Part I: Introduction to Rainfall-Runoff Myths and Measurement

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University of Florida

J. Sansalone P.E. : Industry and Academic Background

PROFESSIONAL EXPERIENCE:

• (1983-86)	Design/Build Engineer at Sanso Inc.	(Cincinnati, Ohio)
• (1986-89)	Design Engineer at JRS and Company	(Cincinnati, Ohio)
• (1986-89)	Co-Owner: Sylvan Hills Land Development	(Cincinnati, Ohio)
• (1991-93)	Senior Engineer at JRS and Company	(Cincinnati, Ohio)
• (1994-)	Consulting Engineer and Inventor	(Ohio, Louisiana, Florida)

ACADEMIC EXPERIENCE:

• (1997-98)	Research Assistant Professor	(University of Cincinnati)
• (1998 -)	Visiting Professor	(Univ. Calabria, Genoa, Bologna, Milano)
• (1998-2005)	Assistant ➔ Associate Professor	(Louisiana State University)
• (2000-2005)	Louisiana Land & Exploration Prof.	(Louisiana State University)
• (2002-2005)	Assoc. Director of LWRRI	(Louisiana State University)
• (2008 -)	Professor in EES/ESSIE	(University of Florida)

ACADEMIC CREDENTIALS:

• B.S.	Civil Engineering (1983)	(Christian Brothers University)
• M.S.	Geotechnical Engineering (1992)	(North Carolina. State University)
• Ph.D.	Environmental Engineering (1997)	(University of Cincinnati)

CURRENT:

- 19 Ph.D. and 12 MSc. graduated in Engineering; 4 Ph.D. and 5 MSc. Student in process
- 100+ archival manuscripts, 2 book chap., 10 patents, 200+ presentations, 2 Editorial Boards.

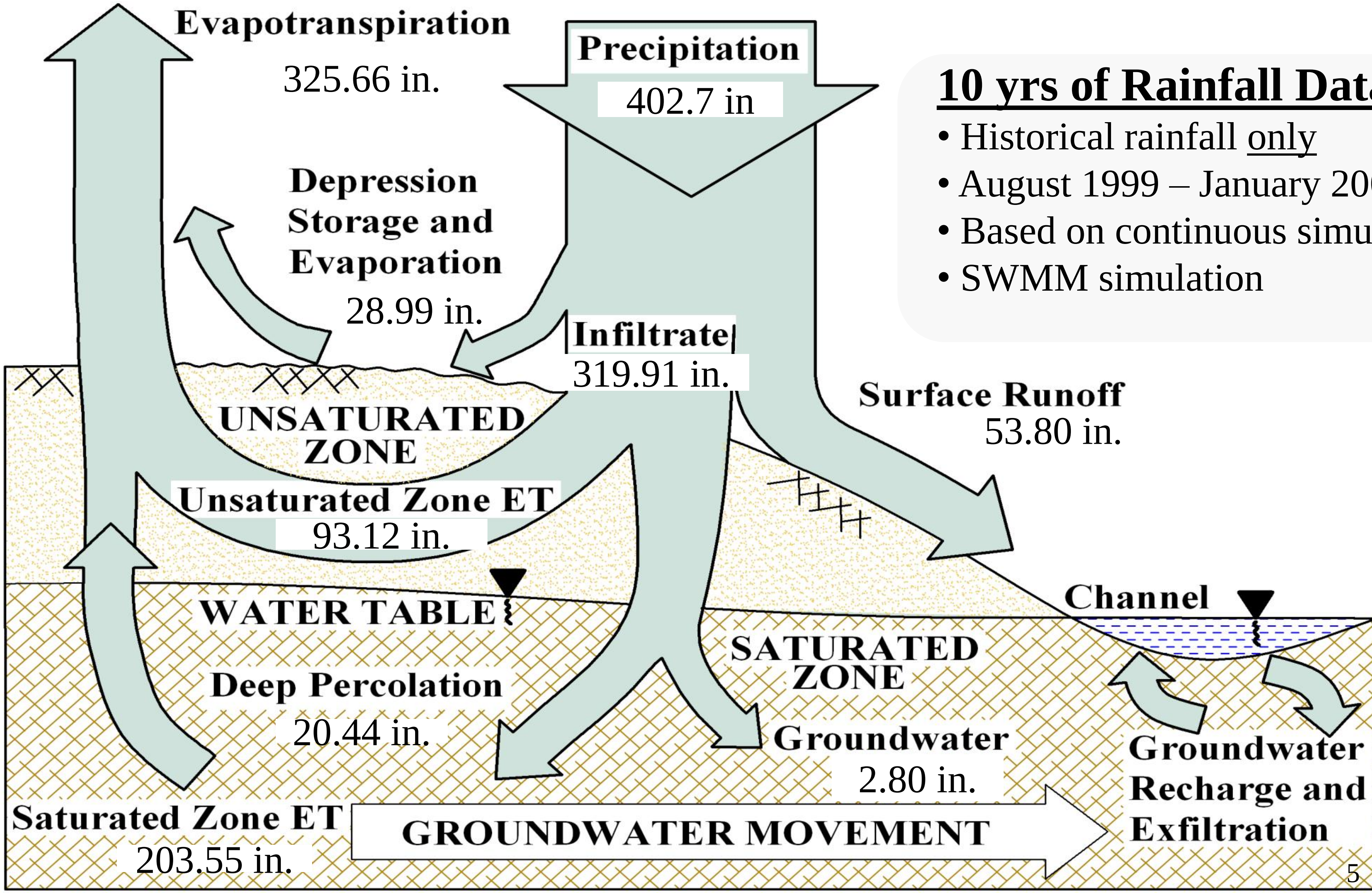
PROBLEM STATEMENT:

The Urban Interface Profoundly Modifies the Coupled Hydrologic, Particulate, Chemical and Thermal Cycles

As a result, monitoring, modeling and control are complex with spatial scales ranging from watershed to molecular and temporal scales from seconds to years.

MnOx on a concrete media substrate

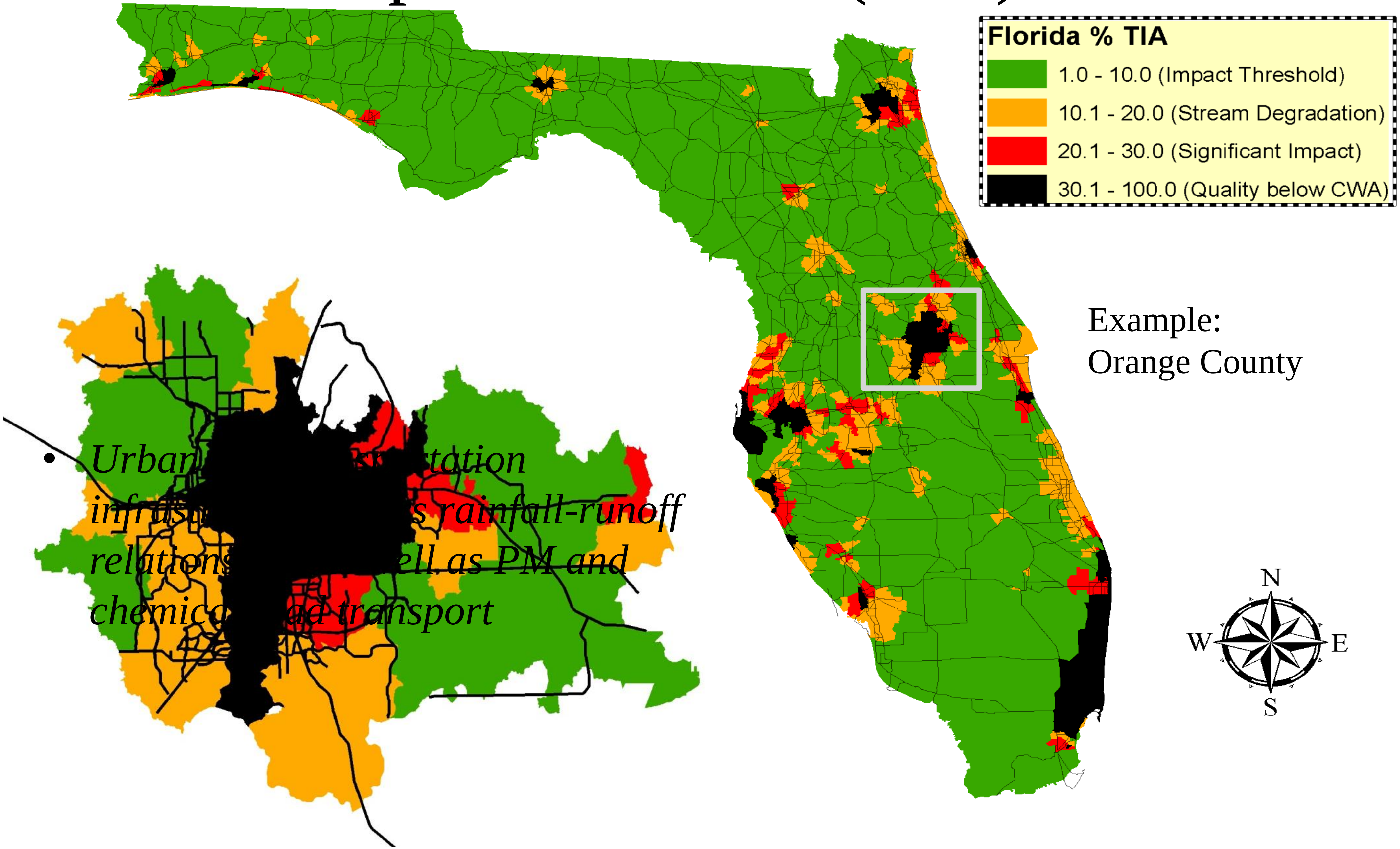
Watershed Pre-Development Hydrologic Cycle



<u>10 yrs of Rainfall Data:</u>

- Historical rainfall <u>only</u>
- August 1999 – January 2009
- Based on continuous simulation
- SWMM simulation

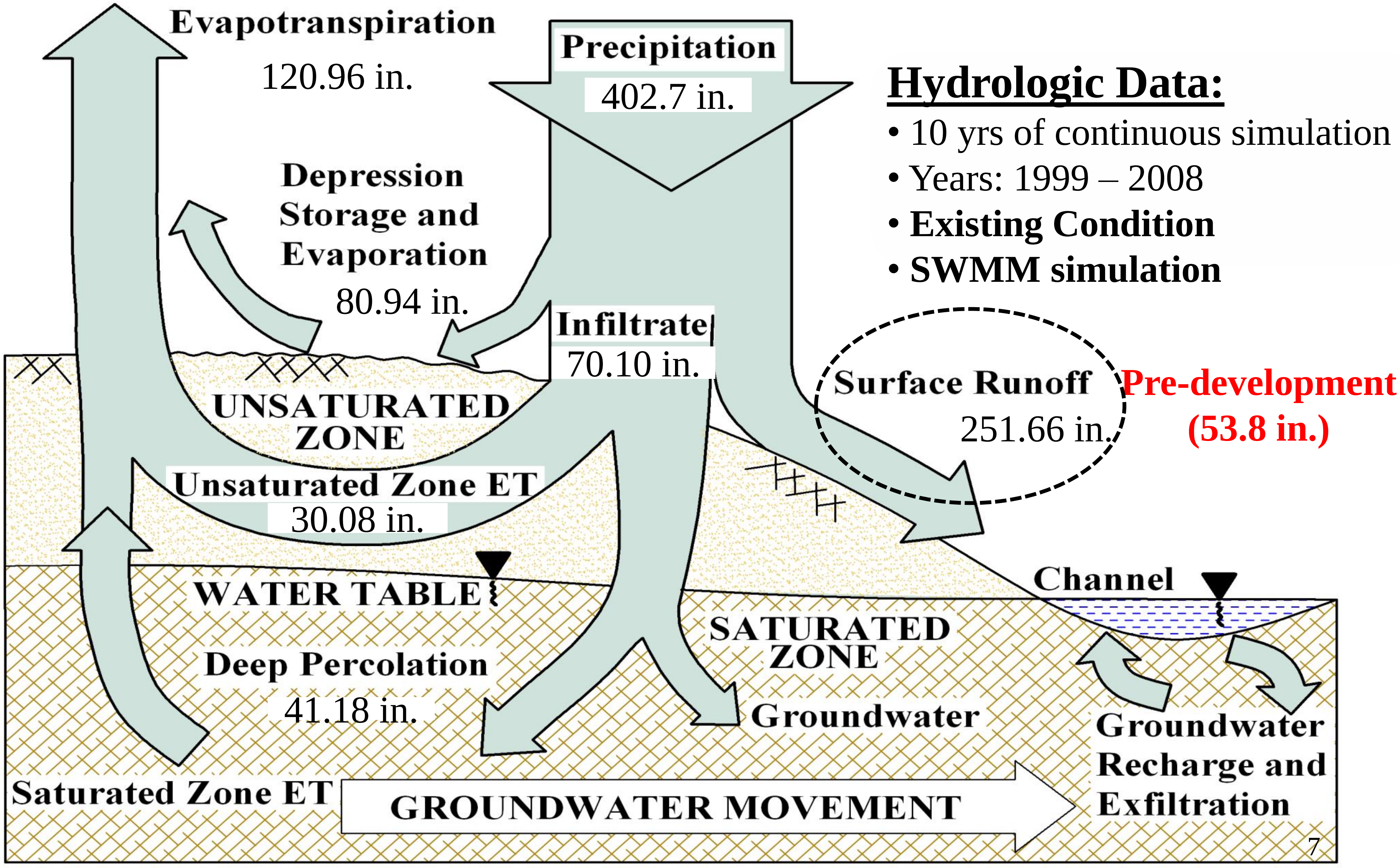
Total Impervious Area (TIA): Florida



Example:
Orange County

- *Urban ... tation infras ... s rainfall-runoff relations ... ell as PM and chemic ... ad transport*

Catchment Post-Development Hydrologic Cycle



Hydrologic Data:

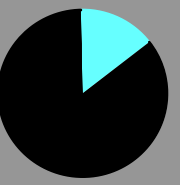
- 10 yrs of continuous simulation
- Years: 1999 – 2008
- **Existing Condition**
- **SWMM simulation**

Urban Runoff *vs.* Untreated Wastewater Loads

Urban data utilized:

- 800,000 population (250-Lpd/capita)
- 1050 mm mean annual rainfall (C = 0.7)*
- 40 km^2 interstate and arterial road areas
- 0.5 * equilibrium partitioning fraction

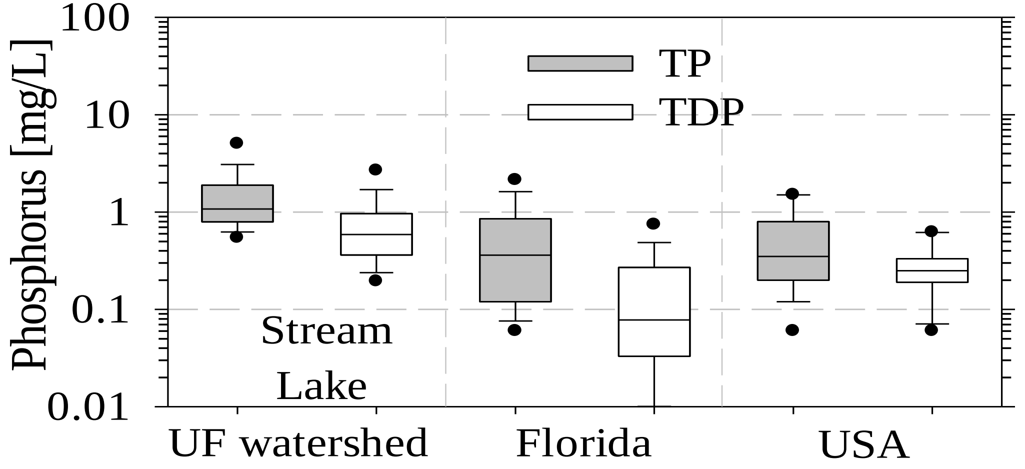
40-km^2 as a % of total pavement area of the urban area

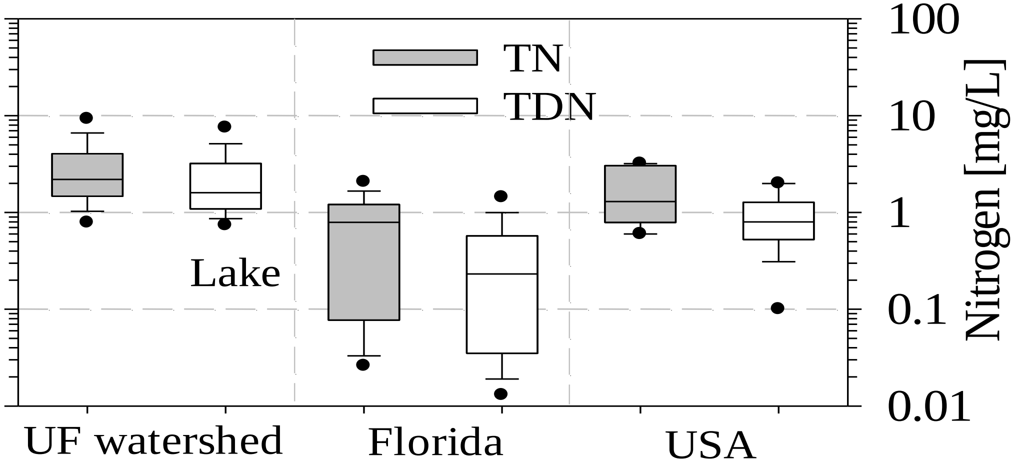


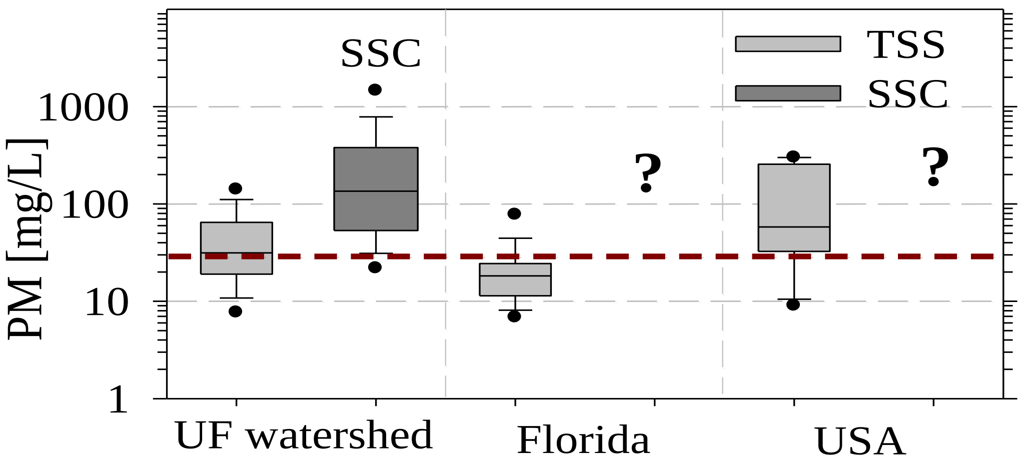
	ANNUAL RUNOFF	WASTEWATER
Flow (M^3)	3.1×10^9	5.3×10^9
COD [mg/L]	350	400
TSS [mg/L]	200 [1] (62,000 $tons_m$)	220
Zn_T* [µg/L]	1000 (310 $tons_m$)	75 (USEPA 1993)
Cu_T* [µg/L]	150 (47 $tons_m$)	35
Pb_T* [µg/L]	90 (28 $tons_m$)	10
Cd_T* [µg/L]	10 (3 $tons_m$)	1

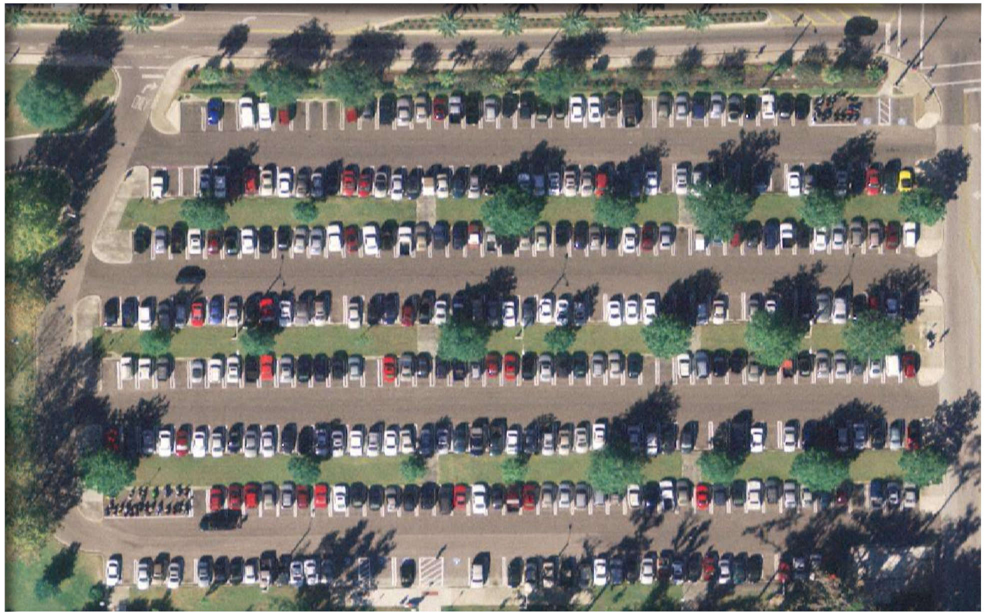
[1] TSS: 180-mg/L (81 Urban commercial/residential areas, NURP, 1983)

P, N and PM comparison between watershed studies with urban land use conditions (UF watershed: COE/Rietz Union parking)

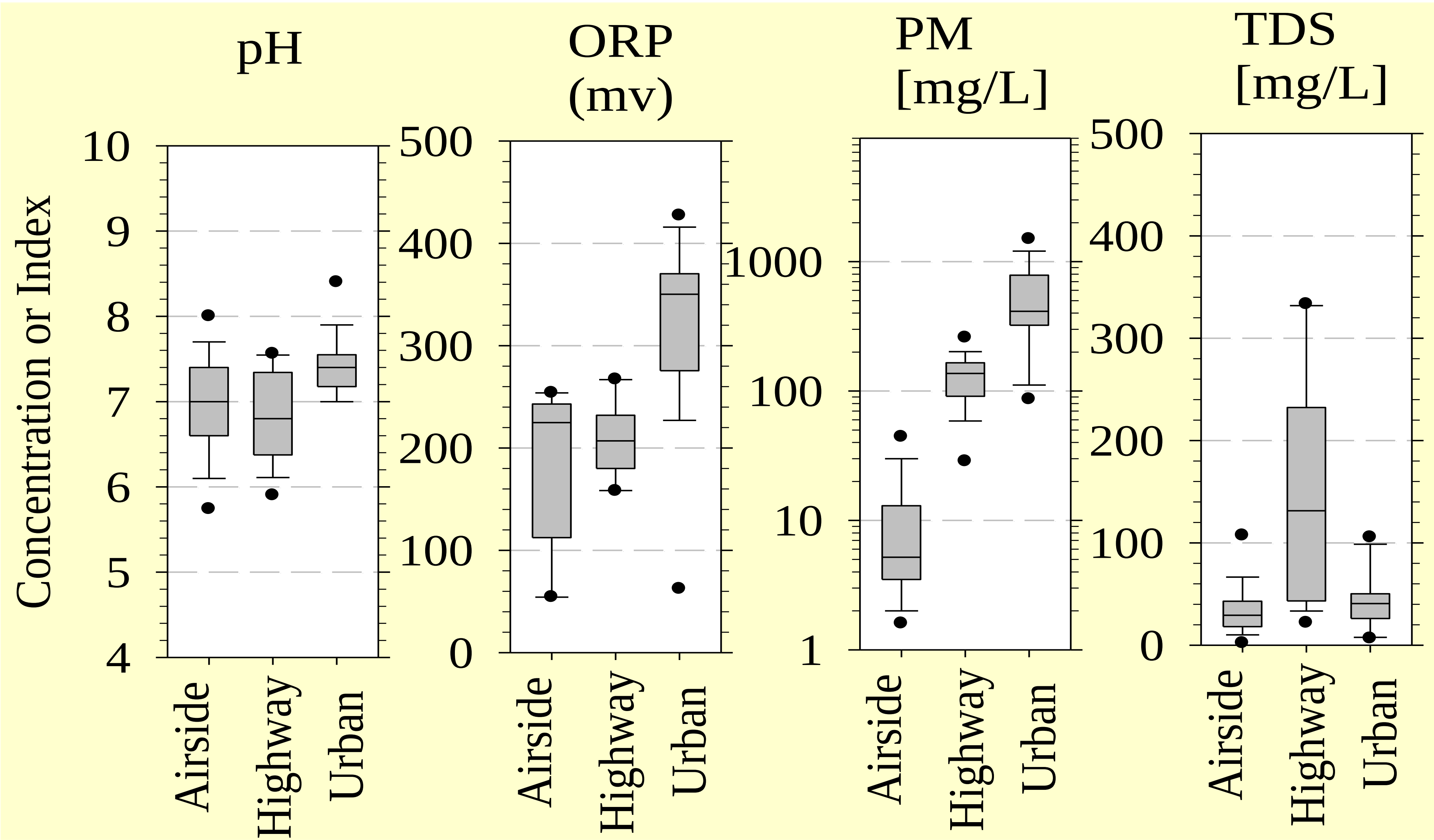




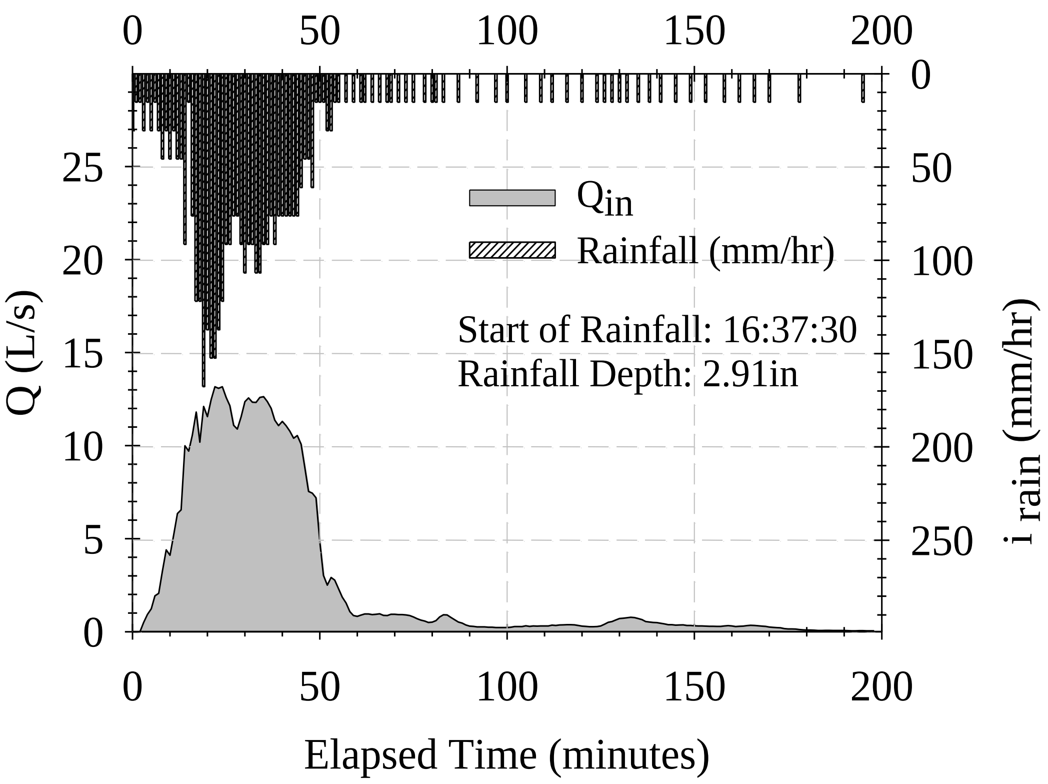




Water Chemistry Indices for Land Use Categories

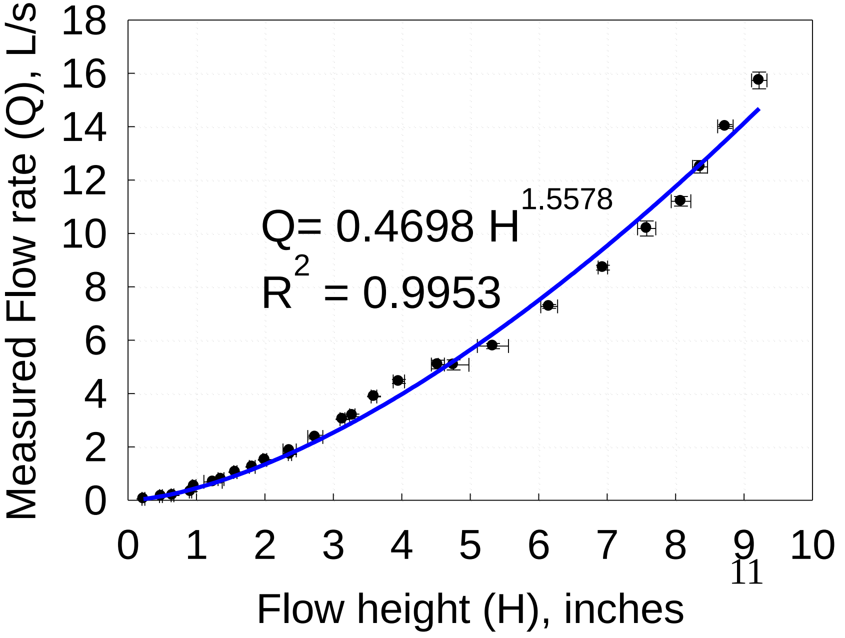


8 July 2008 event at a instrumented UF watershed
(models without validating measurements can be hydro-fantasy)

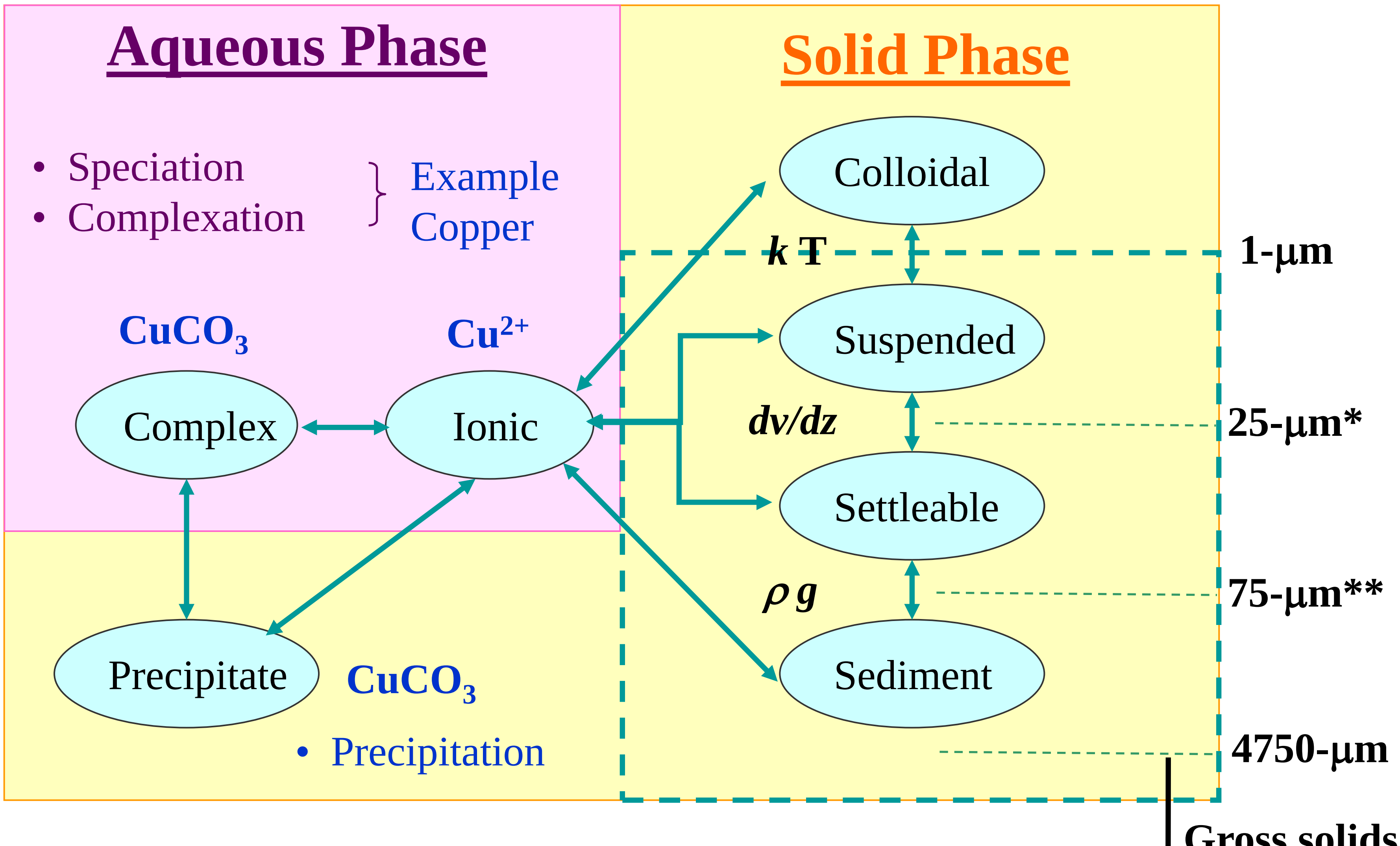


- Paved watershed (75% asphalt) and approximately 500 m^2
- Direct rainfall-runoff relationship
- Rain measured at 0.01 inch increments (tipping bucket gage located at watershed), validated from www.wunderground.com (Station KFLGAINE10 on UF campus)

- Runoff depth measured by Parshall flume at 1 minute intervals and translated to flow using a **calibrated** power law of flume stage-discharge data

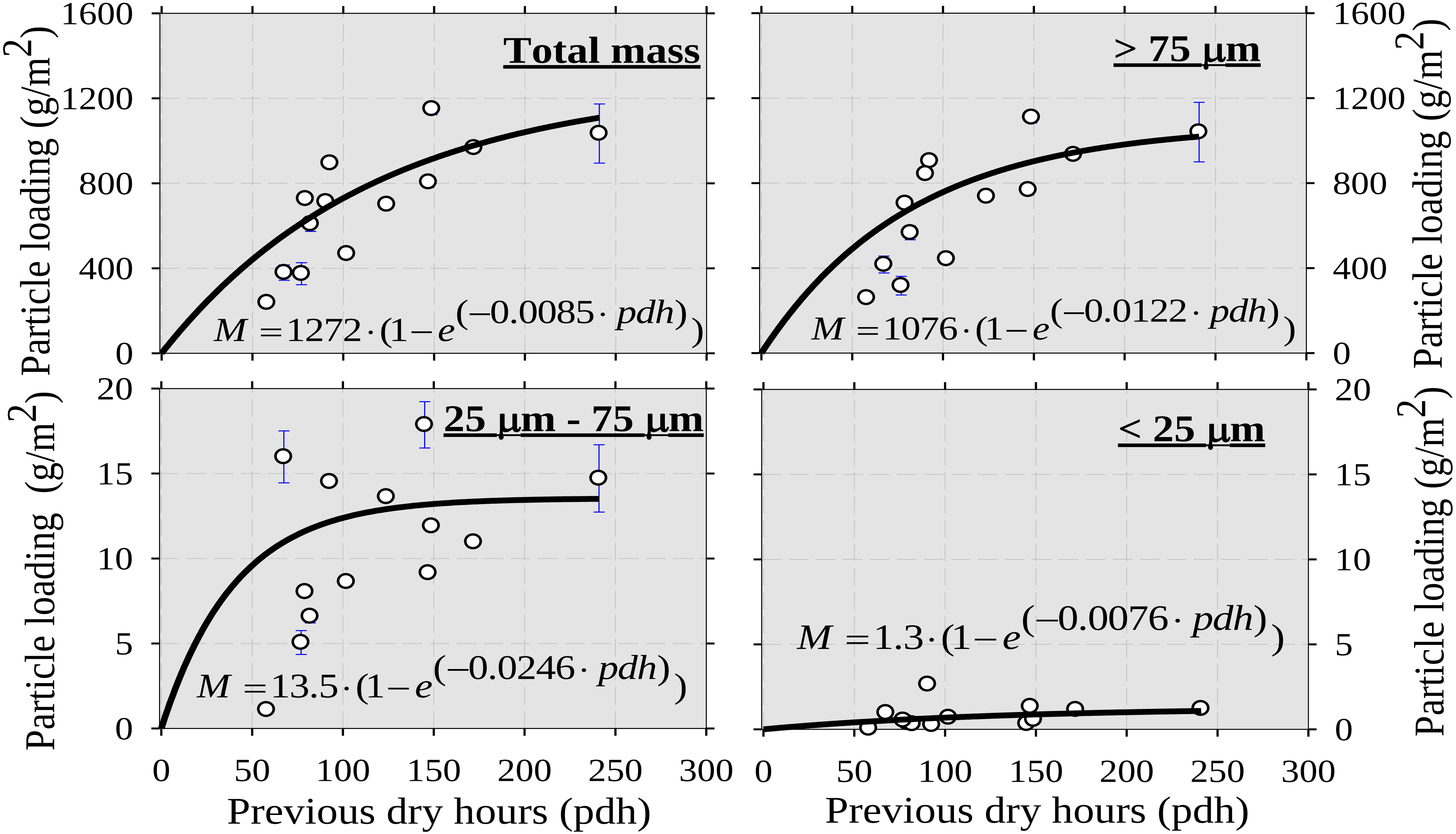


Categorizing PM and Physical-Chemical Phenomena



* Based on 1-hr Imhoff settling test; ** < 75 μm "silt" size

Urban PM "Build-Up" models: A tool for street cleaners



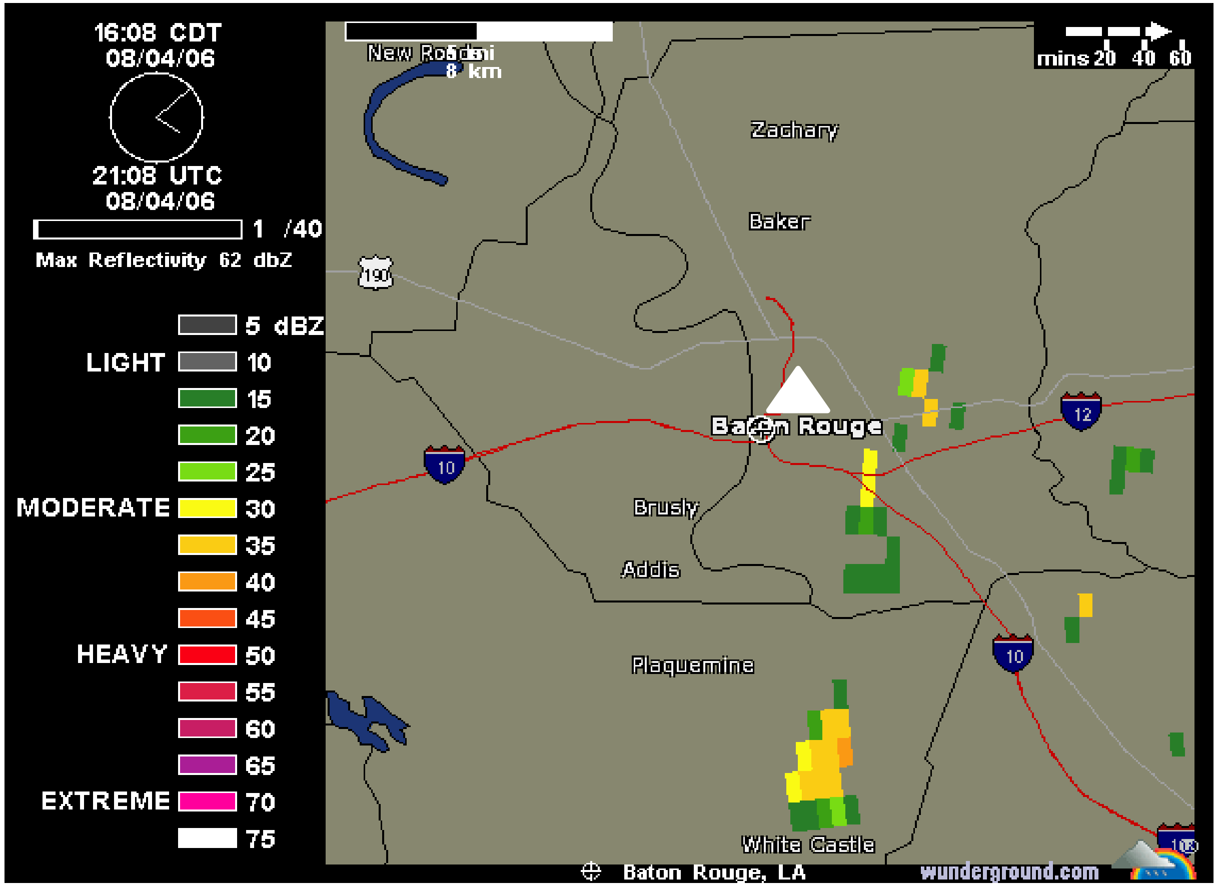
First Flush: Intuitive Misconception vs. Reality

<u>Concept</u>: A "first flush" is a disproportionate delivery of a constituent during initial portion of a runoff event that may be used to estimate a treatment capture volume or water quality volume, WQV. ***(Urban runoff to sea in Sorrento, Italia, 2004)***

<u>Reality</u>: ***"First-flush" delivery can be <u>proportionate</u> delivery (flow-limited), may not be <u>initial</u>, and is dependent on: method of <u>measurement</u>, the <u>goal</u>, the <u>constituent</u> <u>phase</u>, the <u>geometry</u> of the watershed, <u>location</u> in the watershed; and is never known <u>a-priori</u>.*** **WITH REUSE, REGULATION BASED ON FIRST FLUSH ARE DATED**

Any treatment design based on volume requires that we evaluate a WQV and first-flush transport

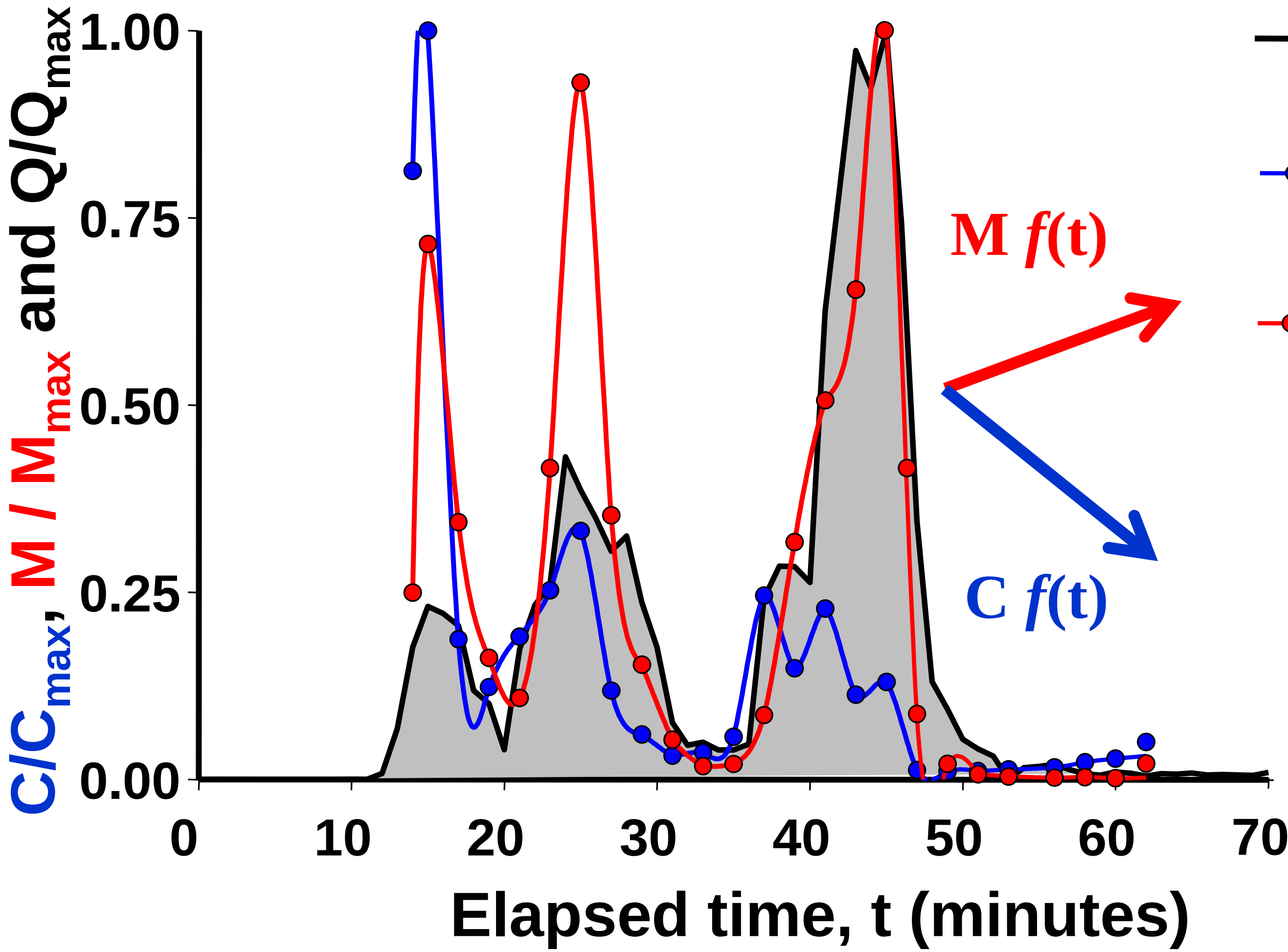
1. The "first-flush" is the assumed disproportionate delivery of mass during the rising limb of the hydrograph
2. A water quality volume (WQV) for urban catchments is a fixed depth of runoff (i.e. 1 inch)
3. As small catchments of differing times of concentration combine into more complex and larger urban watersheds, a first-flush (mass-limited behavior) is greatly diminished to non-existent and the WQV increases
4. Complicating this complexity is the lack of "a-priori" knowledge



04 August 2006 Event in Baton Rouge: The "a-priori" challenge

Hydrologic Delivery of Concentration and Mass

(1) *Does a "first-flush" exist* ? (2) *What volume would you capture/treat* ? (3) *Is this behavior known a-priori ?*



— (Q): Flow
Q_{max} = 244 L/minute

[C]: Concentration (SSC)
C_{max} = 689 mg/L

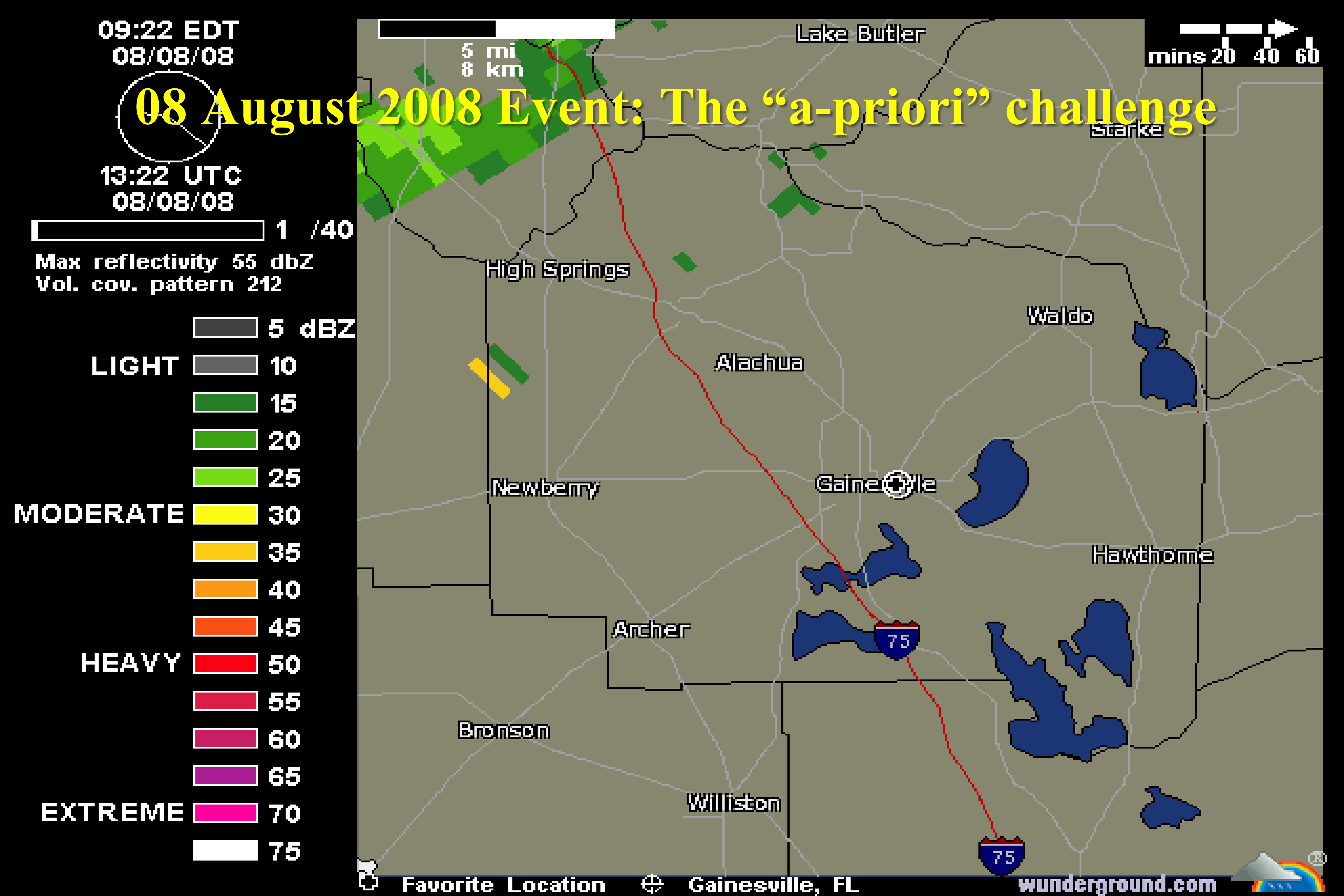
(M): Mass (SSC)
M_{max} = 41,460 mg

SSC: suspended sediment concentration

- 300 m^2 paved source area urban catchment

- ***In part, <u>acute</u> toxicity is associated with concentration and time; <u>chronic</u> toxicity with mass and time***

08 August 2008 Event: The "a-priori" challenge



8 JULY 2008 (University of Florida Catchment)

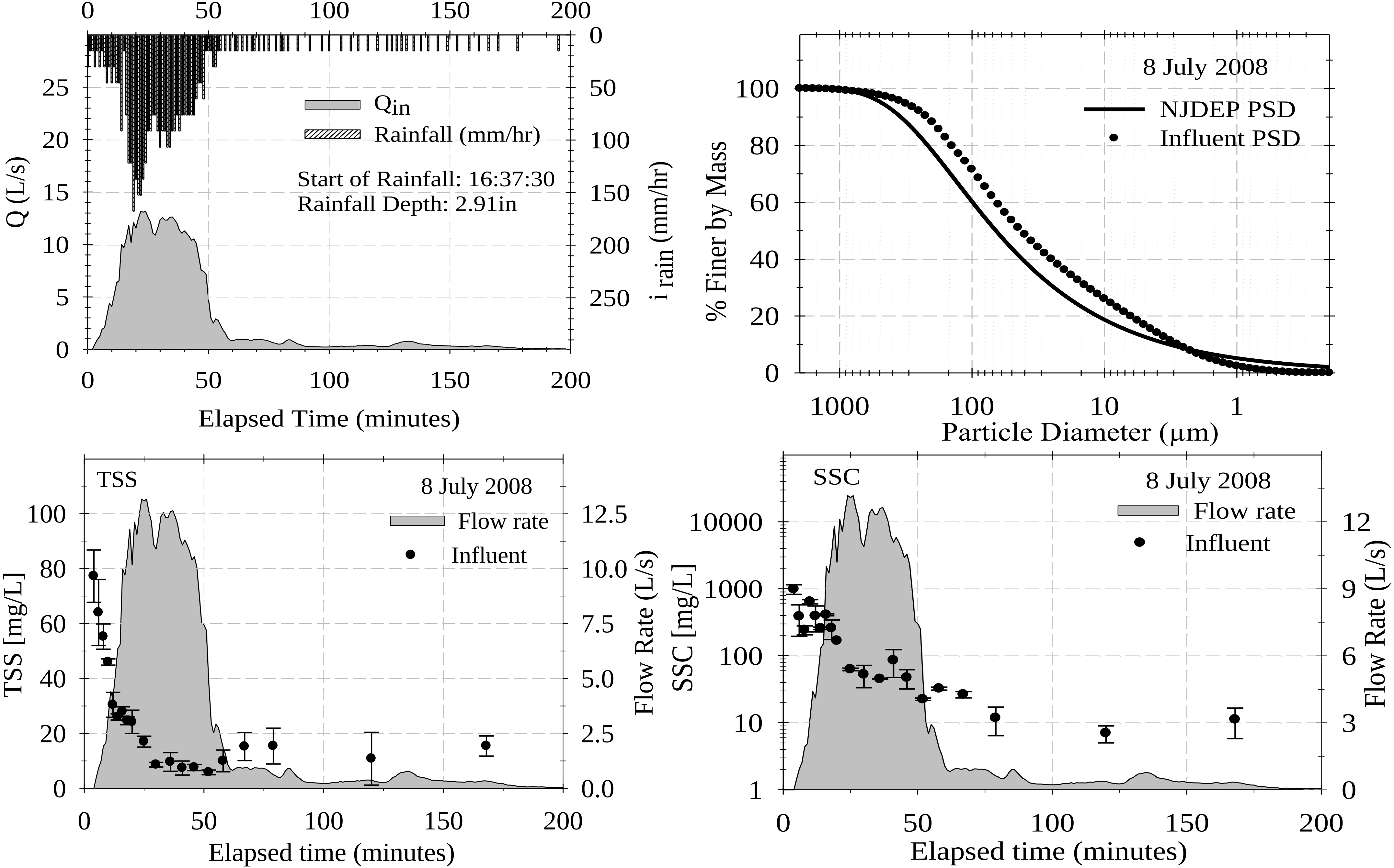
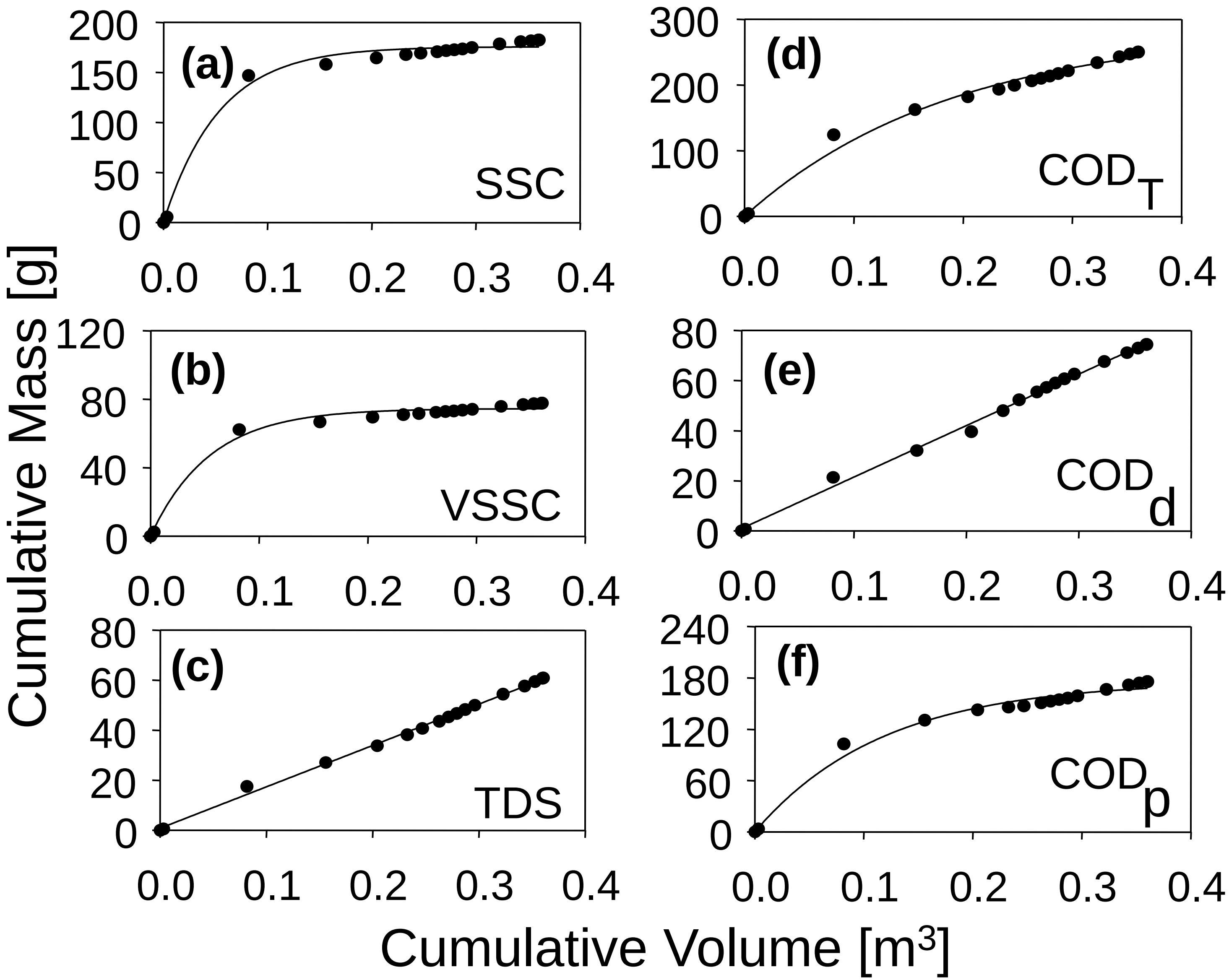


Illustration that constituent fractions exhibit differing transport behavior for same event – What is the WQV basis ??



31 May 2001 event
Baton Rouge, LA

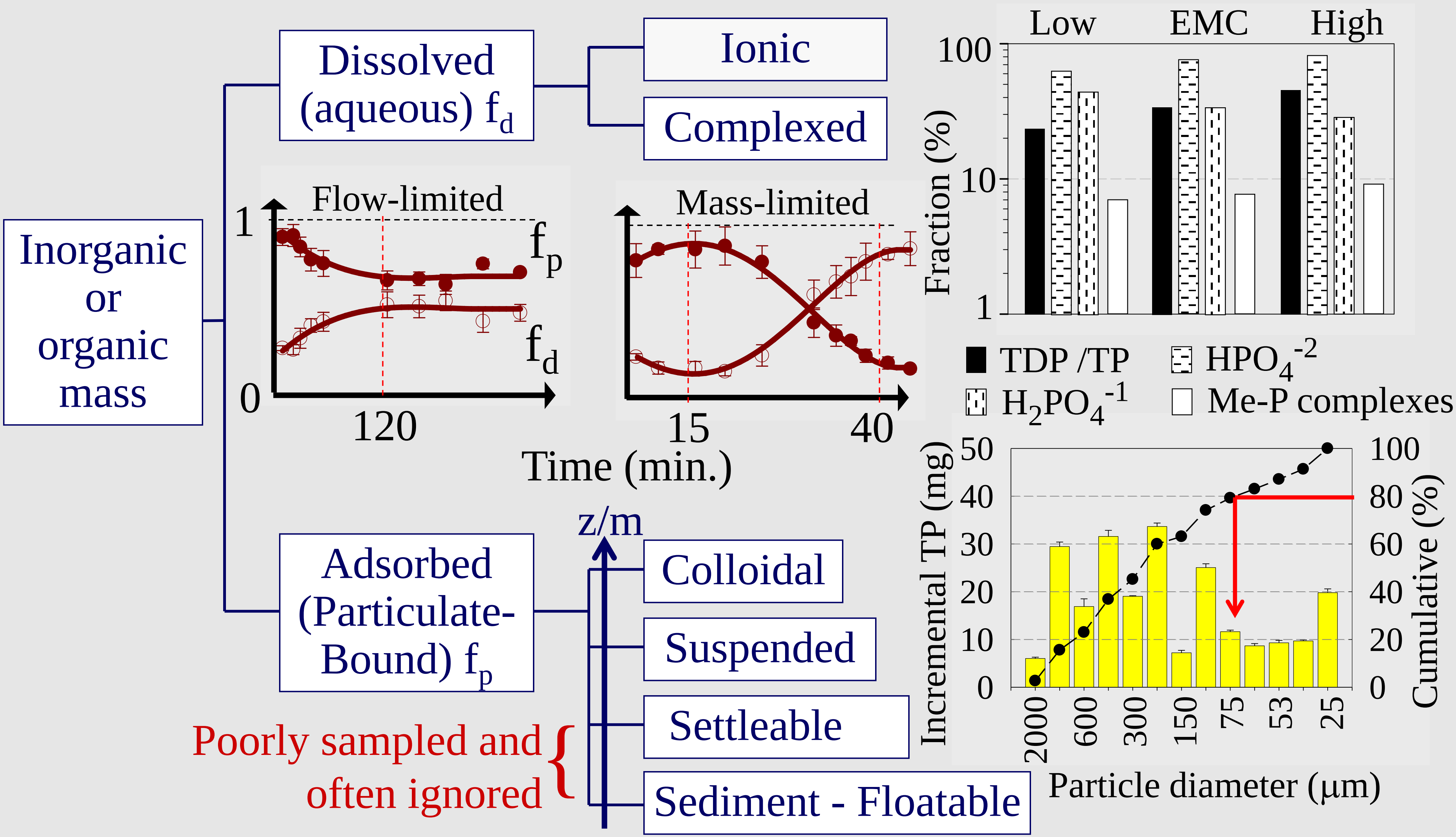
Mass-limited:

- SSC (plot a);
- VSSC (plot b);
- COD_T (plot d);
- COD_p (plot f).

Flow-limited:

- TDS (plot c);
- COD_d (plot e).

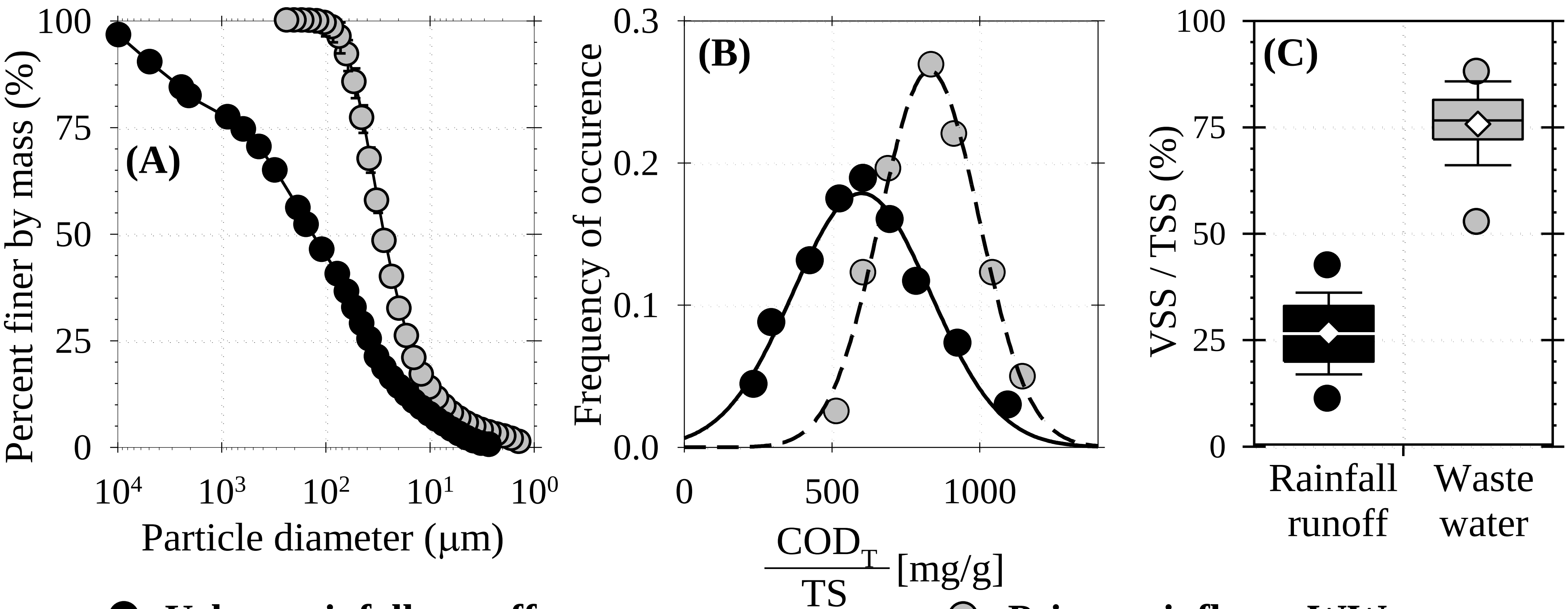
Partitioning and distribution of mass (example – P)



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 urban practices (street, CB cleaning) is lower than using conventional BMPs**

Urban Rainfall-Runoff vs. Wastewater PM



● **Urban rainfall-runoff** ● **Primary influent WW**

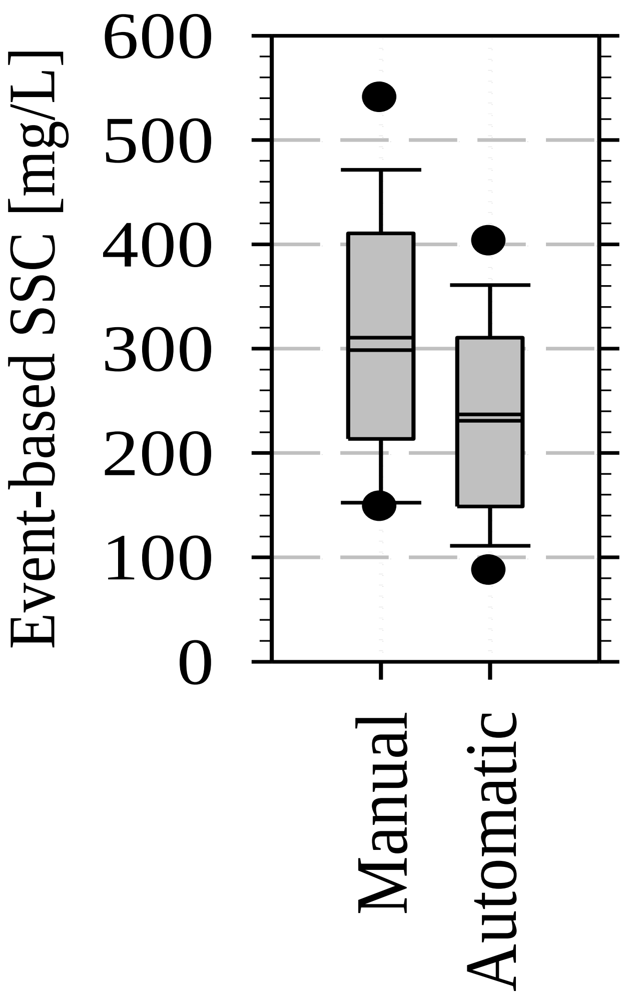
Constitutive Aspects:

(A) Granulometry (PSD)

(B) Oxygen Demand

(C) Organic (Volatile) %

Sampling Representativeness of Total PM
(Index: Influent Suspended Sediment Concentration, SSC)

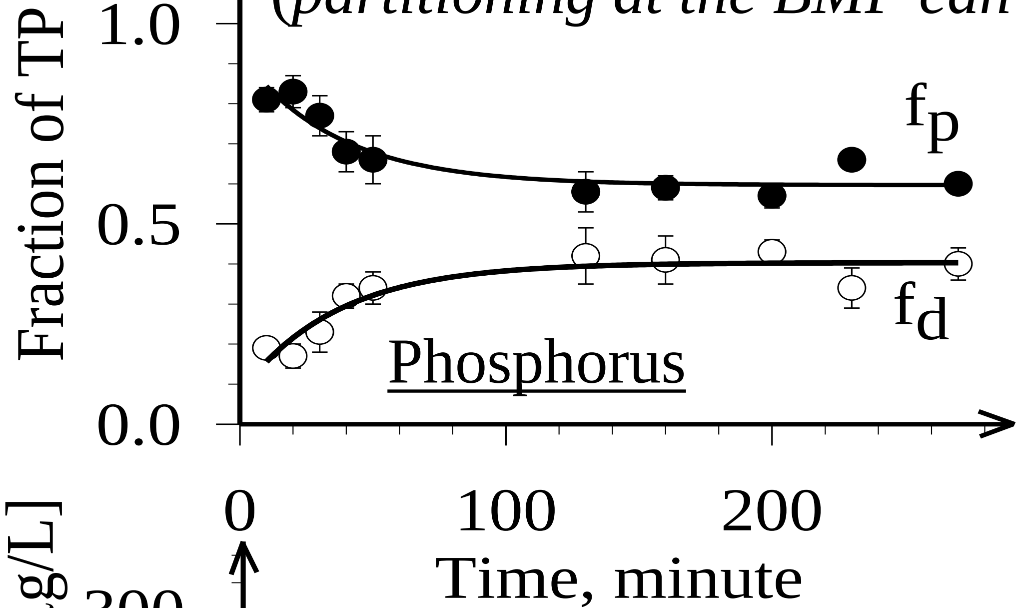


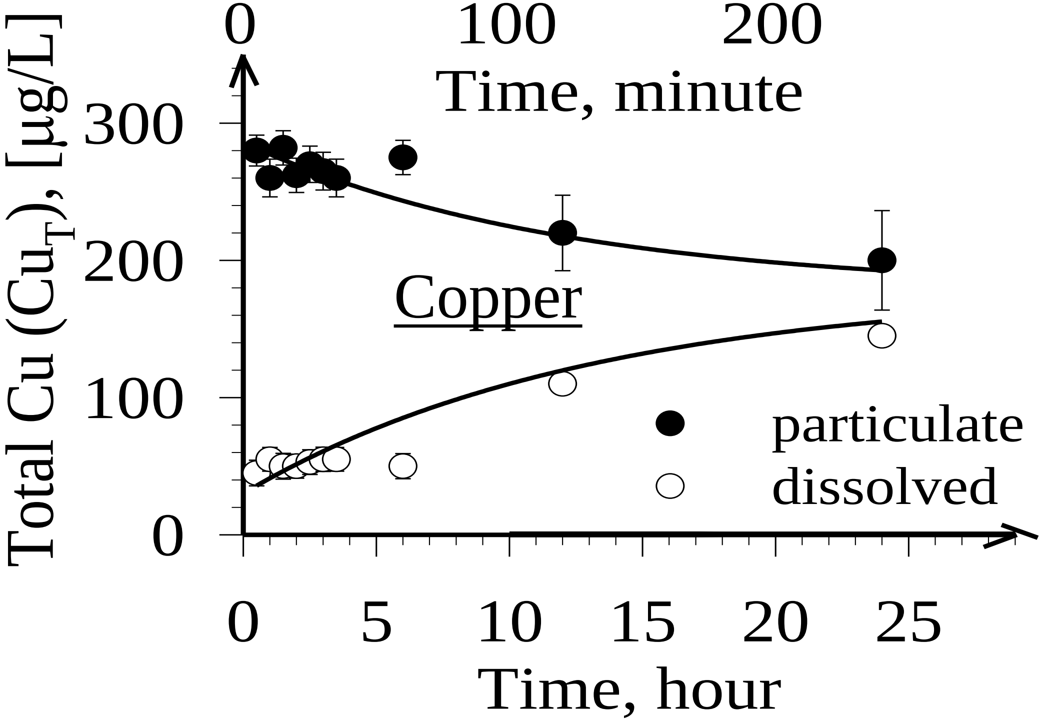
Liu, Ying and Sansalone, JEE, 136(12), 2010

1. Non-parametric analysis based on 18 paired runoff events of **event-based composites**
2. SSC for ***manual*** sampling composites:
   - Median (50th %): 299 mg/L
   - Mean: 310 mg/L
   - (5% , 95%): (148 mg/L, 549 mg/L)
3. SSC for ***automatic*** sampling composites:
   - Median (50th %): 237 mg/L
   - Mean: 230 mg/L
   - (5%, 95%): (87 mg/L, 402 mg/L)
4. Implications include quantifying level of unit treatment, mass capture and BMP maintenance
5. While intra-event concentrations are log-normal to exponential, **event-based composites** for a given catchment can fit a Gaussian distribution

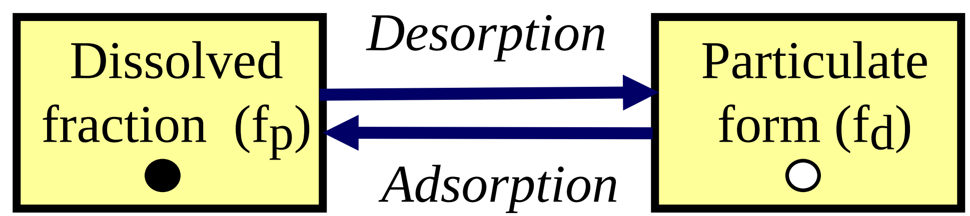
Influence of sample holding time: TP and Cu_T

(partitioning at the BMP can be very different than what lab reports)





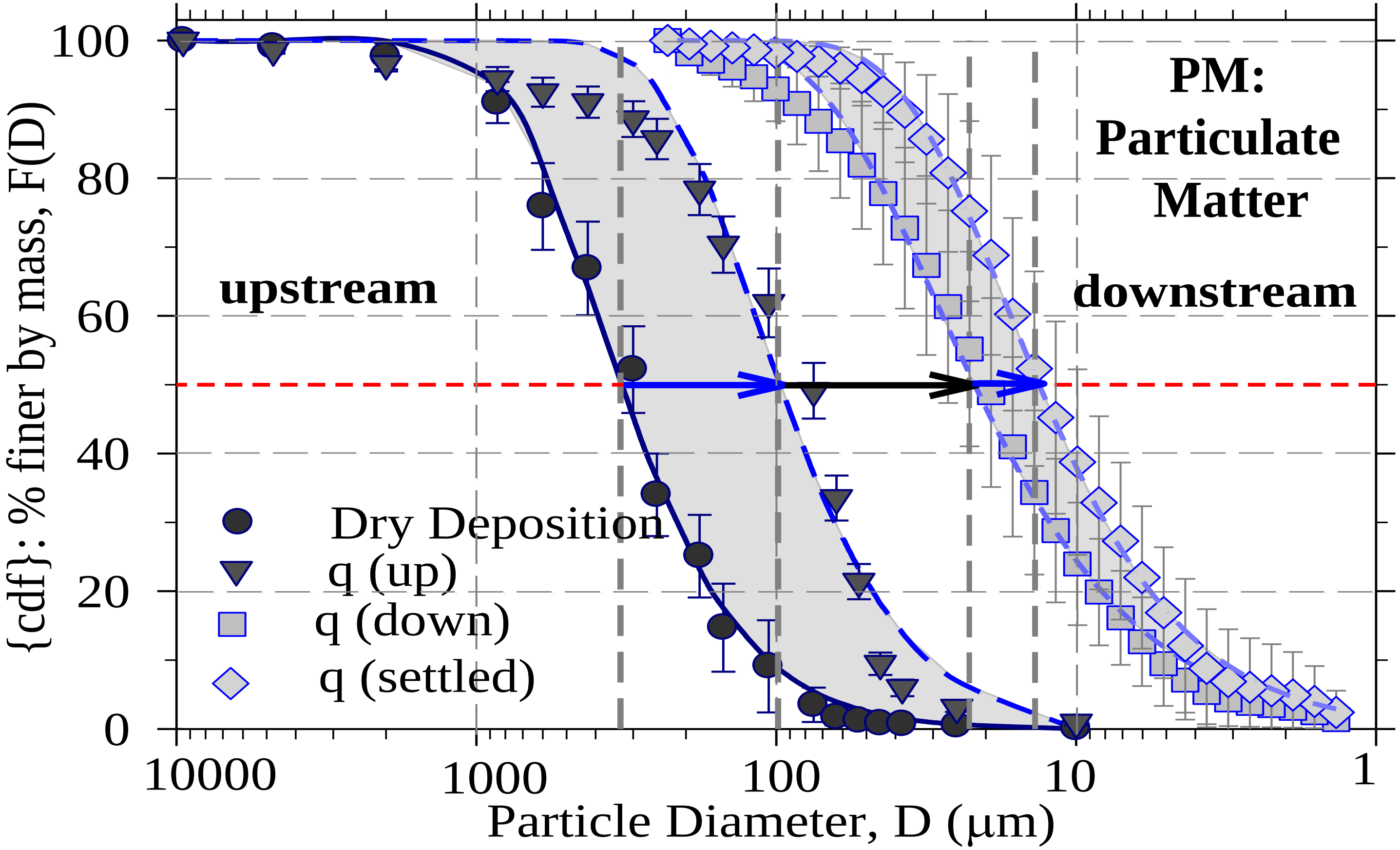
- Equilibrium f_p (TP) : 0.65
- Equilibrium f_d (TP) : 0.35
- Equilibrium Cu_d: 200 µg/L
- Equilibrium Cu_p: 150 µg/L



- Sample holding time is critical for accurate representation of partitioning, speciation and treatment effectiveness
- Water chemistry at a BMP is different than what the lab receives 24 hr. later

Sansalone and Buchberger, JEE, 1997

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



PSD gamma model

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

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

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

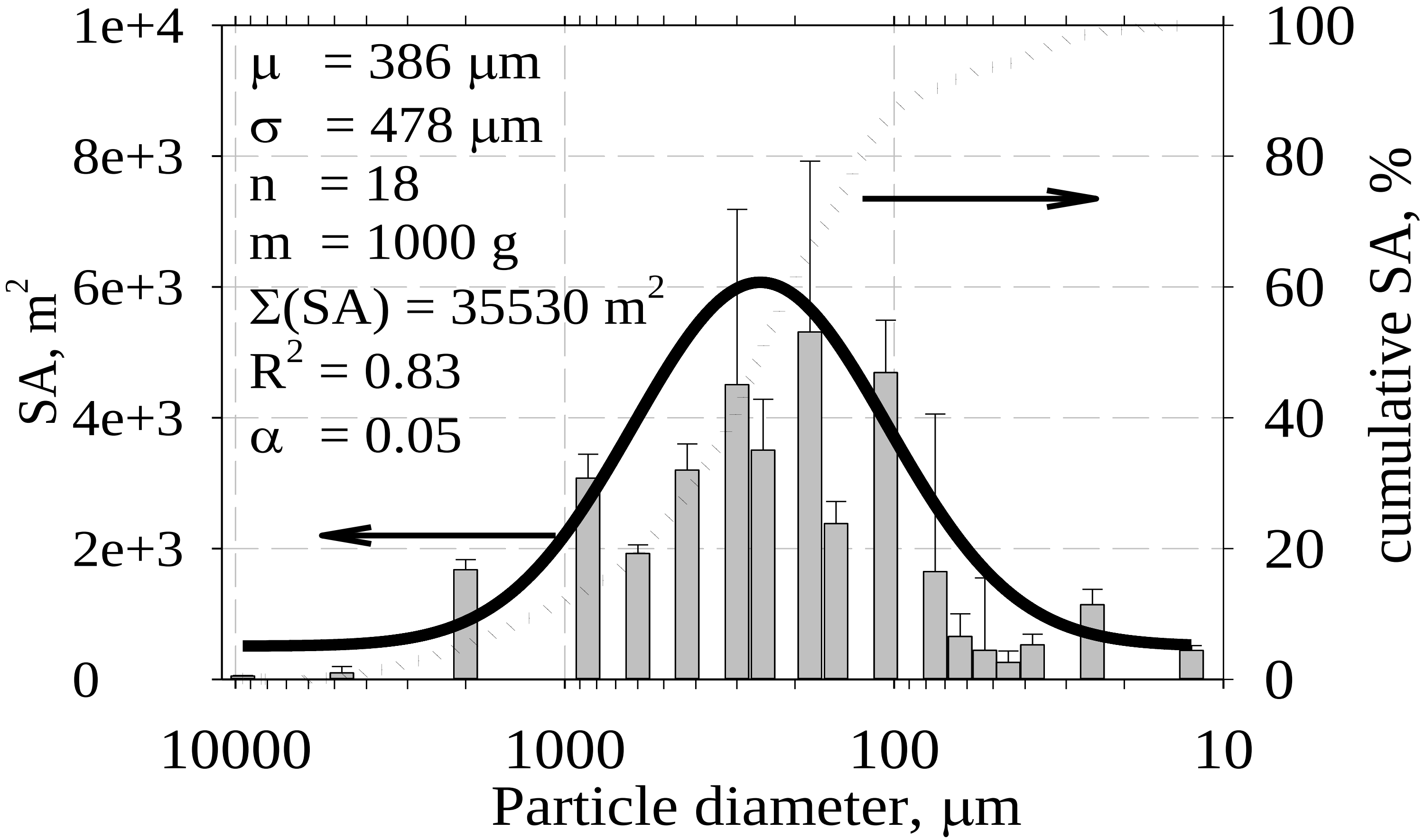
$$\Gamma_D(\gamma) = \int_0^D x^{\gamma-1} e^{(-x)} dx$$

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)

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

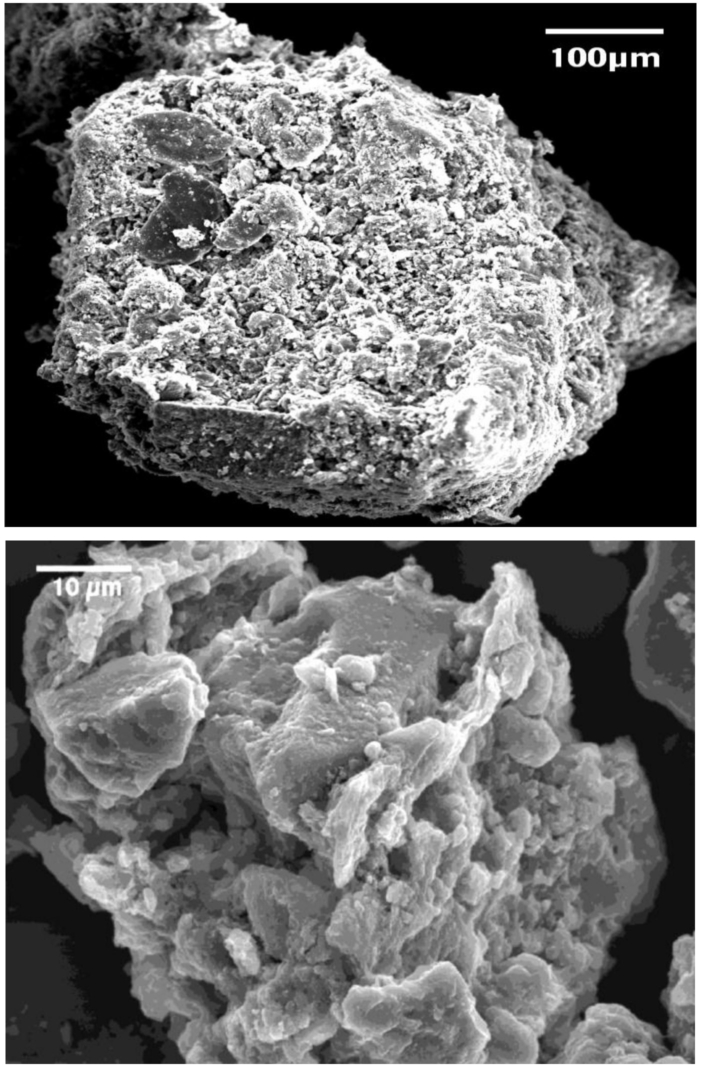
Chemical loads are correlated to PM surface area (SA)



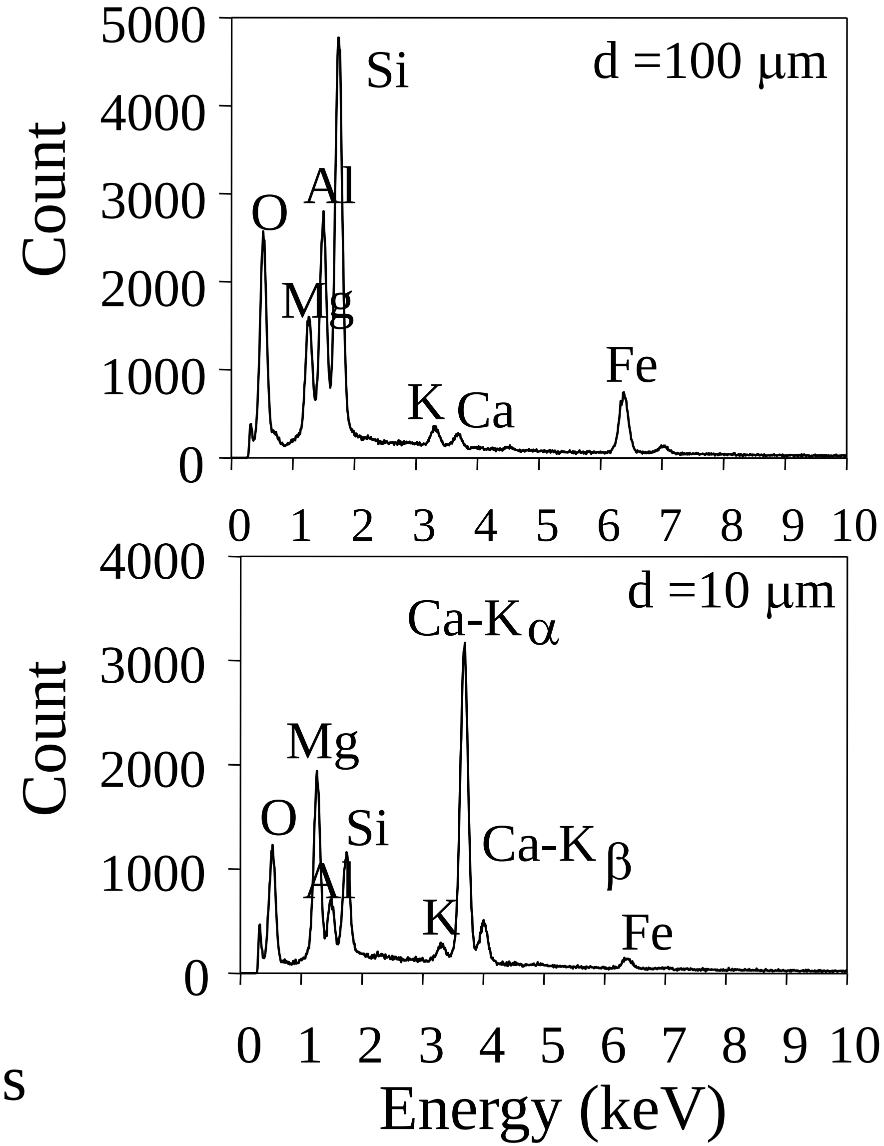
- SA distribution as function of PM size are log-normal
- *Ying and Sansalone, J. of Hydrology, 2010*
- *Sansalone and Cristina, JEE, 2004*

- SA result represents the integration of PSD (mass) and specific surface area (SSA) to yield a resulting SA distribution.
- PM-associated chemical mass (metals, phosphorus) correlates to SA of PM **not** SSA.

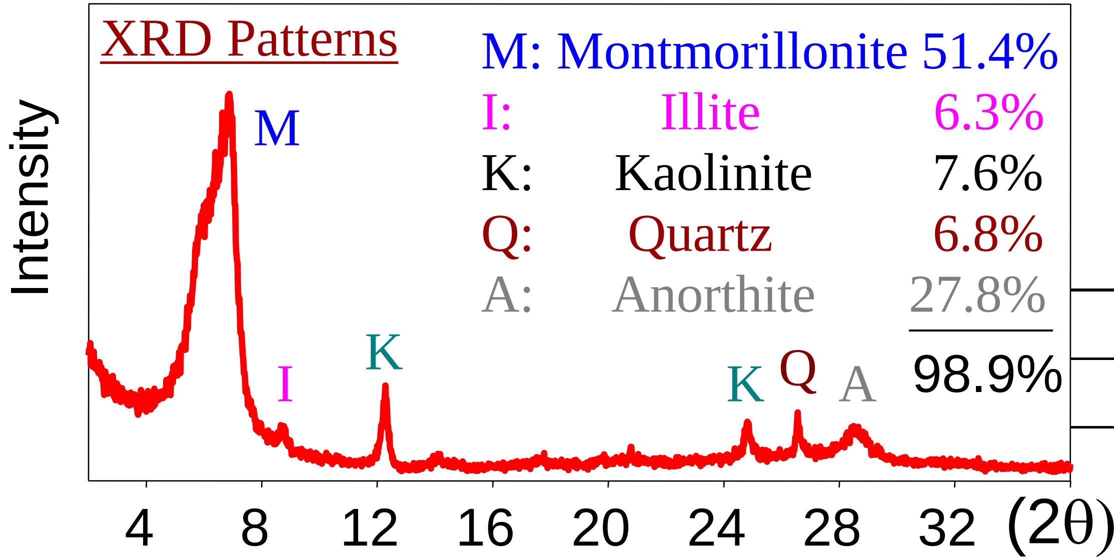
Urban Anthropogenic Particles
(Examination with SEM, energy dispersive X-ray spectra)

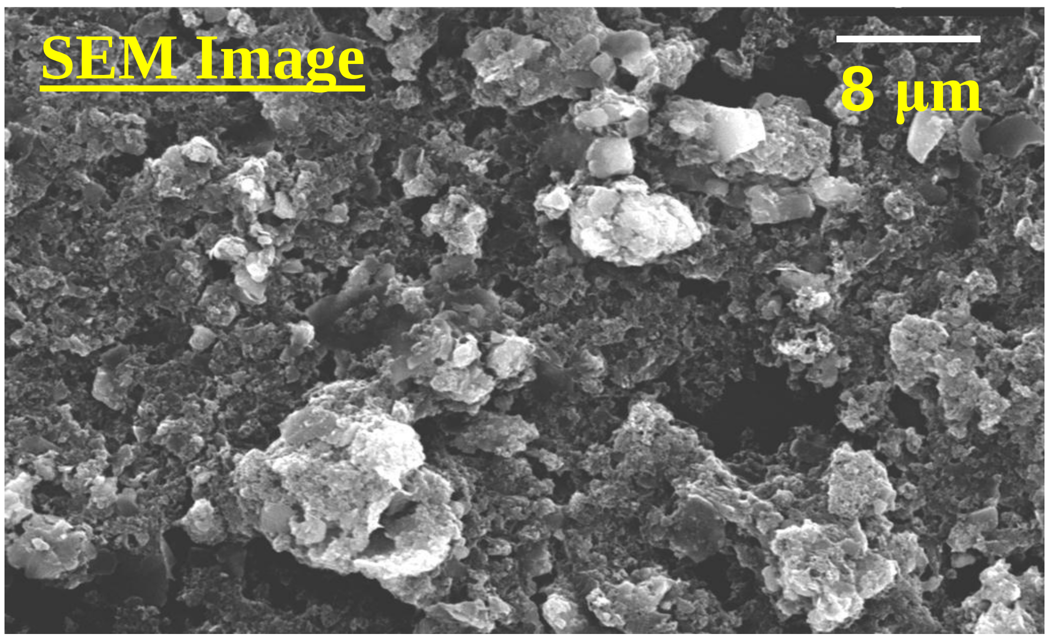


SEM images for runoff particles



Clay-size Fraction in Rainfall-Runoff





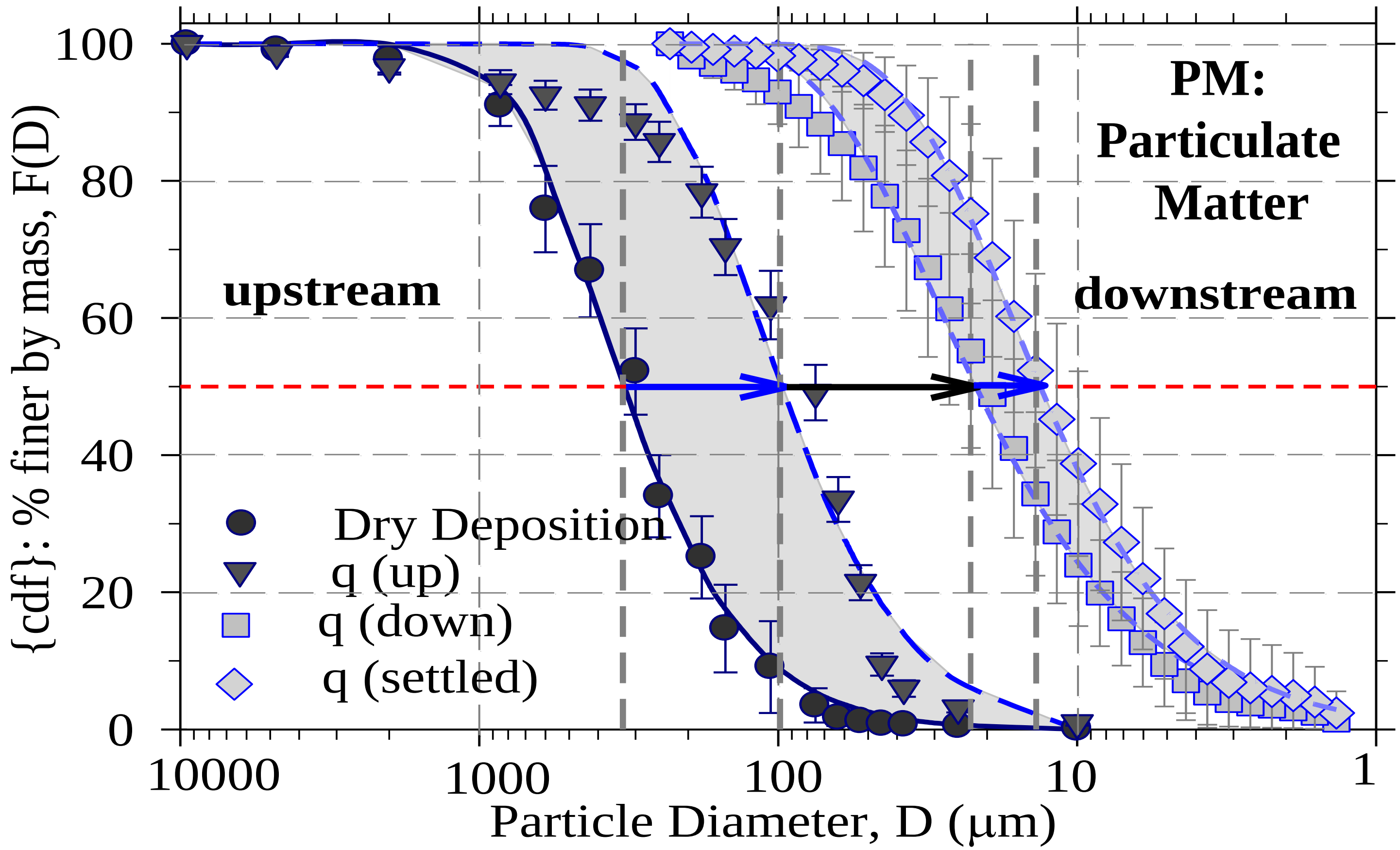
Physical Indices:

d_{50} (µm)	3.5
ρ_s (g/cm^3)	2.68
SSA (m^2/g)	130
PZC	5.8
D2 (Fractal)	1.93

Composition:

Cu (mg/kg)	210
Zn (mg/kg)	2160
Cd (mg/kg)	8.84
Pb (mg/kg)	728
Mg (mg/kg)	1510
Ca (mg/kg)	7610
Al (mg/kg)	43000
Fe (mg/kg)	30500
Mn (mg/kg)	114

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



PSD gamma model

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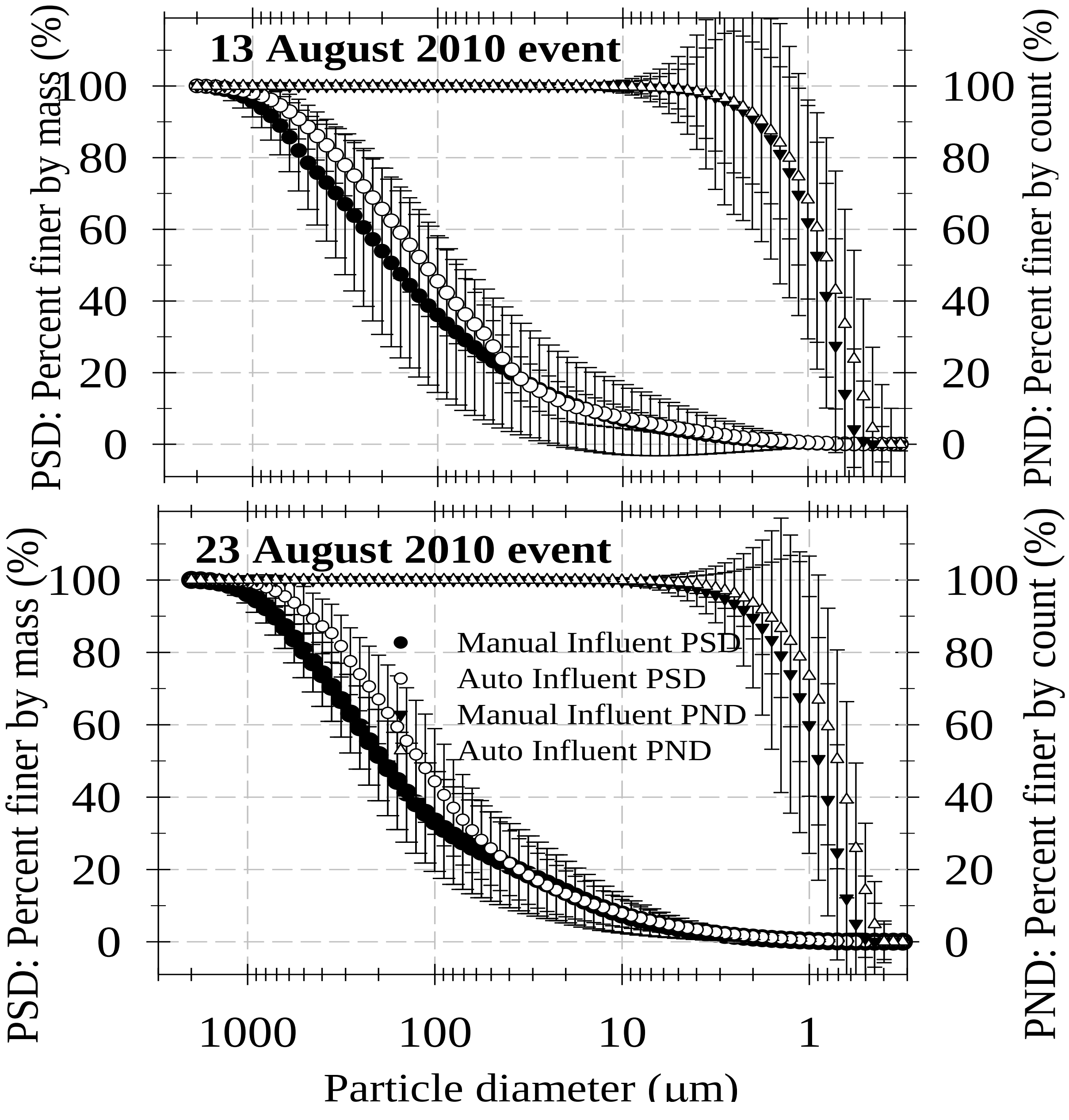
PSD and PND – Tests for Significant Difference



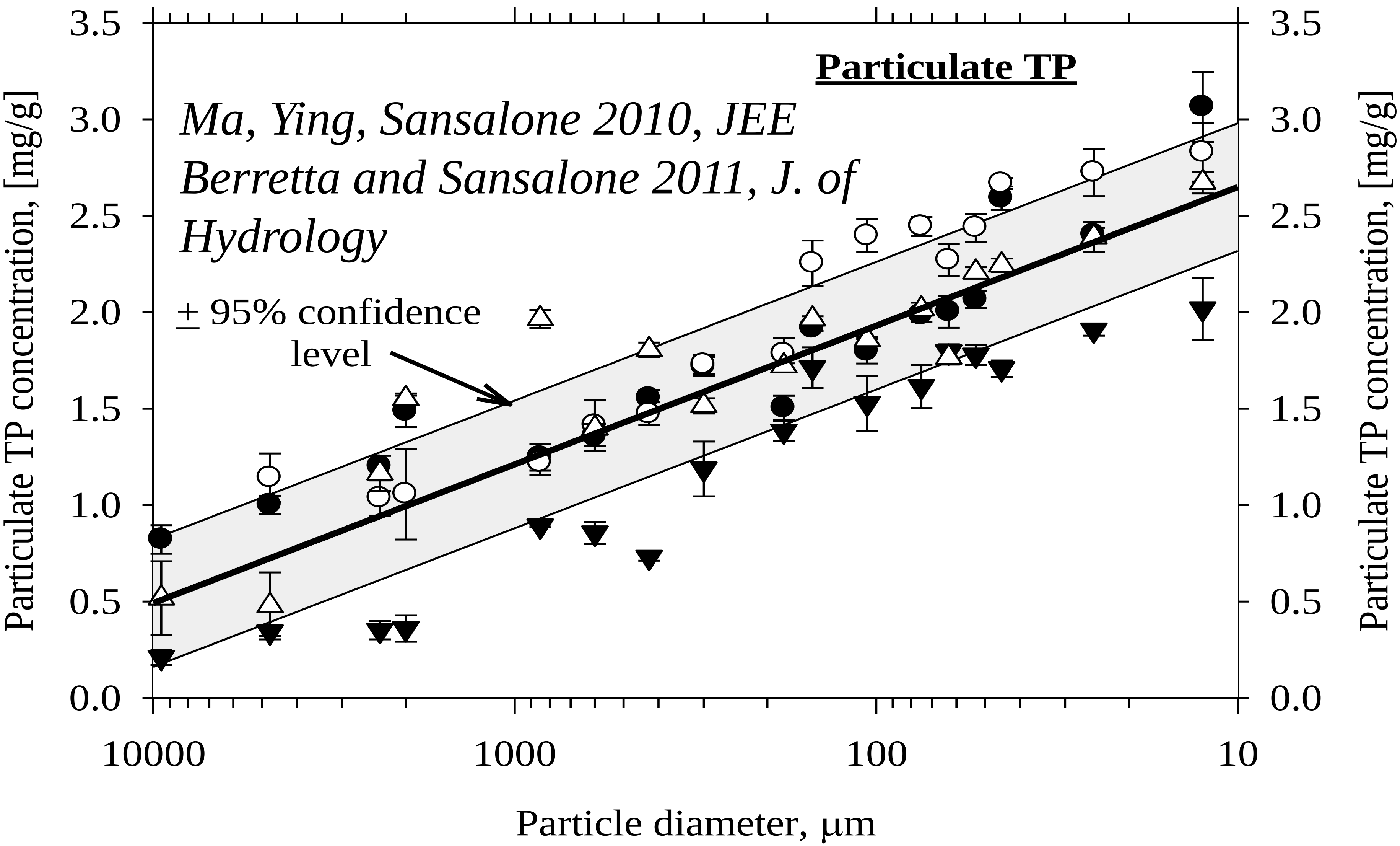
Kruskal-Wallis H Test* :

$$H_{calc} = \frac{12}{s(s+1)} \sum \frac{r_i^2}{s_i} - 3(s+1)$$

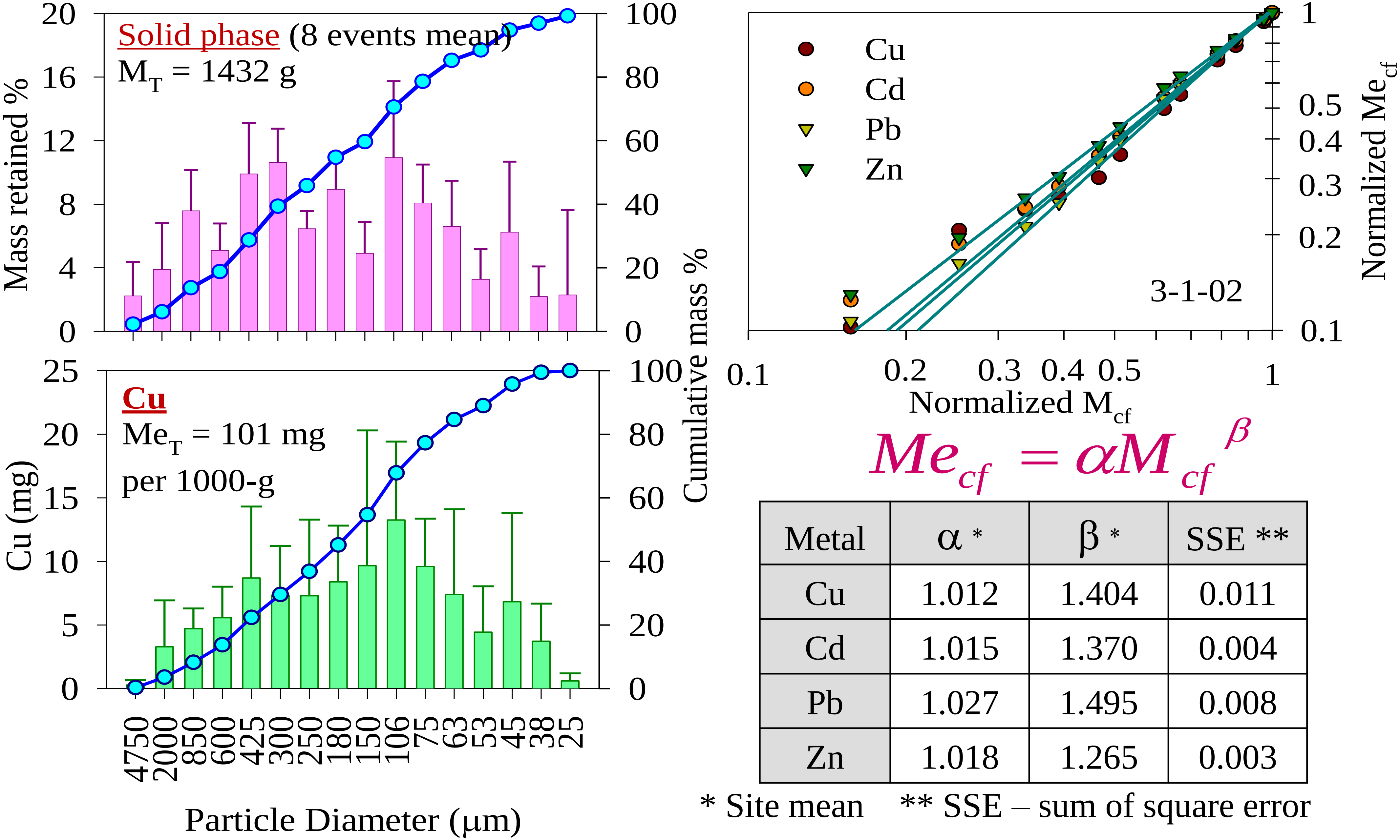
Conclusions		
PSD Inf	< 159µm ≥ 159µm	No difference Difference
PSD Eff	All sizes	No difference
PND Inf	All sizes	No difference
PND Eff	All sizes	No difference

*Nonparametric test

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



Treatment evaluations and constitutive relationships

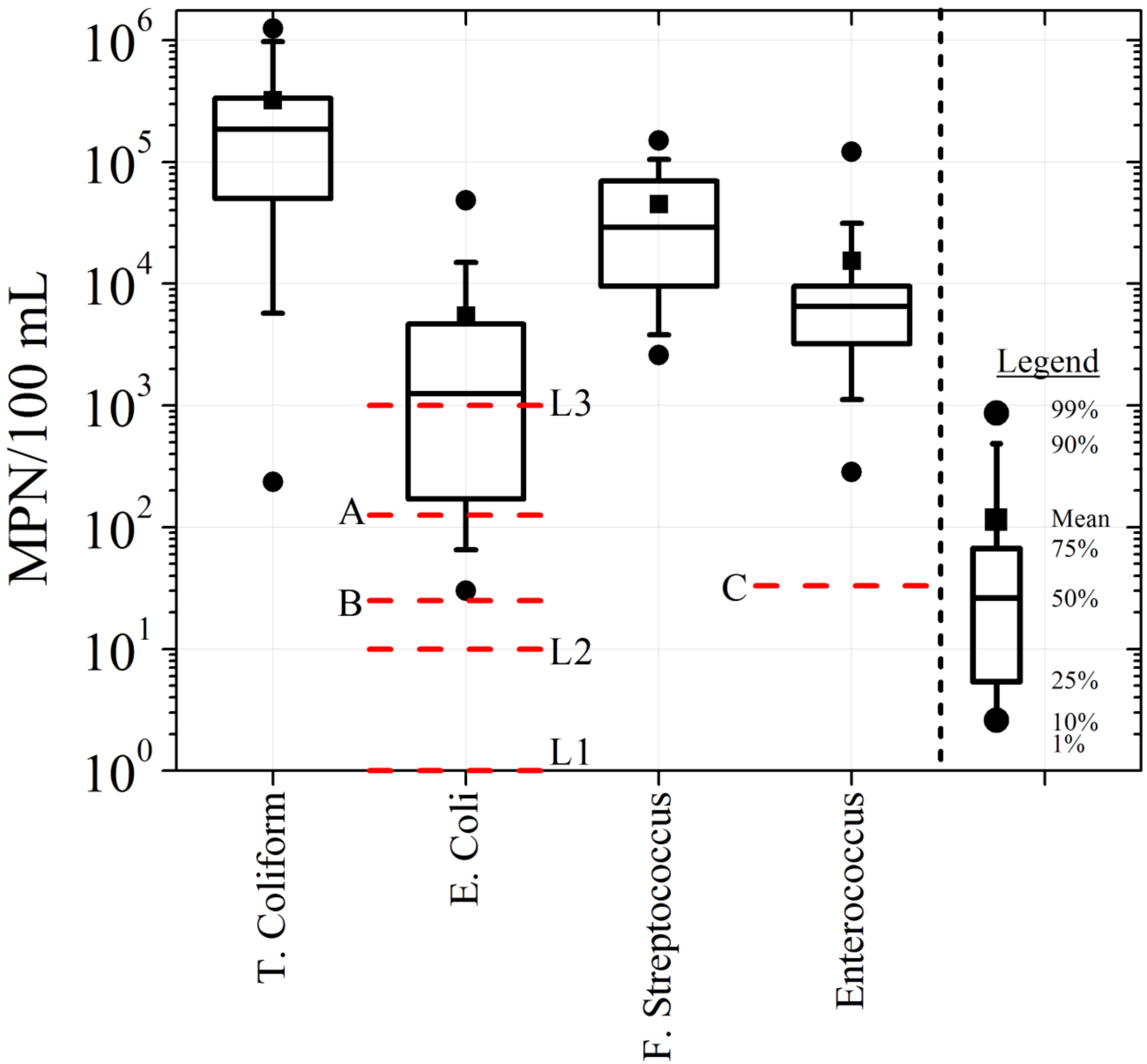


$$Me_{cf} = \alpha M_{cf}^{\ \beta}$$

Metal	α *	β *	SSE **
Cu	1.012	1.404	0.011
Cd	1.015	1.370	0.004
Pb	1.027	1.495	0.008
Zn	1.018	1.265	0.003

* Site mean ** SSE – sum of square error

Event-based (n = 25) MPN data for Gainesville, FL

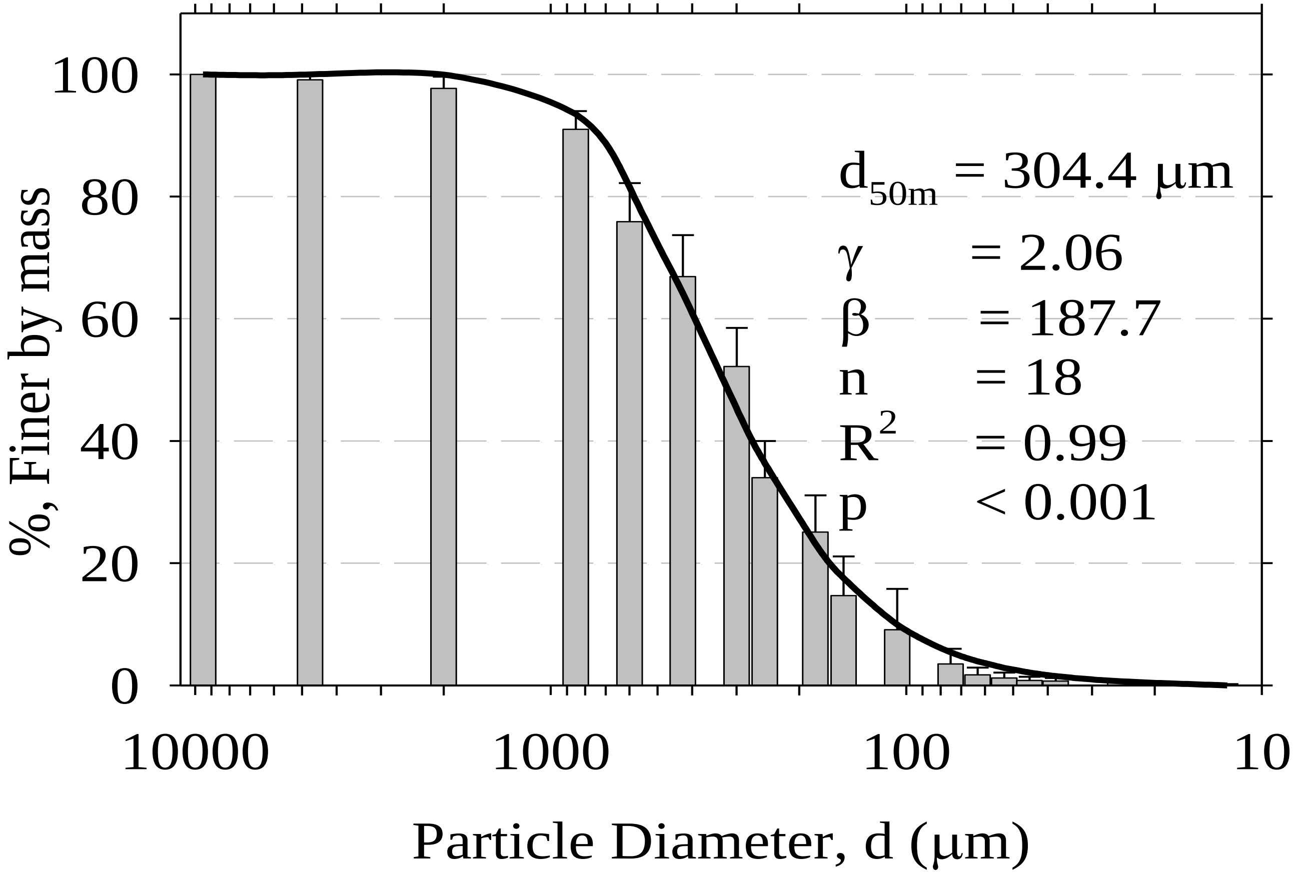


- A: USEPA freshwater recreational use (E. Coli)
- B: Florida unrestricted urban reuse water (F.S.)
- C: USEPA Saltwater recreational use (Enterococcus)
- L1: Australian urban reuse non-potable residential
- L2: Australian urban reuse un-restricted access
- L3: Australian urban reuse restricted access

NNC: Myths and Measurement Foundation

1. Myths or urban legends regarding ("first-flush" transport, TSS, automated sampling, sample holding time, distribution of nutrients or metals on PM …) have been introduced.
2. These myths are illustrated utilizing measurements that recognizes the inherent complexity when hydrologic and physical-chemical phenomena are coupled at an urban interface.
3. Knowledge/measurements of partitioning, speciation, PSDs, and distribution of nutrients as inputs for nutrient control are far more robust and economical than current "BMP" approaches.
4. Sustainability of urban water and nutrient/PM control requires hydrologic restoration, engineering controls, modeling tools and quantitative maintenance (if we do this NNC is just a footnote)

PSD for urban PM



Gamma distribution function

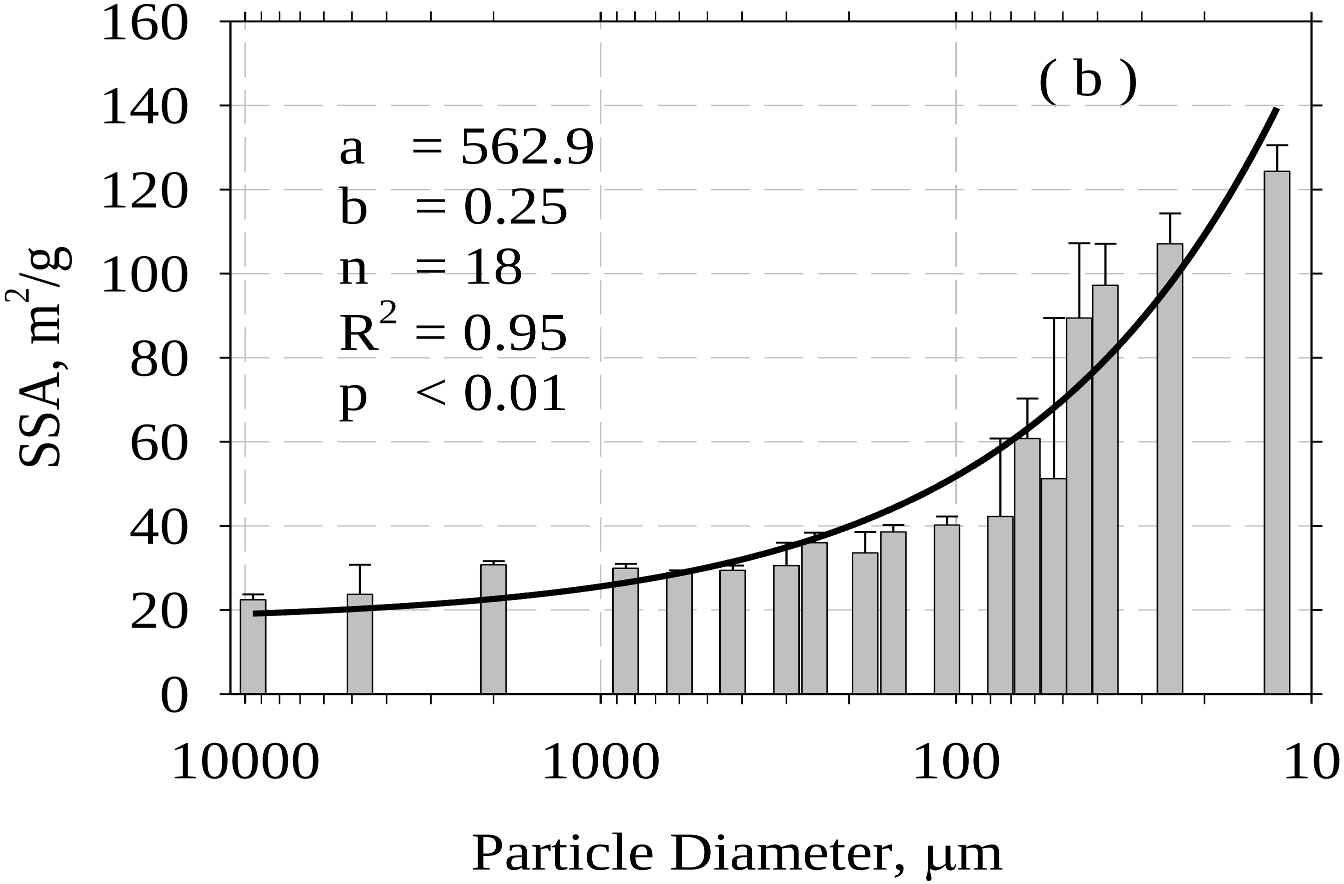
$$f(d) = \frac{(d/\beta)^{\gamma - 1} e^{(-d/\beta)}}{\beta \cdot \Gamma(\gamma)}$$

$$f(d) = \frac{(d/188)^{1.1} e^{(-d/188)}}{188 \cdot \Gamma(2.1)}$$

$$F(d) = \Gamma_d(\gamma)/\Gamma(\gamma)$$

$$F(d) = \Gamma_d(2.1)/\Gamma(2.1)$$

Specific surface area (SSA)



<u>Exponential growth function</u>

$$SSA = SSA_0 + a \cdot b^d$$

$$SSA = 25 + 563 \cdot (0.25^d)$$