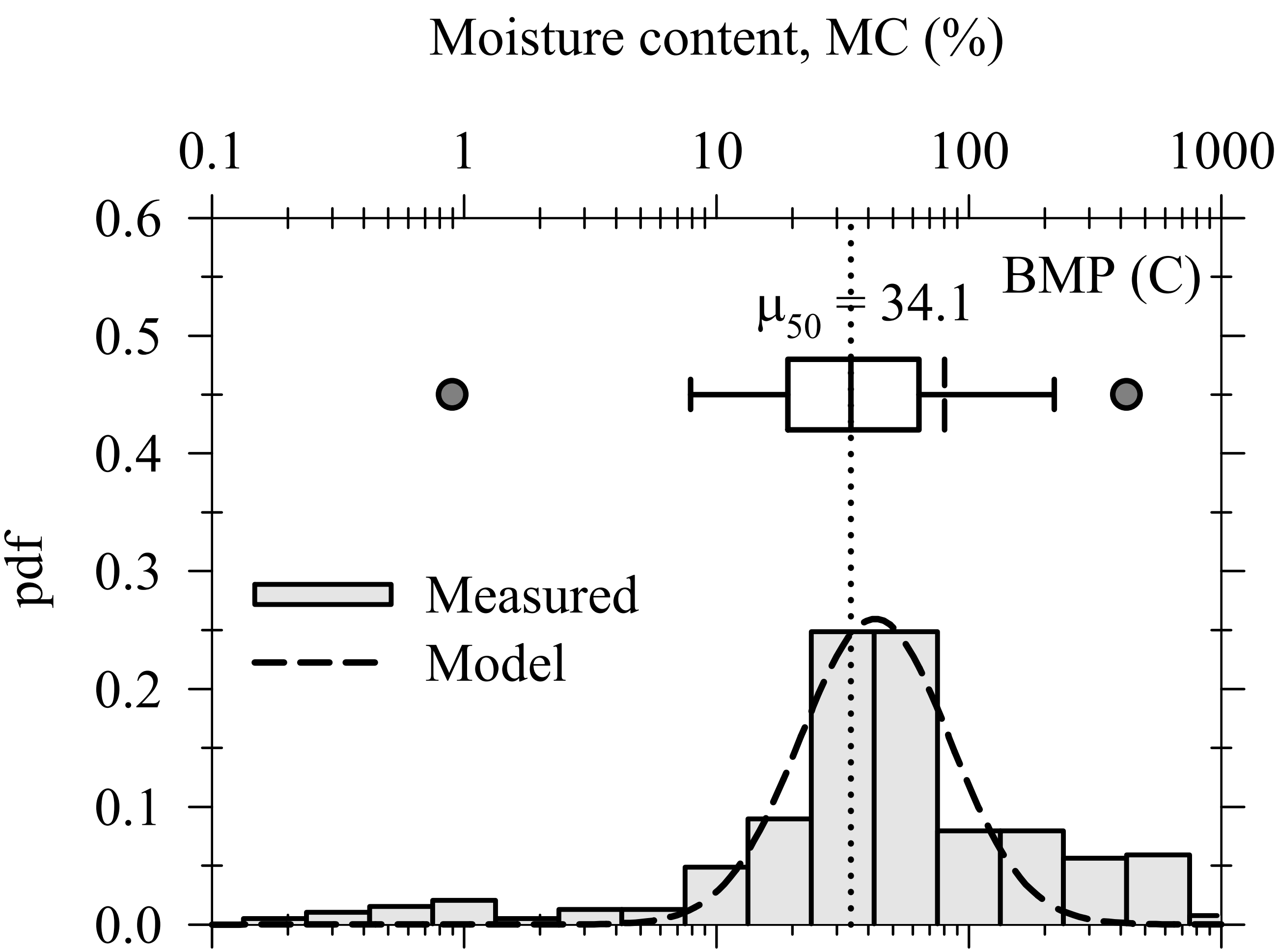
1. MC results fit a log-normal distribution
2. Given that the results are log-normally distributed the median value (50th percentile) is utilized as representative
3. The median value of ~ 6% represents the PM deposits with the least moisture as compared to CBs and BMPs
4. MS4s that do not want to utilize this Florida-based value will have to generate their own MC results

Florida-based results: A representative moisture content (MC) associated with recovery of PM from CBs



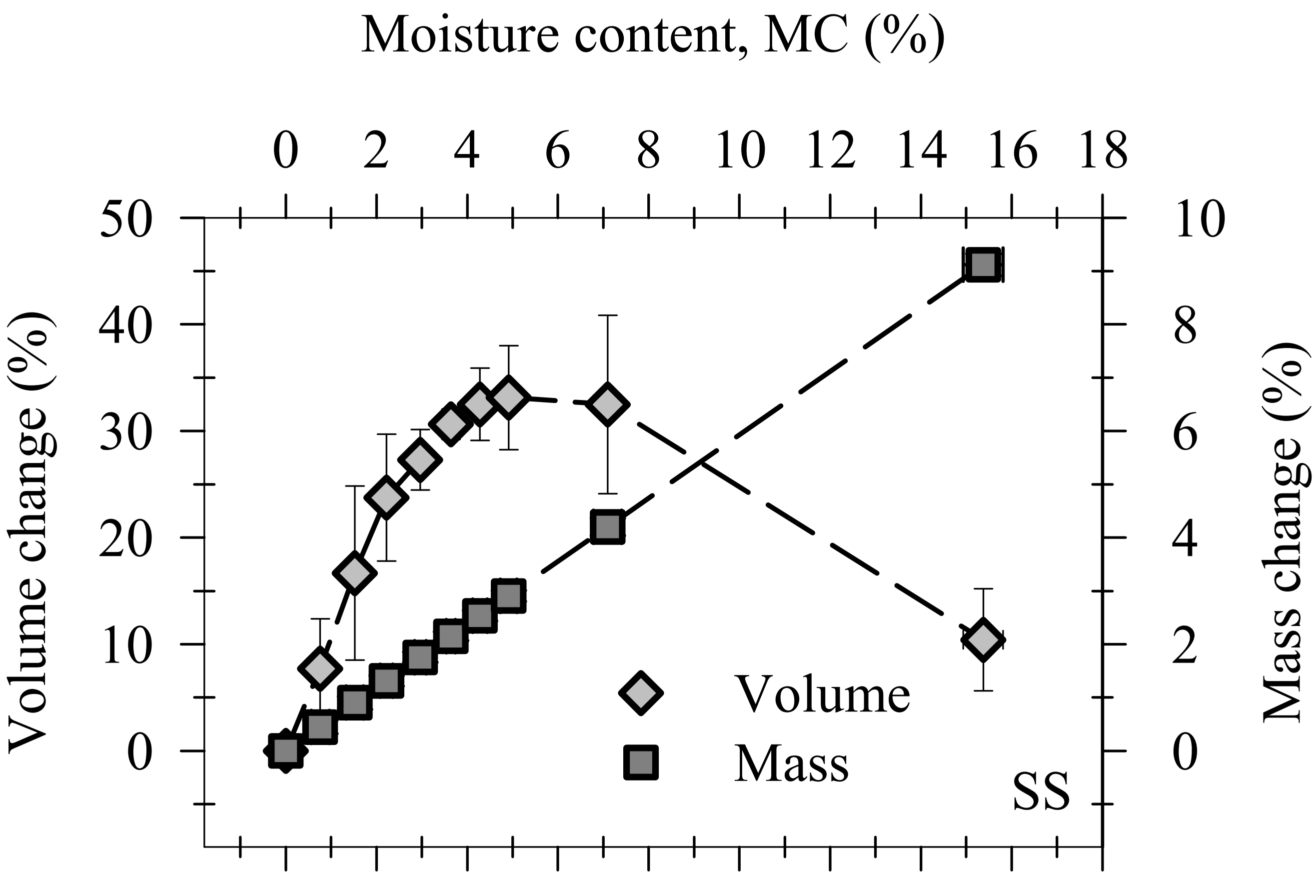
1. MC results fit a log-normal distribution
2. Given that the results are log-normally distributed the median value (50th percentile) is utilized as representative
3. The median value of ~ 27% represents the PM deposits with intermediate moisture as compared to SS and BMPs
4. MS4s that do not want to utilize this Florida-based value will have to generate their own MC results

Florida-based results: A representative moisture content (MC) associated with PM recovered from BMPs



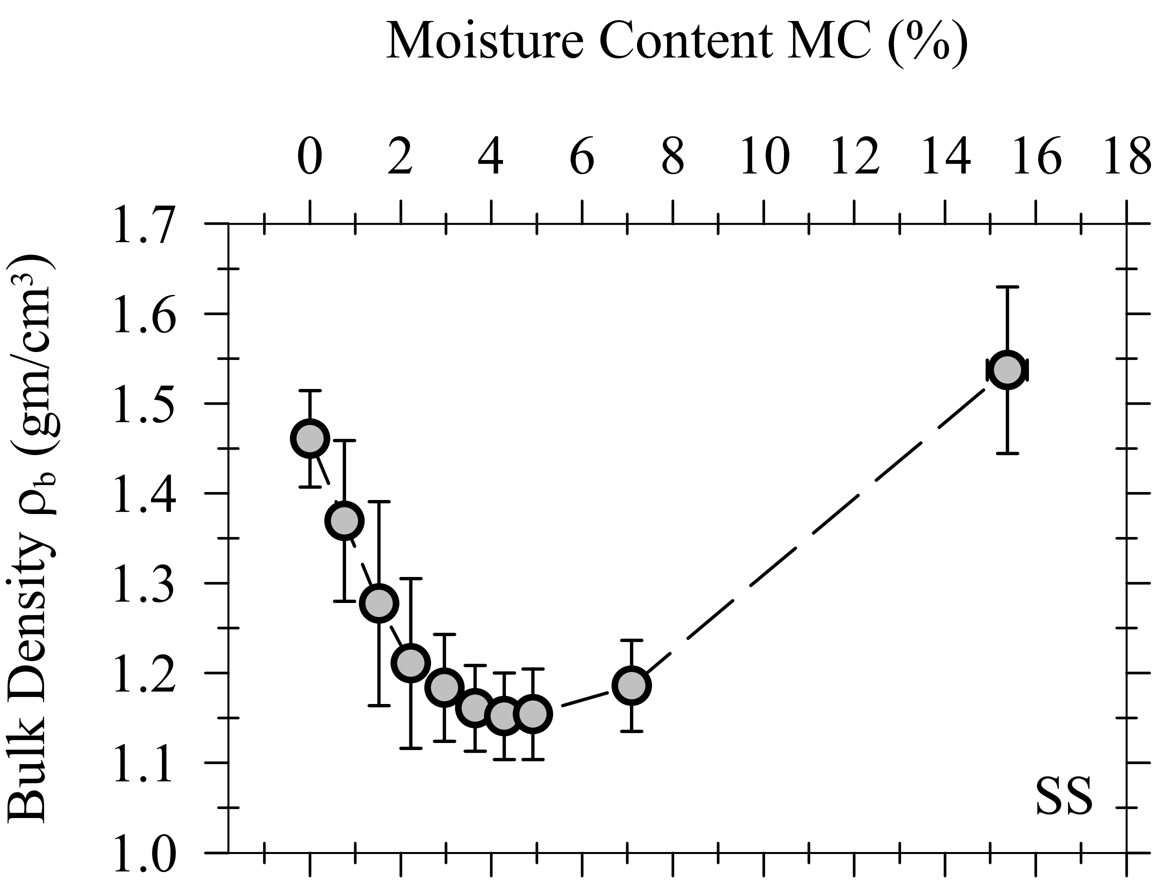
1. MC results fit a log-normal distribution
2. Given that the results are log-normally distributed the median value (50th percentile) is utilized as representative
3. The median value of ~ 34% represents the PM deposits with the highest moisture as compared to CBs and SS
4. MS4s that do not want to utilize this Florida-based value will have to generate their own MC results

Florida-based results: Variation of bulk density (ρ_b) associated with moisture content (MC) of PM from SS



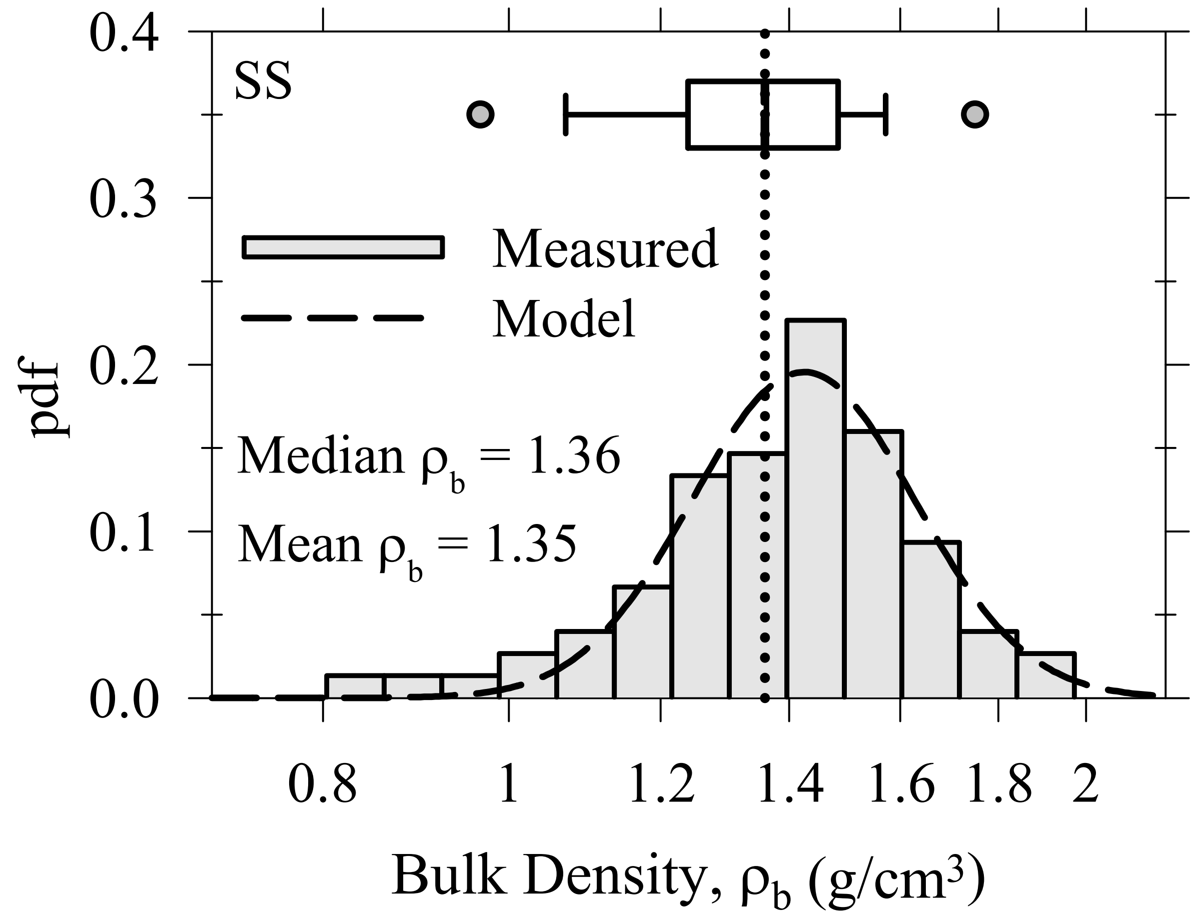
1. Change in mass is function of MC and for these results is reasonably linear
2. This allows a simple relationship between PM mass and MC; with both measured
3. However, the relationship between change in volume and MC is highly non-linear, a function of many parameters
4. If an MS4 does not use Florida-based results AND measures PM by volume a MS4-specific set of results is needed

Illustration of variation of bulk density (ρ_b) as a function of moisture content (MC) for PM from SS



1. With a MC = 0 results indicate a dry bulk density of ~1.45 gm/cm^3
2. However, bulk density is a non-linear function of MC (as well as densification, granulometry, …) and these parameters interact in a non-linear manner
3. Densification controlled by pluviation of PM by gravity from 0.5 m of height
4. The ρ_b-MC relationship is complex, with variability between PM samples from the same HFU as shown by the range bars
5. While ρ_b can relate volume to mass, a direct PM mass is more robust

Florida-based Results: Distribution of dry bulk density (ρ_b) associated with PM from SS



1. Variability in SS bulk density results across Florida
2. This is largely a function of granulometry (including organic content, PSD, particle shape
3. If an MS4 does not use Florida-based results AND measures PM by volume a MS4-specific set of results is needed
4. For comparison, the density (specific gravity) of water is nominally 1.0, and 2.6 for silica sand

Questions

Example: Street Sweeping Costs

- Cost of street sweeping is based on utilizing a street sweeping contractor, a common practice in Florida

<u>Street Sweeping Cost:</u> $30.14 per mile (City of Oakland Park, Florida by FDOT)

(Cost range by Florida MS4s = $17.20 – $28.30)

1 pound of TP → 8.5 pavement miles → $257/lb TP

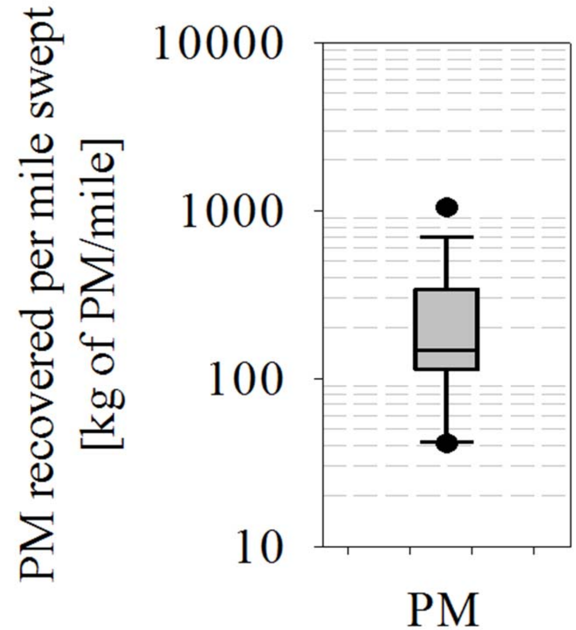
1 pound of TN → 5.5 pavement miles → $165/lb TN

- These costs do not include solid waste landfill disposal (on the order of $80 to $95/ton)
- Note: Recovery costs for maintenance of each HFU or BMP type does not include solid waste landfill costs

Why measure [kg of PM/mile] and not just miles swept?

A pavement cleaning (street sweeping) metric [kg of PM/mile] depends on:

1. how loaded with PM is the pavement
2. frequency swept
3. inter-event rainfall time
4. previous rainfall frequency/intensity/duration
5. equipment type
6. how the equipment is operated, i.e. speed
7. location on the pavement



8. PSD (particle size distribution): more work is required to differentiate PSDs

However, [mg of N,P/kg of PM] is not dependent on 1 to 7 but dependent on 8 (at this time there is no substitute for load verification based on kg of PM/mile)

Example: BMP Separation and Recovery: PM, TP, TN

- This examples utilizes a common screened **hydrodynamic separator (screened HS)** and monitored data for the performance of a screened HS subject to actual storm events
- HS units and comparison of HS units subject to controlled and uncontrolled loadings (actual events) are well-documented:
- (Kim and Sansalone 2008; Sansalone and Ying 2008; Sansalone and Pathapati 2009; Dickenson and Sansalone 2009, Pathapati and Sansalone 2011).

<u>**Parameters:**</u> (Note: in this case knowledge of runoff loads must be used)

1. Drained urban area of 2000 m^2
2. Annual removal efficiency of 50% for PM
3. No washout and scour from screened HS (Hydro-fantasy !)
4. A yearly rainfall depth of 1270 mm (for GNV, from NOAA)
5. Based on 22 monitored rainfall-runoff events for GNV
6. Watershed-based 400 mg/L PM (suspended + settleable + sediment)
7. Hydrology: Berretta and Sansalone, 2011a; Berretta and Sansalone 2011b

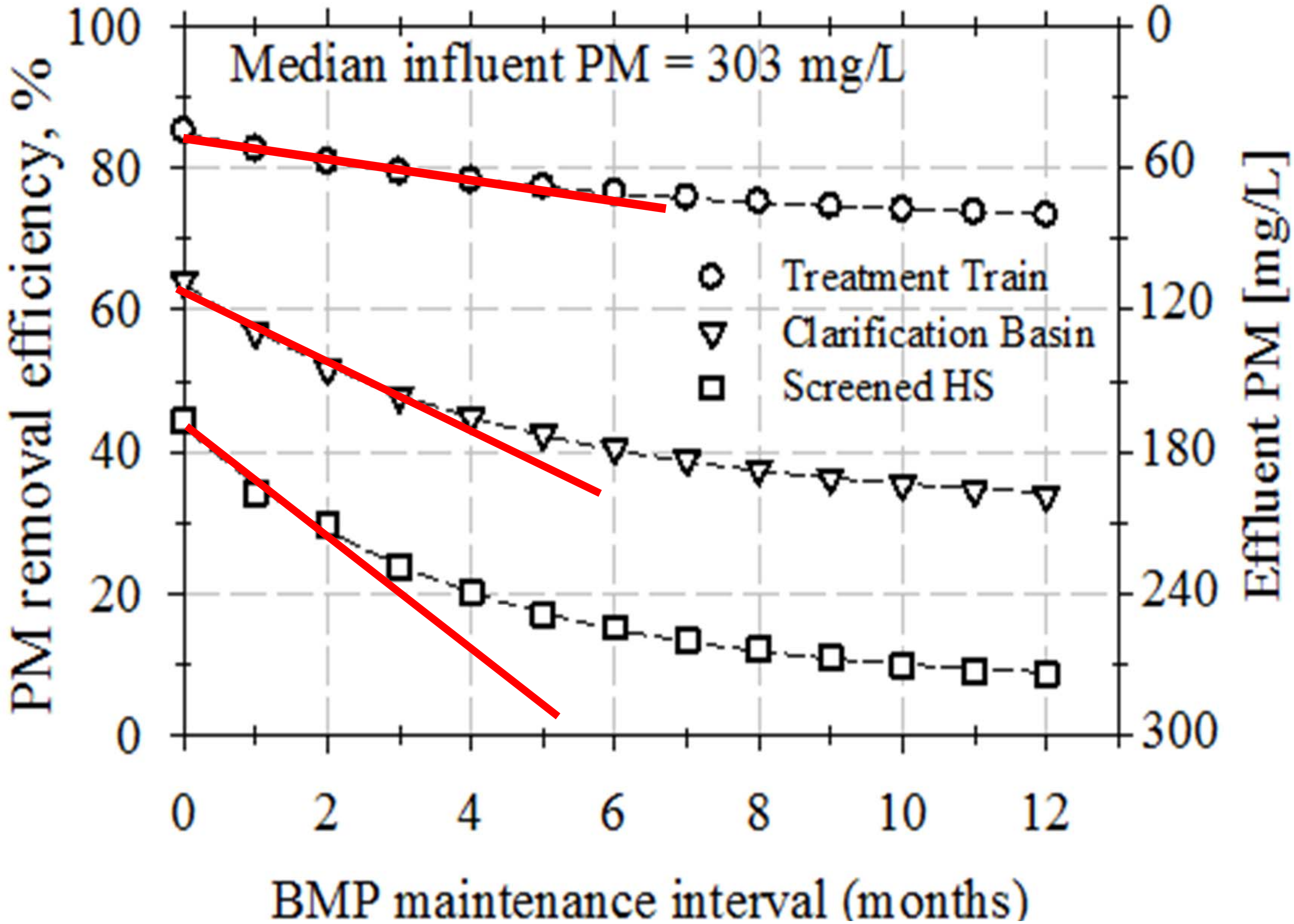
Impact of maintenance interval on PM removal efficiency
(Results validated with actual events of return periods at ~ 1 month)

Treatment Train:
- Primary (Type I) settling followed by secondary filtration

Clarification Basin:
- Primary (Type I) setting

Screened HS:
- Primary (Type I) setting and size exclusion by screen

Screened HS function governed by cleaning interval, whereas treatment train can be governed by head loss



Example: PM, N, P Recovery from BMPs

- Utilizing example parameters and peer-reviewed scientific literature:

627 lb of PM (284 Kg) separated yearly by a screened HS (BMP)

627 lb PM → 0.23 lb TP and 0.56 lb TN separated for one BMP

To recover 1 pound of TP → 4.4 BMPs need to be maintained

To recover 1 pound of TN → 1.8 BMPs need to be maintained

- While example uses annual maintenance frequency, most BMPs need more frequent maintenance to reduce PM washout and changing inter-event sump water chemistry

<u>Excerpt from Table 8 of FSA Report:</u>

HFU	**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

Example: BMP Costs

1. Catch basin have only a maintenance cost (not designed or intended for PM separation)
2. BMP costs include the capital cost for the BMP (designed and purchased for PM separation) and the cost of maintenance
3. For this example utilizing a screened HS and GNV hydrology:
   - Median capital costs ($25K) (range is $20K to $30K) at 4% interest
   - BMP design life is 25 years ➔ Annualized capital cost ~ $1600
   - With an annual frequency ➔ Annualized maintenance cost ~ $500
4. 1 pound of TP → 4.4 BMPs → $9.2K/pound of TP (3.2K – 36.7K)
5. 1 pound of TN → 1.8 BMPs → $3.7K/pound of TN (1.3K – 14.9K)
6. The bracketed ranges allow for parameter variability of:
   - Annual interest rate from 0 to 6% and capital costs from $20 to 30K
   - PM separation efficiency from 90% to 20%
   - Maintenance frequency of once per year to twice per year

Cost $/Pound: PM, TP, TN Separation or Recovery

Separation or Recovery Method	Cost ($/lb) (excluding SW landfill costs) 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 Cleaning (lowest cost)	**165**	**257**	**0.10**
Catch Basin Cleaning[d] (2nd lowest)	1,016	1,656	0.70

[a] Wet basin sedimentation followed by granular media filtration, UF, 2010.

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

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

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

Conclusions of Florida-based MS4 study

1. The consistent log-normality of TN and TP results leads to the recommendation of a median (50^{th} percentile) concentration [mg/dry kg of PM] from each TN and TP distribution.

2. This result is important for **allocation of load credits** because the results are not represented by a singular concentration [mg/kg] but by log-normal distributions

3. Through 3 MS4s, results illustrate reclaimed wastewater does enrich urban PM and detritus with P and likely other constituents (not measured herein). Results have physical basis.

4. The cost of load recovery for PM, TP and TN by maintenance practices, in particular for street sweeping, is significantly lower than current manufactured BMPs, even assuming such BMPs are maintained annually and do not scour or washout. (See $/pound slide)

5. Moisture content (MC) and bulk density are critical parameters for load credits. This study recommends that a MS4 measure both for a year as a function of HFUs.

6. Measurement of moist PM mass with MC allows a direct determination of dry PM and is preferred (if possible) over a volume measure of PM converted to mass through bulk density

7. Study results provide a Florida-wide basis and is not intended to compare MS4s