Part II: Rainfall-Runoff Load Management through Structural Practices and Models

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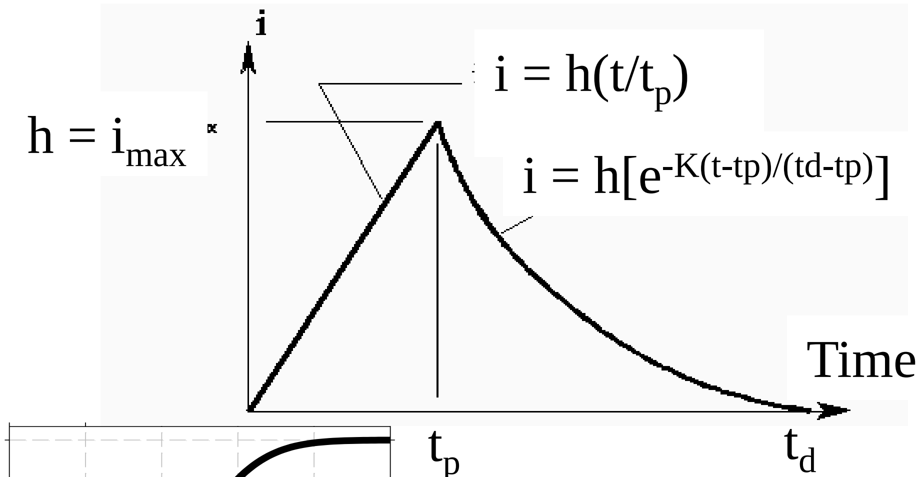
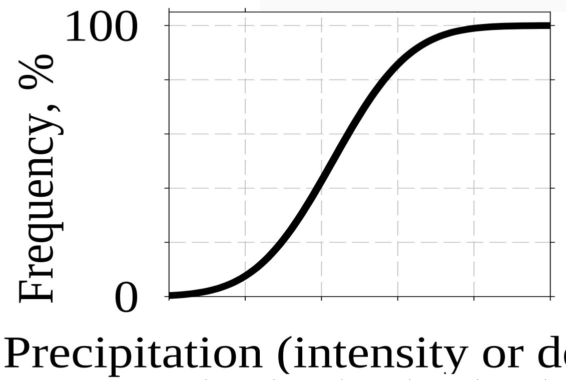
Rainfall-Runoff Modeling Options

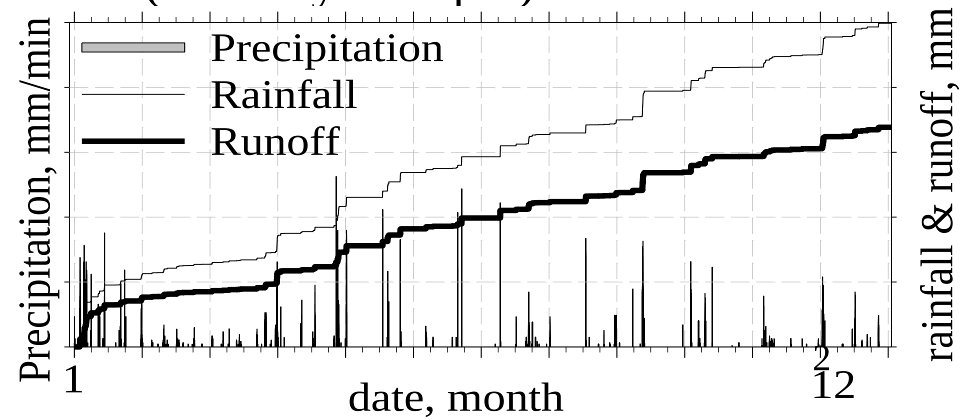
- **Single design event**
  - Store runoff for entire event,
  - Release in 24 hours
- **Frequency method**
  - Develop cumulative density function of precipitation based on analysis of multiple years of precipitation data

  (Beretta and Sansalone 2011)
- **Continuous simulation**
  - Simulate runoff hydrology/chemistry/load using continuous rainfall time series data

  (*Kuang, Ying and Sansalone 2011, J. of Hydrology*)





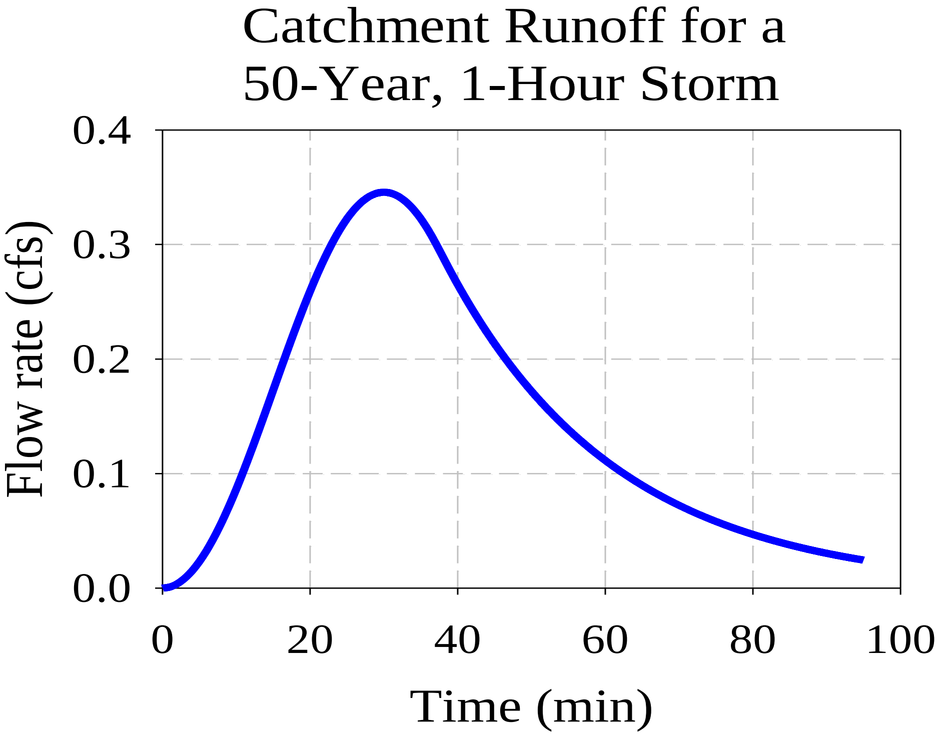


Functions for Event-Based Design Hydrograph

Small watershed step function (*Teng and Sansalone 2004, JEE*):

$0 \le t \le 1.25\, t_p \qquad Q = \frac{Q_p}{2}\left[1 - \cos\left(\frac{\pi \cdot t}{t_p}\right)\right]$

$t > 1.25\, t_p \qquad Q = 4.34 Q_p e^{\frac{-1.3 \cdot t}{t_p}}$

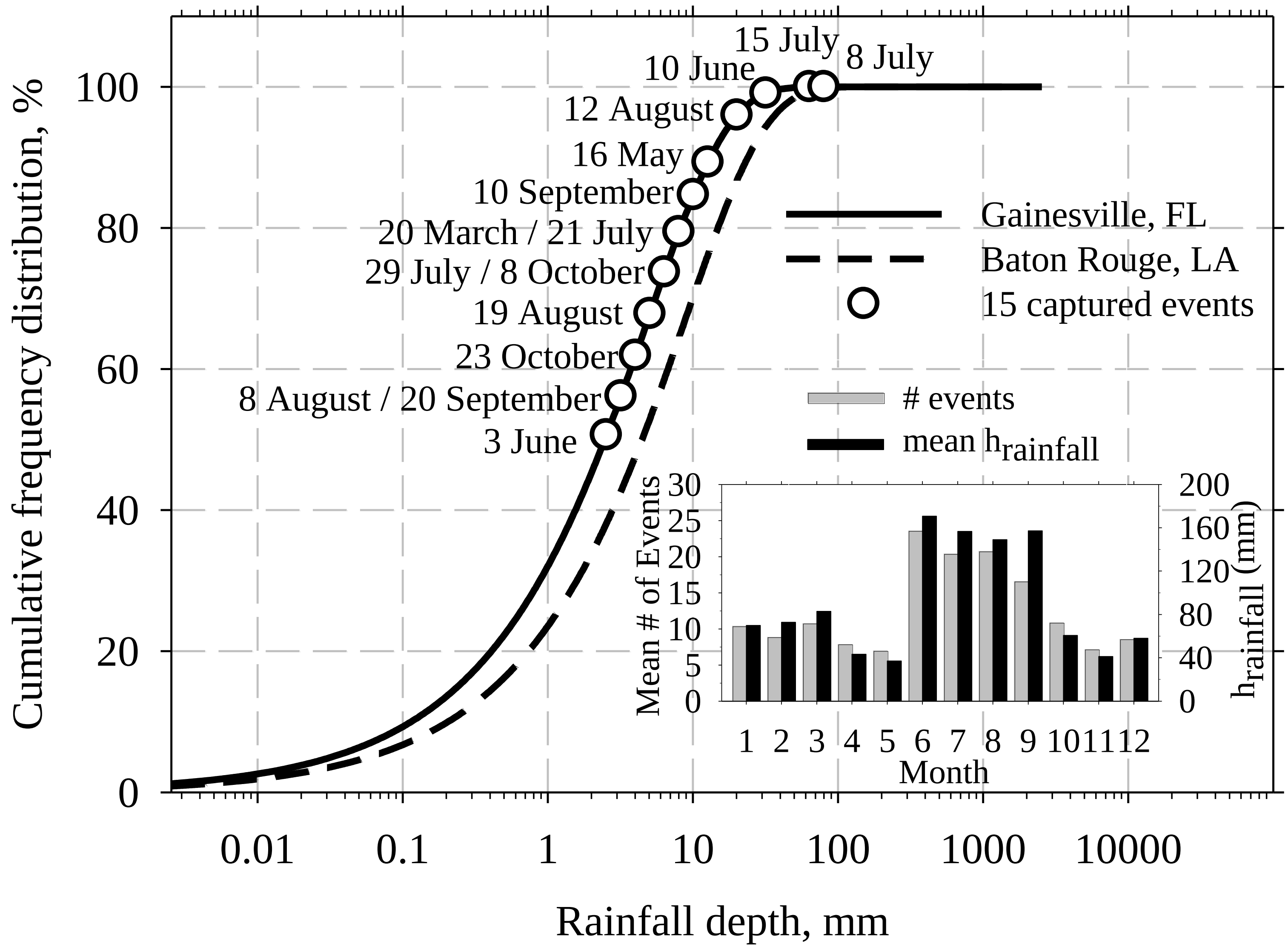


Time to peak based on median from past storm events:

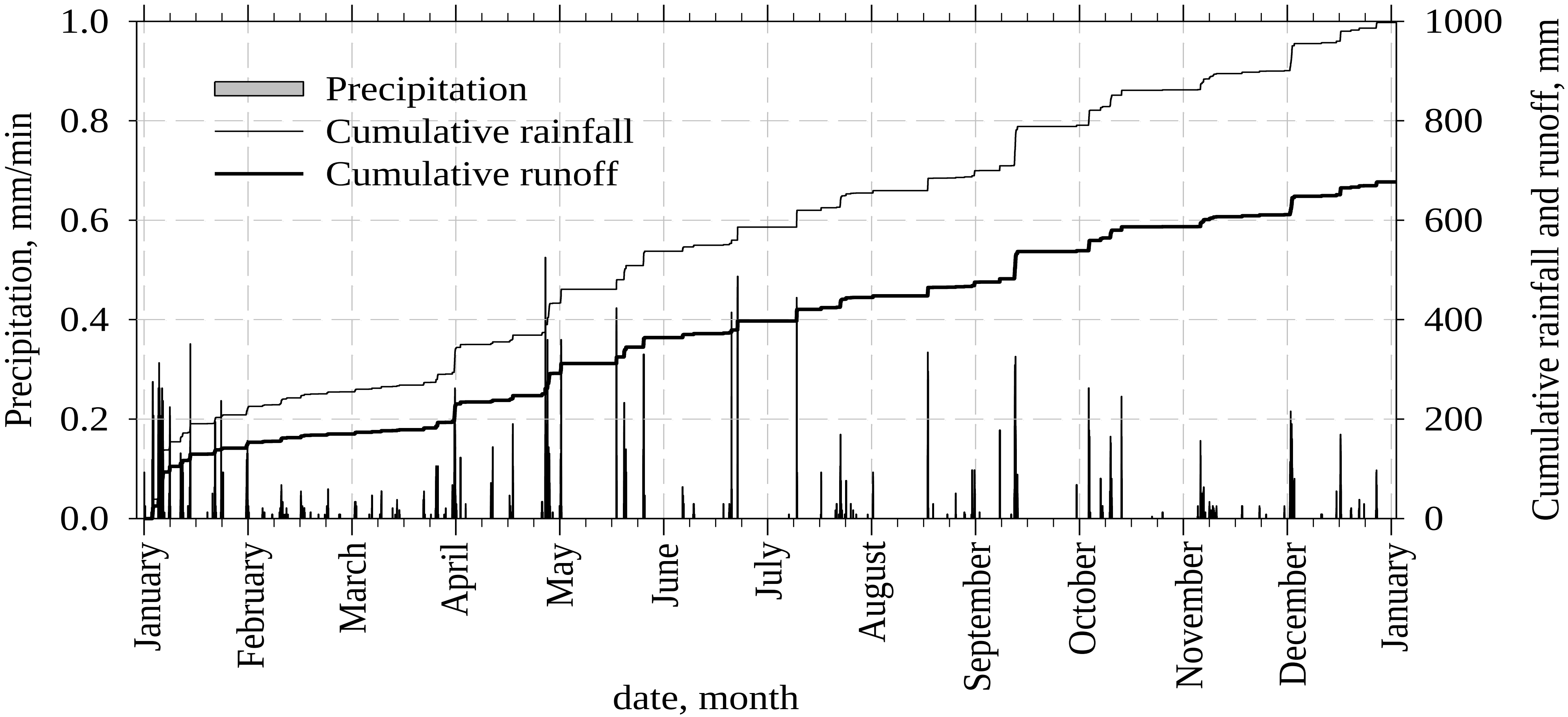
$t_p = 30$ min

Subsequent catchment hydrographs lagged by time of concentration

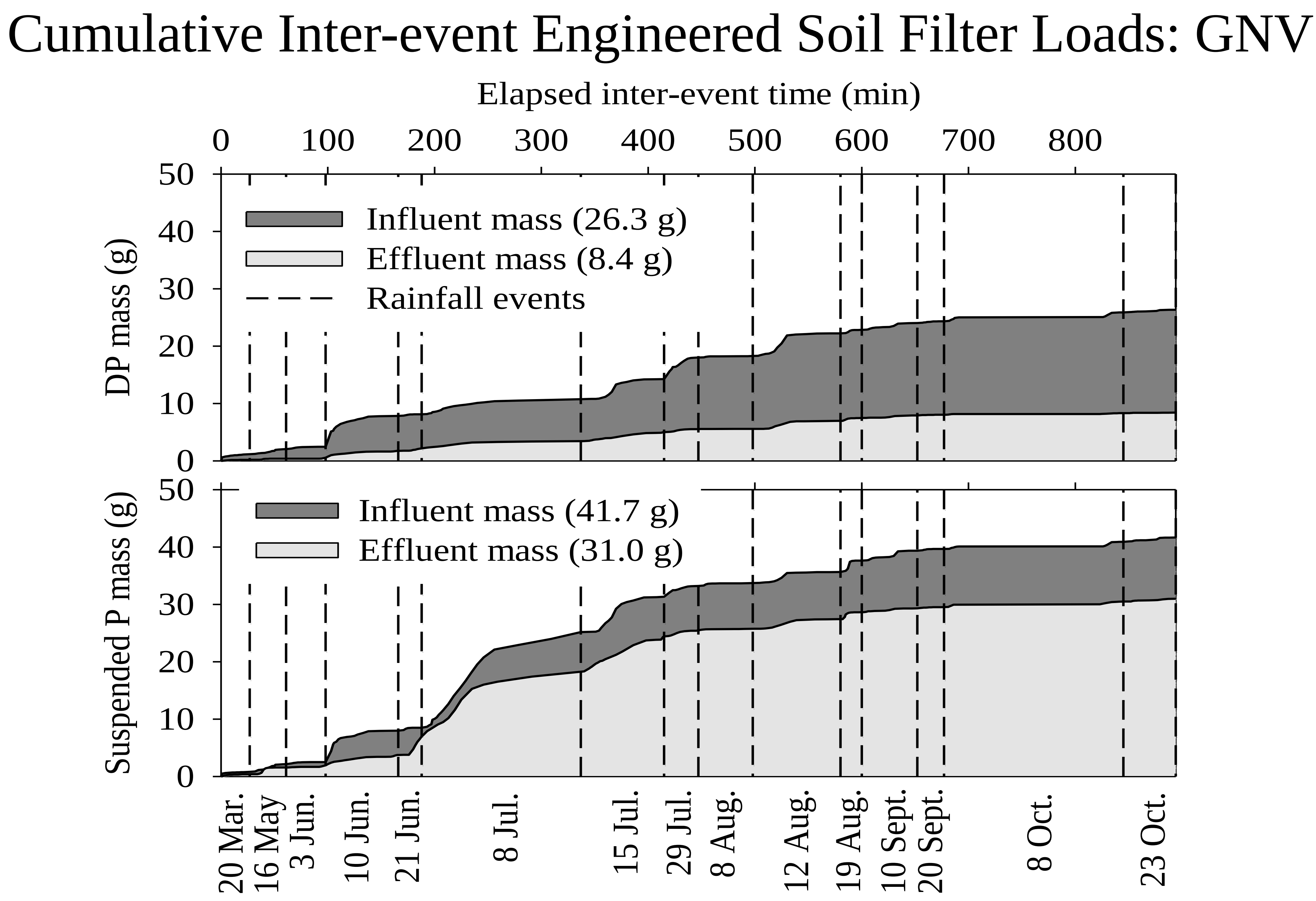
Rainfall Depth Frequency Distributions



Annual depth of precipitation and runoff by validated SWMM simulation of I-75 watershed for 2005



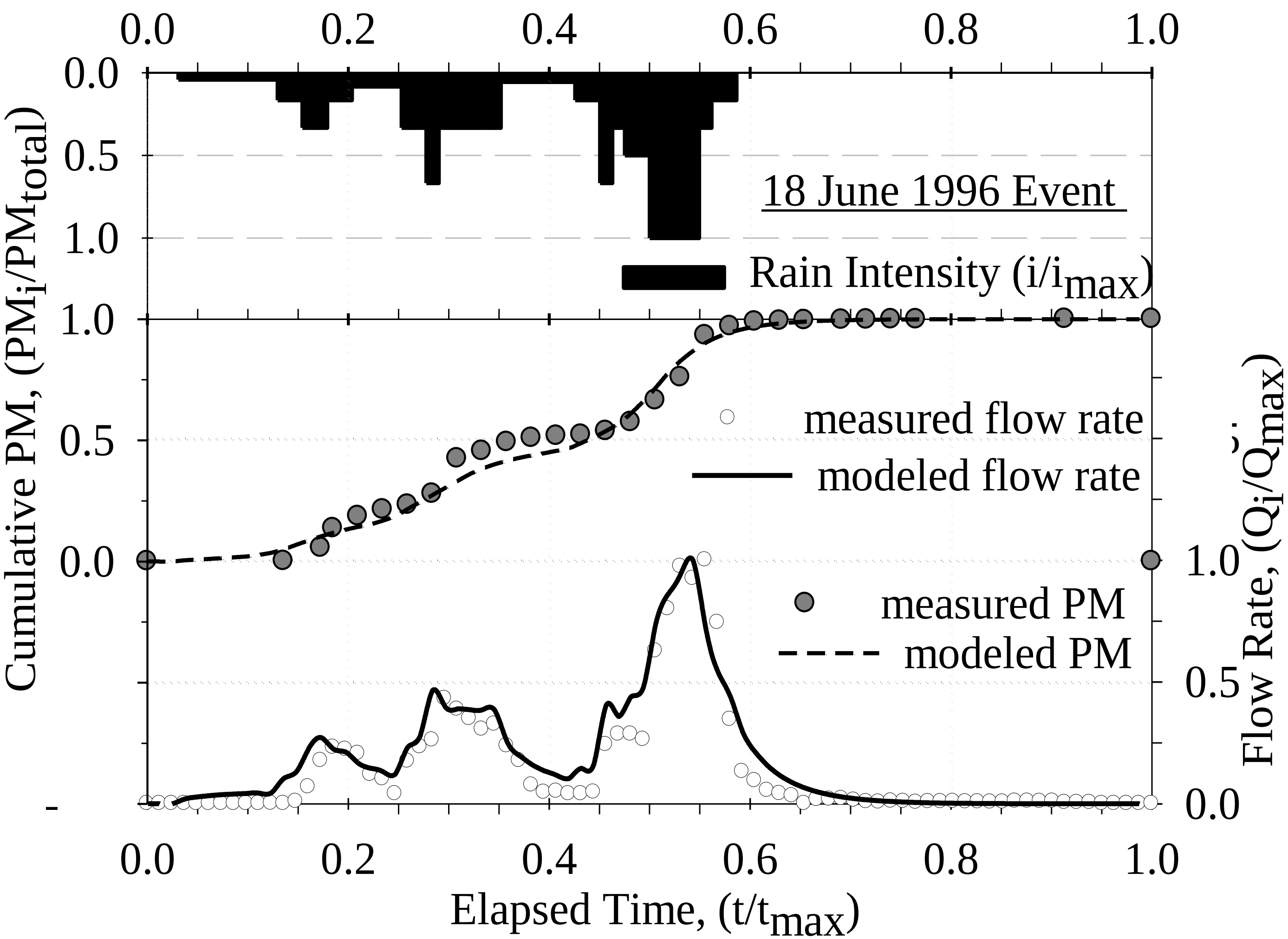
- Annual precipitation : 1004 mm ; Total annual runoff : 694 mm



Cumulative Inter-event Engineered Soil Filter Loads: GNV
Elapsed inter-event time (min)
0
100
200
300
400
500
600
700
800
DP mass (g)
Influent mass (26.3 g)
Effluent mass (8.4 g)
Rainfall events
Suspended P mass (g)
Influent mass (41.7 g)
Effluent mass (31.0 g)
0
10
20
30
40
50
20 Mar.
16 May
3 Jun.
10 Jun.
21 Jun.
8 Jul.
15 Jul.
29 Jul.
8 Aug.
12 Aug.
19 Aug.
10 Sept.
20 Sept.
8 Oct.
23 Oct.

Modeling catchment & unit processes as building blocks

(i.e.: Unit hydrograph, pollutograph for hydrologic functional units, HFU)



<u>Site, Event Parameters:</u>

- Paved, 2% slope
- Traffic loadings
- Q_p = 244 L/min.
- $t_{max.}$ = 68 min.
- V = 2794 L
- PM = .258 kg

<u>Calibrated Site IUH:</u>

- k = 4.02, n = 0.66

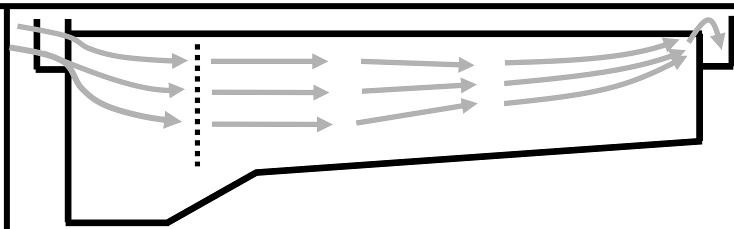
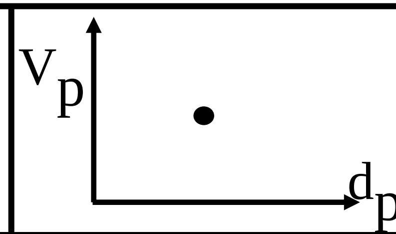
<u>Calibrated Site IUP</u> (PM)

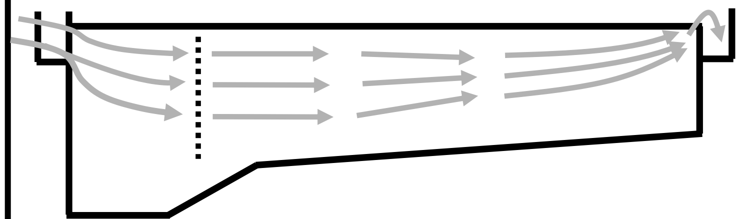
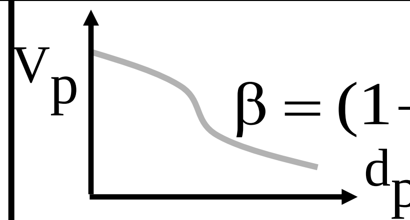
- B = 0.29 min^{-1}
- (NS) R^2 = 0.93

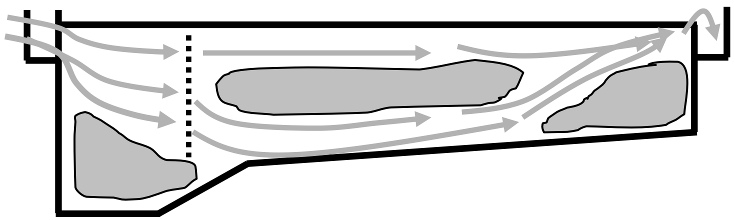
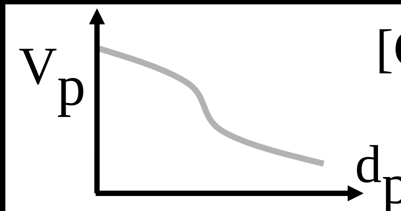
What loading information is required to quantify unit operation ("BMP") behavior and mis-behavior?

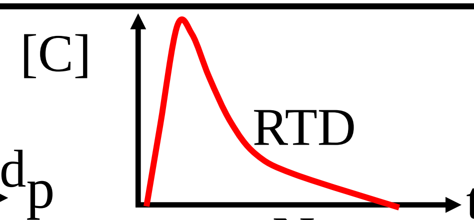
- Knowledge of phase relationships in urban hydrologic and phase separation phenomena
  - *Continuous fluid (aqueous) phase*
  - *Discrete PM phase (PSD, PND, specific gravity, charge properties)*
  - *Gas phase depending on processes such as denitrification or flotation.*
- For treatment and re-suspension the nominal focus is "treating" (separating) the discrete solid (particulate matter) phase (DPM) and the continuous aqueous phase (hydrodynamics)
- The gaseous phase interactions are clearly very important in phase treatment and re-suspension

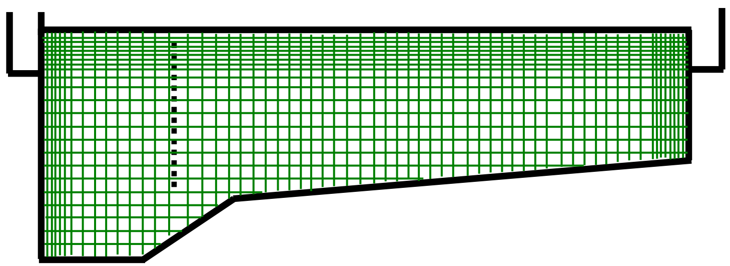
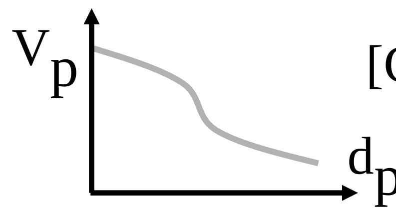
Models for Treatment: Settling (Dominant Mechanism)

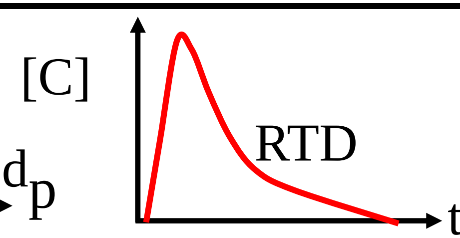
<table>
<tr>
<td>Ideal Overflow Model w/o PSD
- *most common*</td>
<td></td>
<td>

$$V_c = \frac{Q_e}{A_s}$$</td>
</tr>
<tr>
<td>Ideal Overflow Model w/ PSD
- *rare* (<u>Case II</u>)</td>
<td></td>
<td>

$$\beta = (1 - X_c) + \int_0^{X_c} \frac{V_p}{V_c}\, dx$$</td>
</tr>
<tr>
<td>Non-Ideal Semi-Empirical Models w/ PSD
- *infrequent in USA, common in Europe*</td>
<td>
$$N = \frac{t_{50}}{t_{50} - t_p}$$</td>
<td>

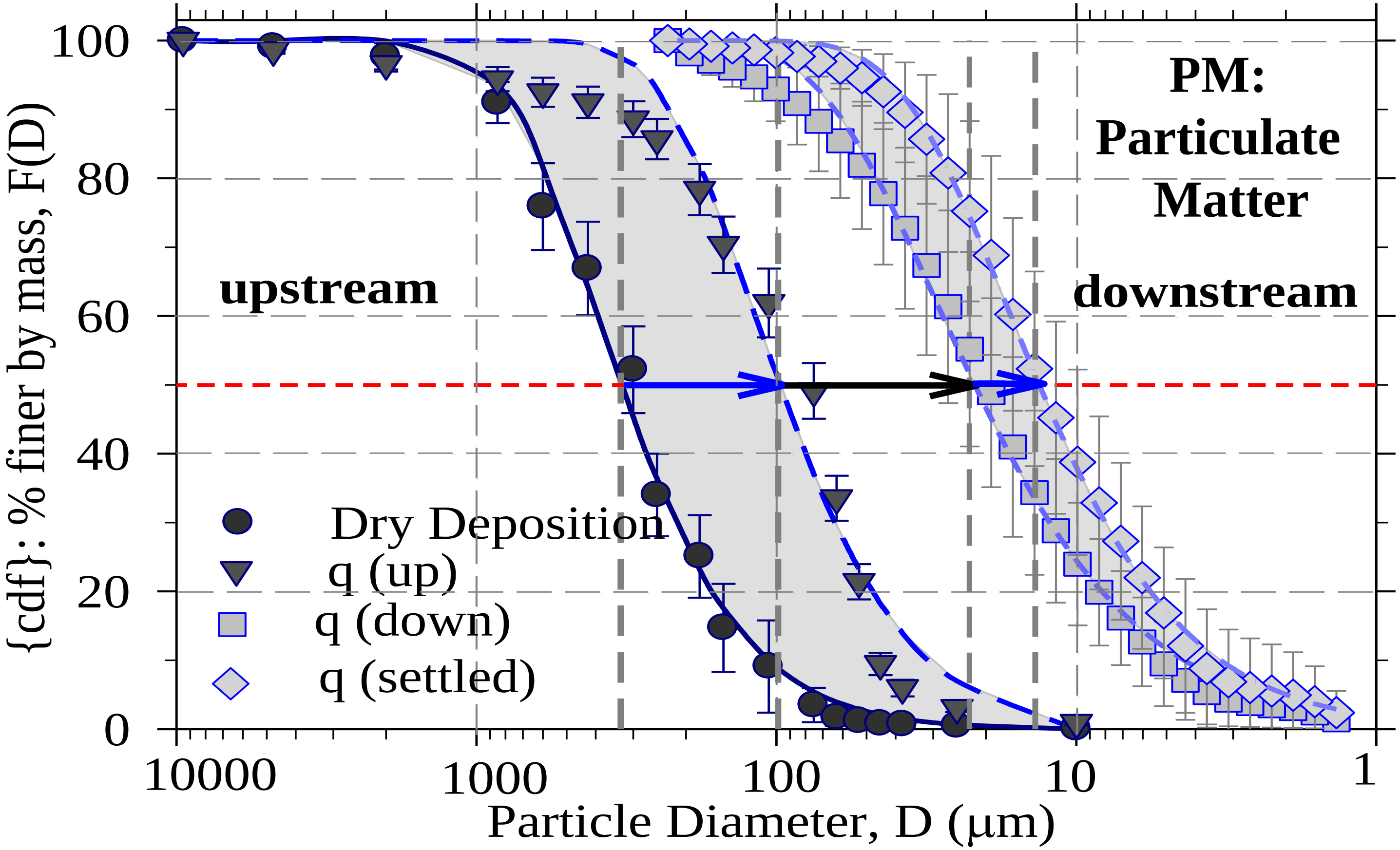


$$\beta = 1 - \left[1 + \frac{V_p A}{NQ}\right]^{-N}$$</td>
</tr>
<tr>
<td>Multi-Phase CFD Models
- *state of the art, rarely applied in practice*
(<u>Case IV</u>)</td>
<td></td>
<td>



$$\beta = \int_{CV} (Q, \rho, \Gamma, \varphi)\, dx\, dy\, dz\, dt$$</td>
</tr>
</table>

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



PSD gamma model

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

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

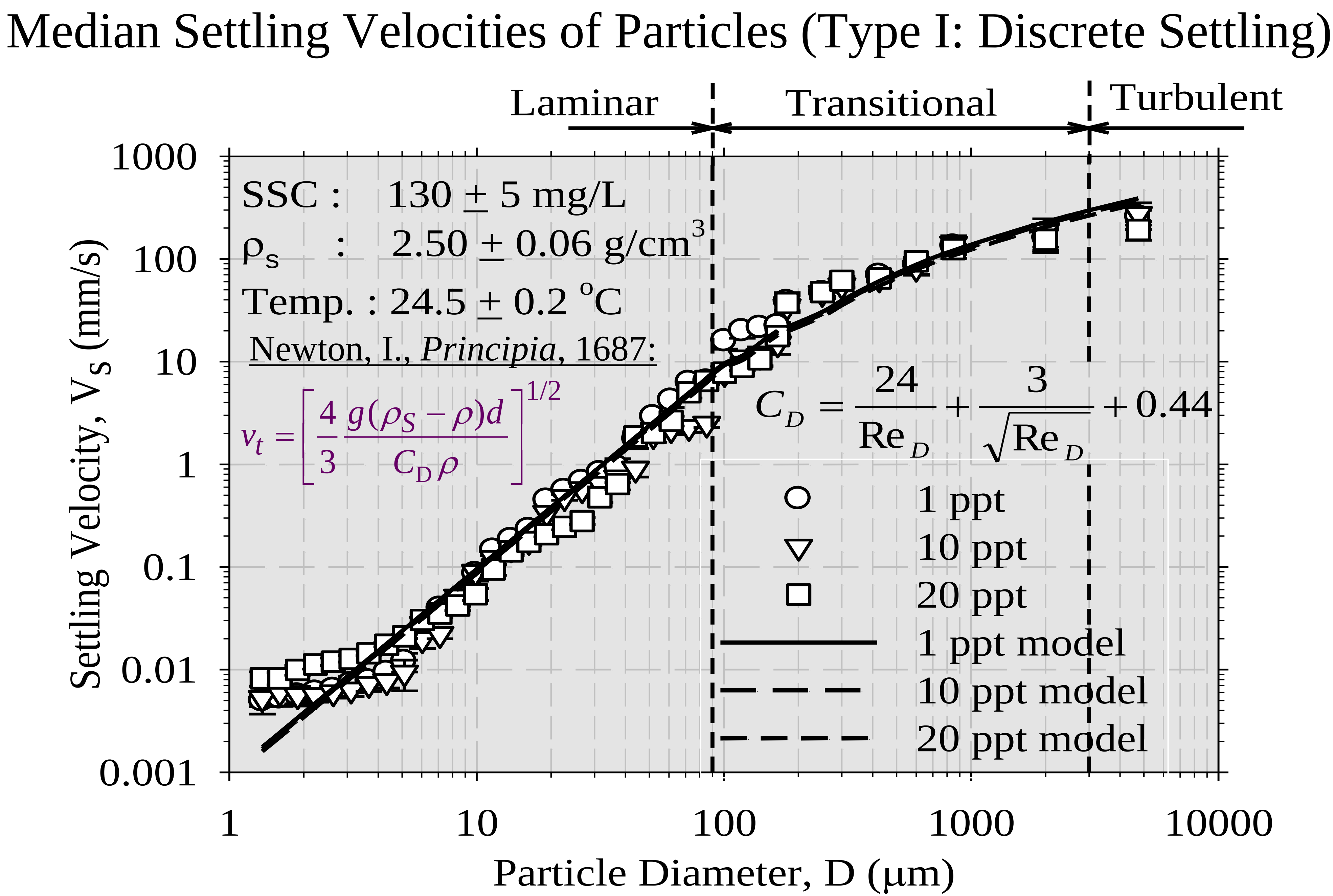
$$\Gamma(\gamma) = \int_0^\infty x^{\gamma-1} e^{(-x)} dx$$

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

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)

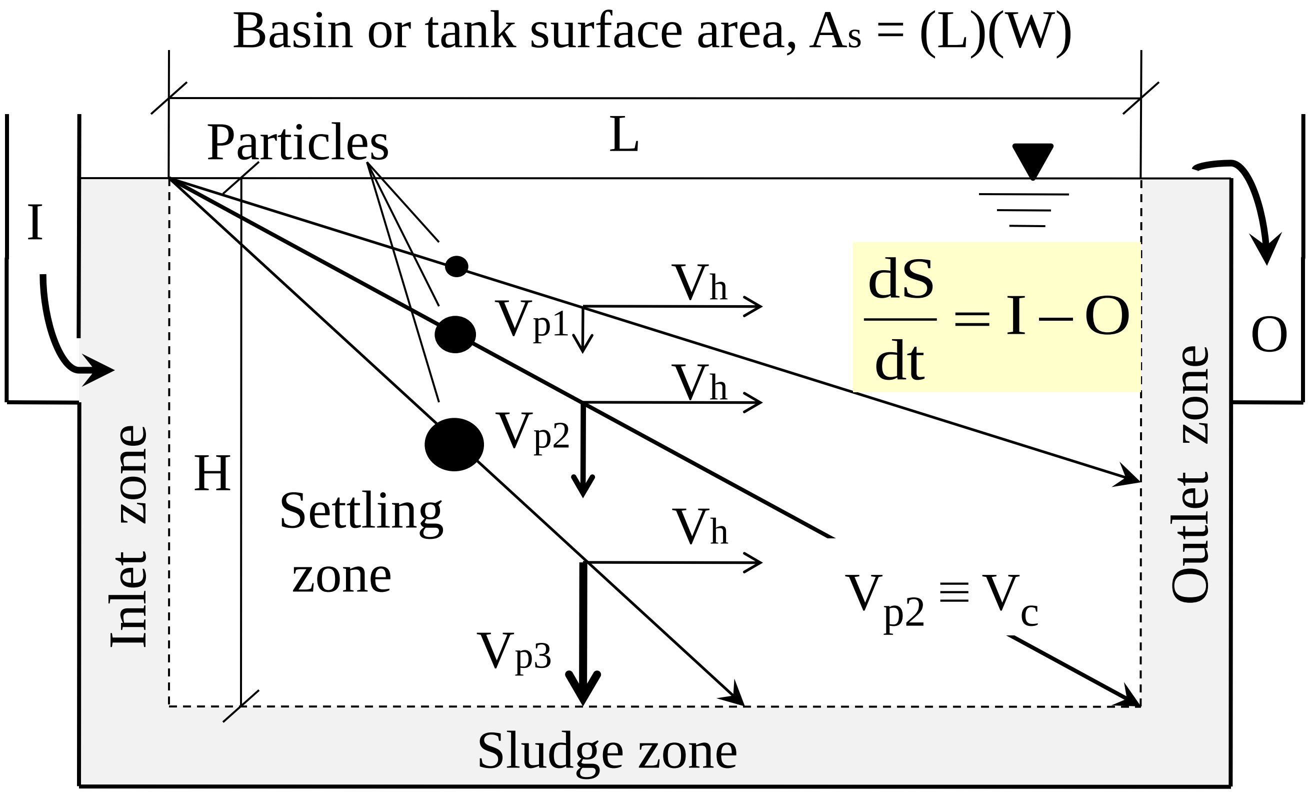
PSD of PM	DD Pavement ***Deposition***	q (up) CB or inlet ***Runoff***	q (down) BMP influent ***Runoff***	q (settled) BMP effluent ***Runoff***
D_{50m}	331 μm	99 μm	23 μm	14 μm



Median Settling Velocities of Particles (Type I: Discrete Settling)
Laminar
Transitional
Turbulent
SSC : 130 ± 5 mg/L
ρ_s : 2.50 ± 0.06 g/cm^3
Temp. : 24.5 ± 0.2 ^{o}C
Newton, I., *Principia*, 1687:
$v_t = \left[\frac{4}{3}\frac{g(\rho_S-\rho)d}{C_D\rho}\right]^{1/2}$
$C_D = \frac{24}{Re_D} + \frac{3}{\sqrt{Re_D}} + 0.44$
1 ppt
10 ppt
20 ppt
1 ppt model
10 ppt model
20 ppt model
Settling Velocity, V_S (mm/s)
Particle Diameter, D (μm)
1000
100
10
1
0.1
0.01
0.001
1
10
100
1000
10000

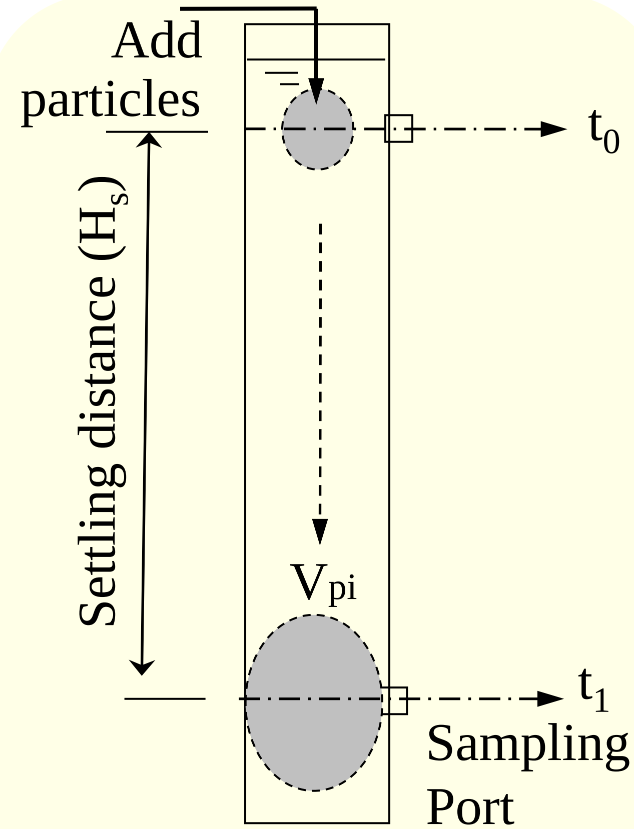
Coupling Surface Overflow Rate and Settling Velocity (V_{pi})

Simple idealized Properties of Urban System:



$$(PM)_i \text{ separated} = (1 - X_c) + \int_0^{X_c} \frac{V_{pi}}{V_c}\,dx \qquad V_c = \frac{Q}{A_s}$$

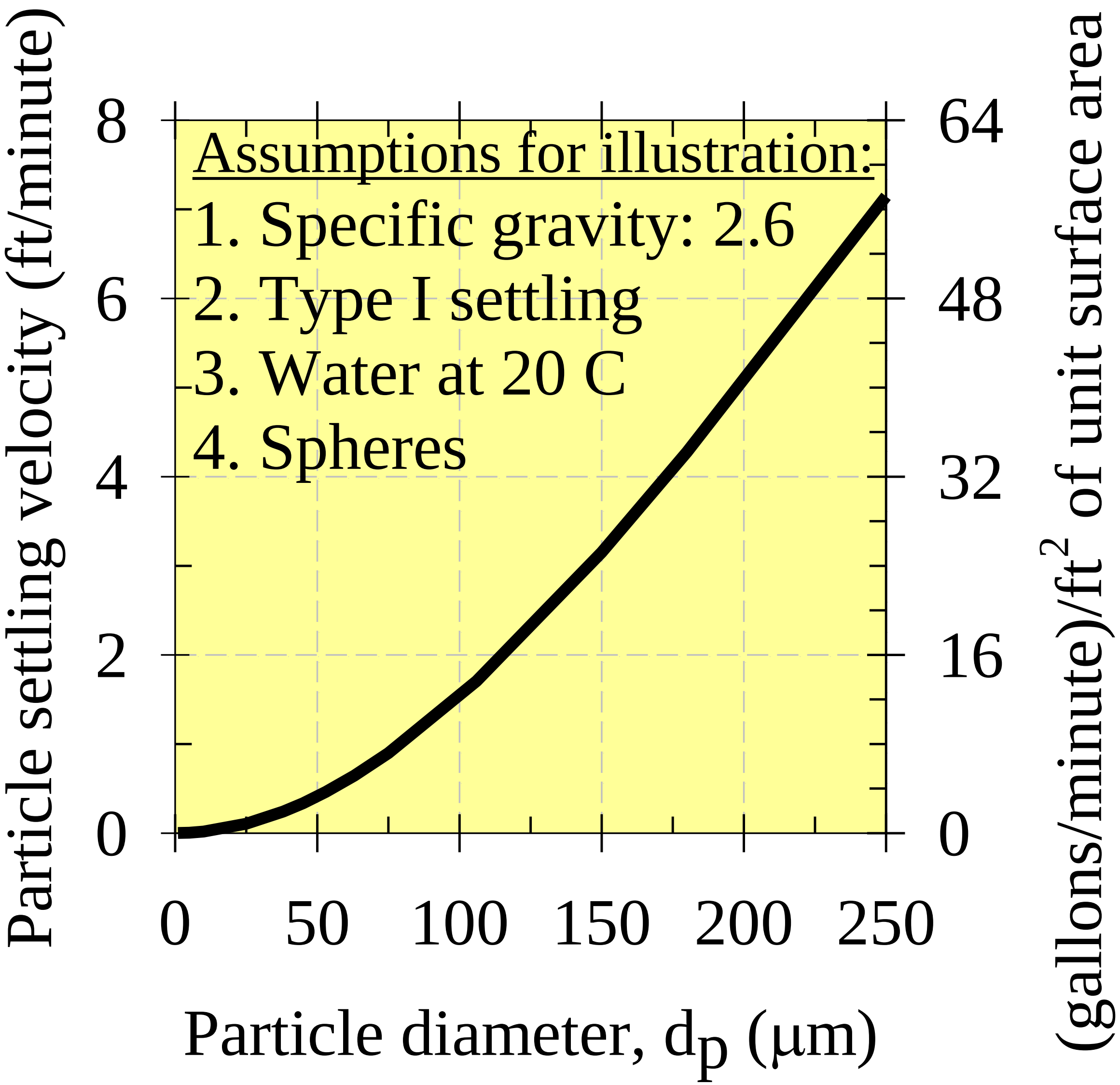
Properties of PM/fluid:



- Type I settling in this case
- Newton's Law or V_{pi} data

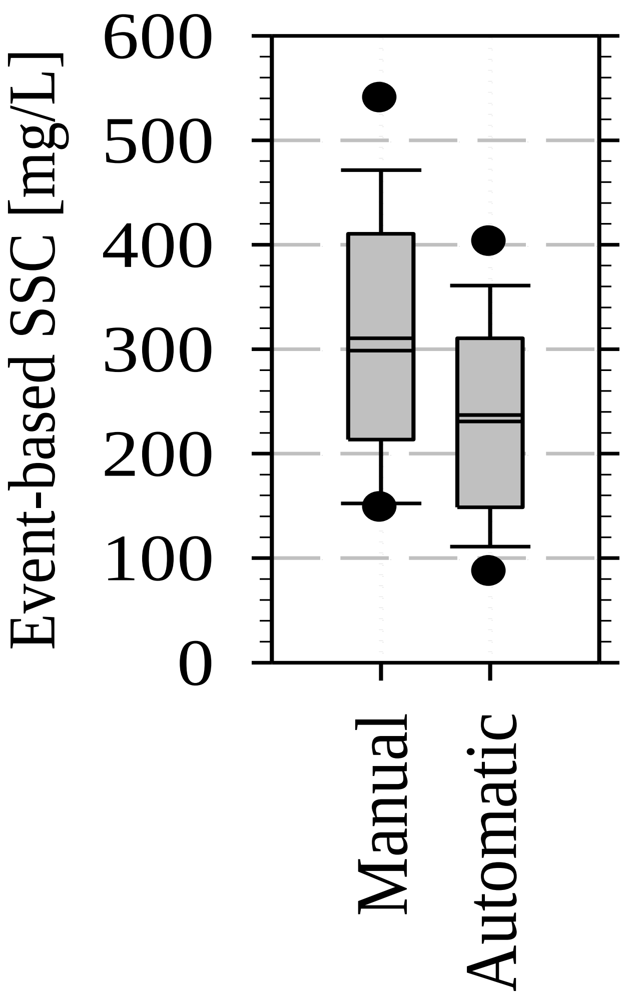
$(PM)_i$ separated = (PM_i fraction with $V_{pi} > V_c$) + (remaining PM_i with $V_{pi} < V_c$)

Is a design flow related to basin effluent particle size?



- YES, as a first order approximation. In reality it is the required effluent PSD that drives design hydraulics with respect to basin treatment capacity.
- Furthermore, basin size (SA, V) is not as important as how the basin volume is utilized. This is illustrated when comparing linear and "baffled" basin of same size for a 25 year design storm.

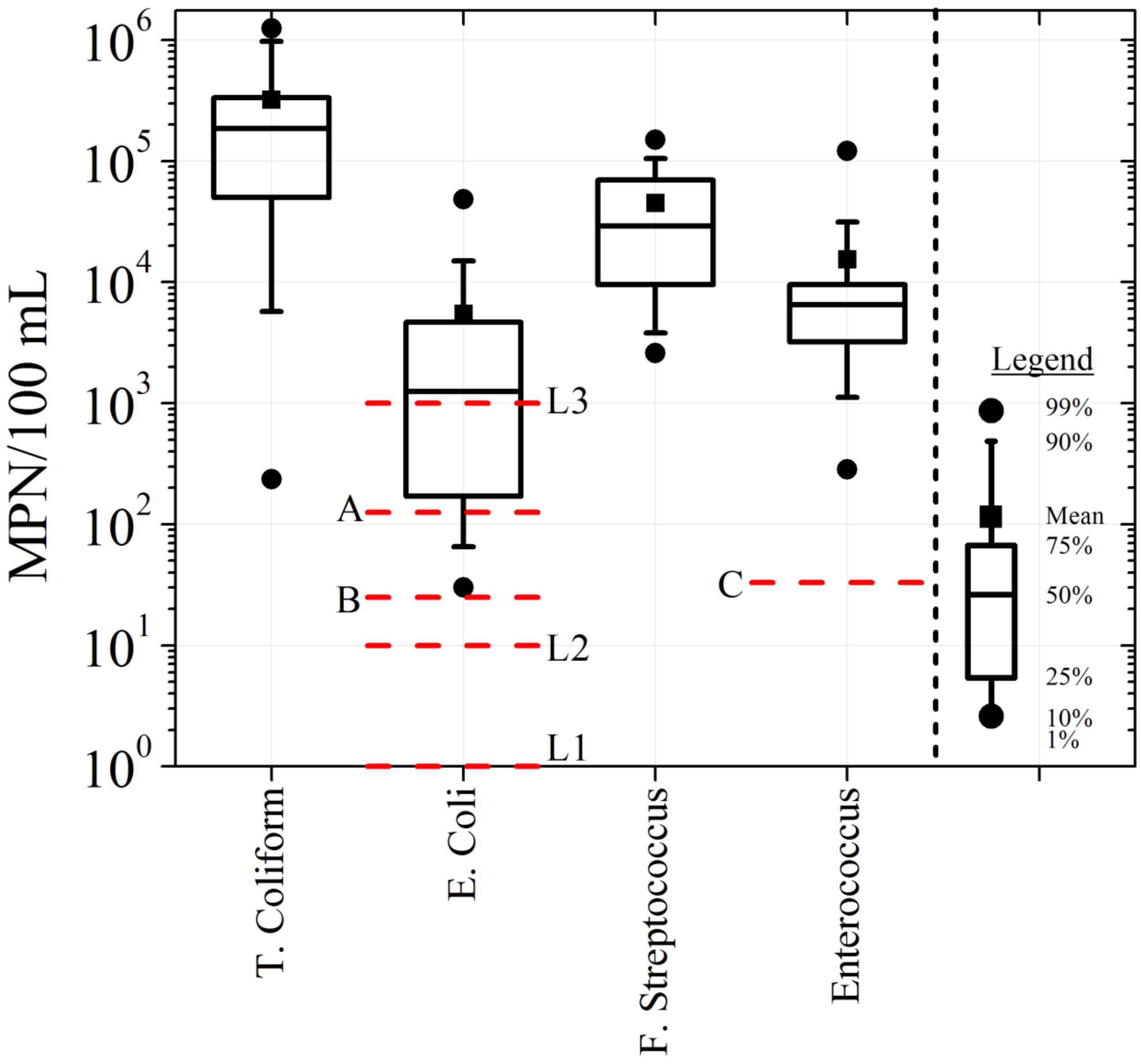
Sampling Representativeness of Total PM
(Index: Influent Suspended Sediment Concentration, SSC)



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

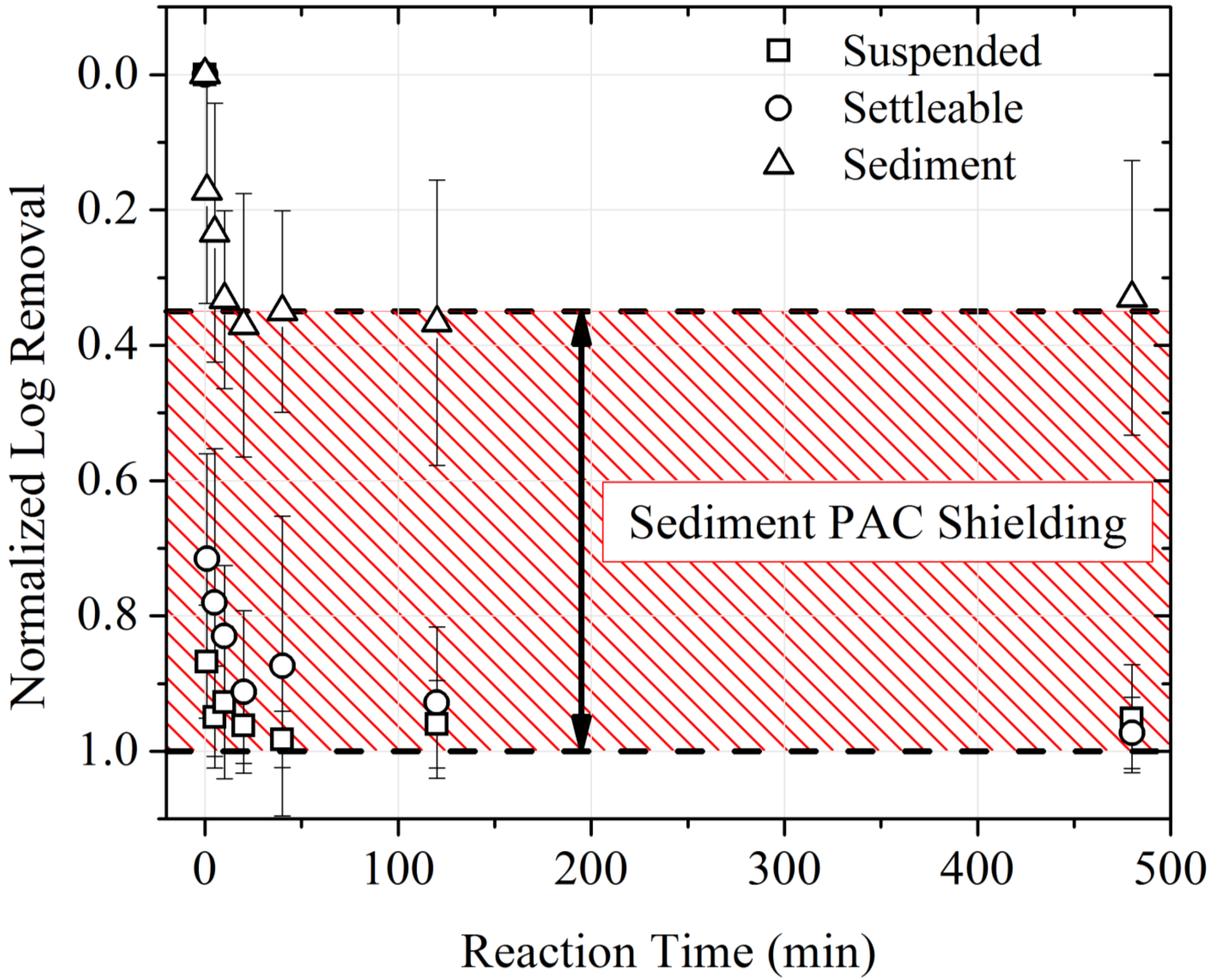
1. Non-parametric analysis based on 18 paired runoff events of **event-based composites**
2. SSC for ***manual*** sampling composites:
   - Median (50th %): 299 mg/L
   - Mean: 310 mg/L
   - (5% , 95%): (148 mg/L, 549 mg/L)
3. SSC for ***automatic*** sampling composites:
   - Median (50th %): 237 mg/L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

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

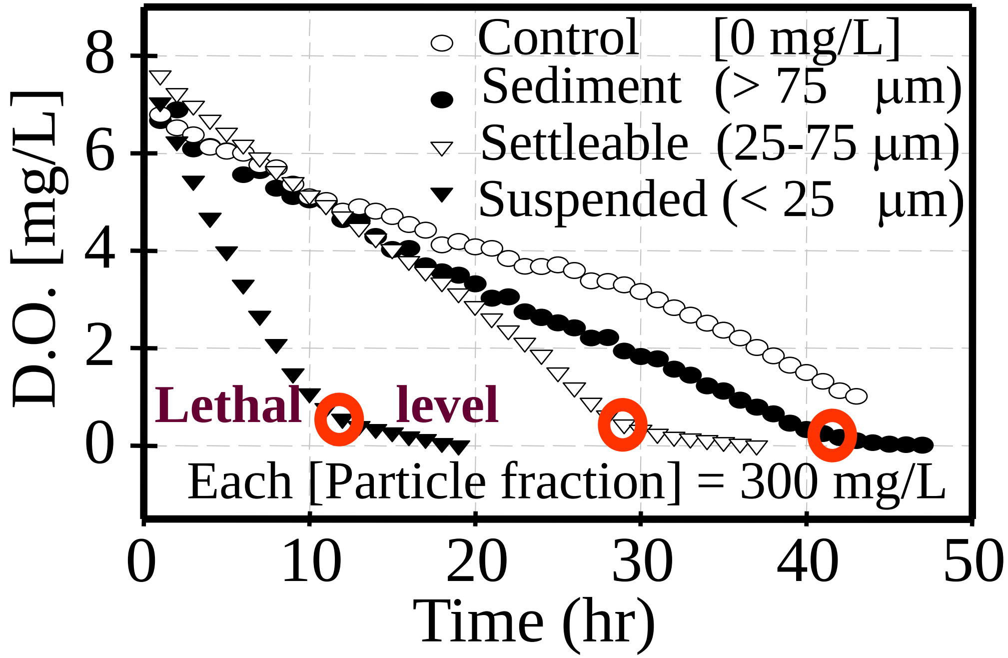


- A: USEPA freshwater recreational use (E. Coli)
- B: Florida unrestricted urban reuse water (F.S.)
- C: USEPA Saltwater recreational use (Enterococcus)
- L1: Australian urban reuse non-potable residential
- L2: Australian urban reuse un-restricted access
- L3: Australian urban reuse restricted access

PM Associated Coliform Shielding (HOCl = 45 mg/L)



Lethality Of Suspended PM that are Eluted from BMPs



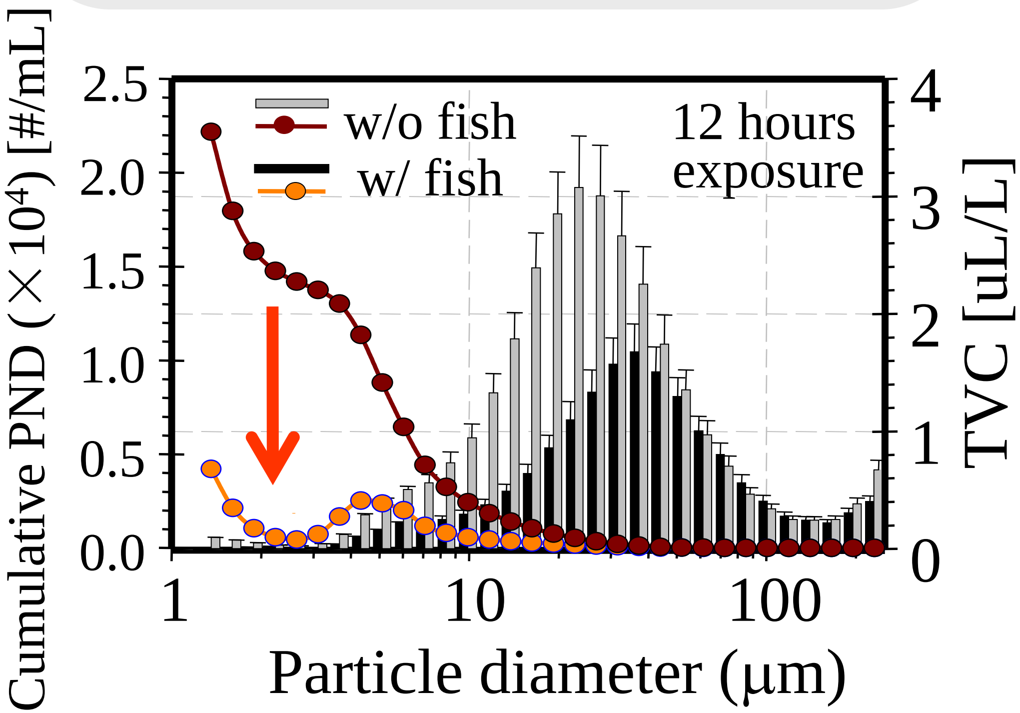
Oxygen consumption rate: mg/(g-hr)

- Amount of dissolved oxygen (D.O.) consumed in 1 hour based on the unit weight of the organism
- Sub-lethal test (gill function)

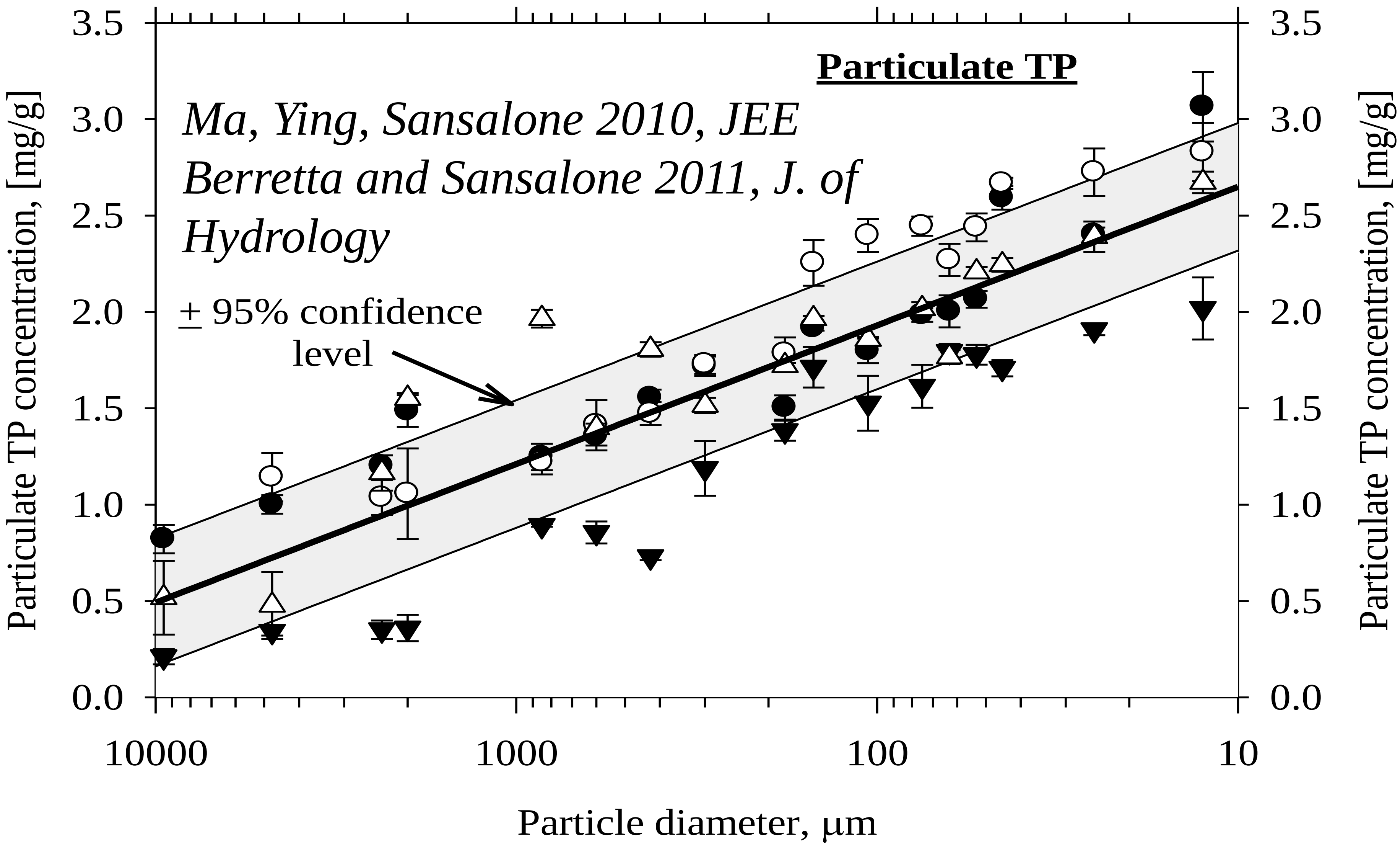
Lethal level:

- D.O. level at which gill pumping stops

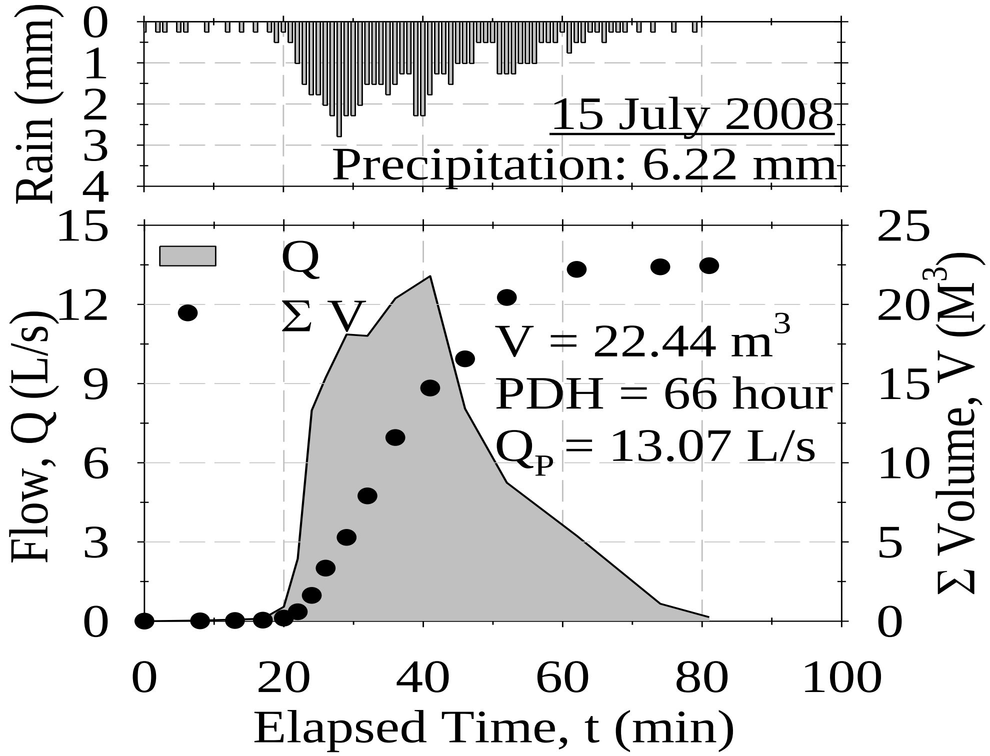
- Suspended particles trapped by gill tissue
- Settleable and sediment particles have a significantly lower effect on gill function
- Level of lethality indicated on time axis at the inflection point of each D.O.- time curve. The control generated no lethality.

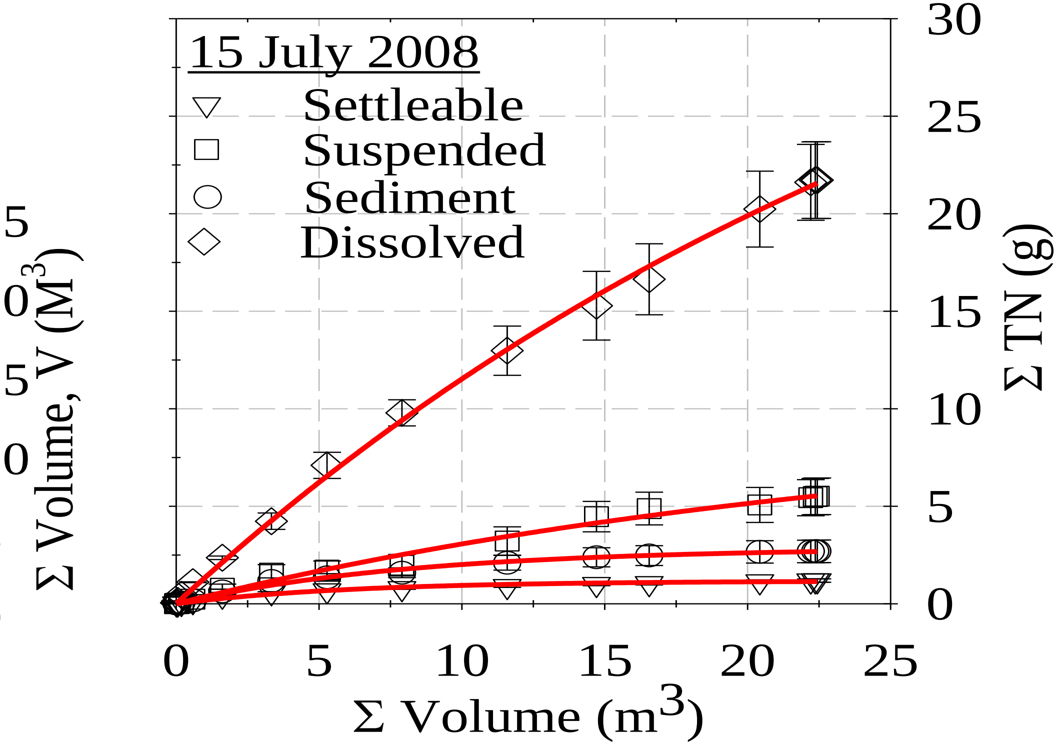


Relationship between granulometry and particulate TP based on University of Florida rainfall-runoff event datasets



Mass-limited Transport behavior of N fractions





Mass-limited transport: $\Delta M_t = M_0(1 - e^{-K_1 V_t})$

Where M_t *: cumulative mass delivered [M]*

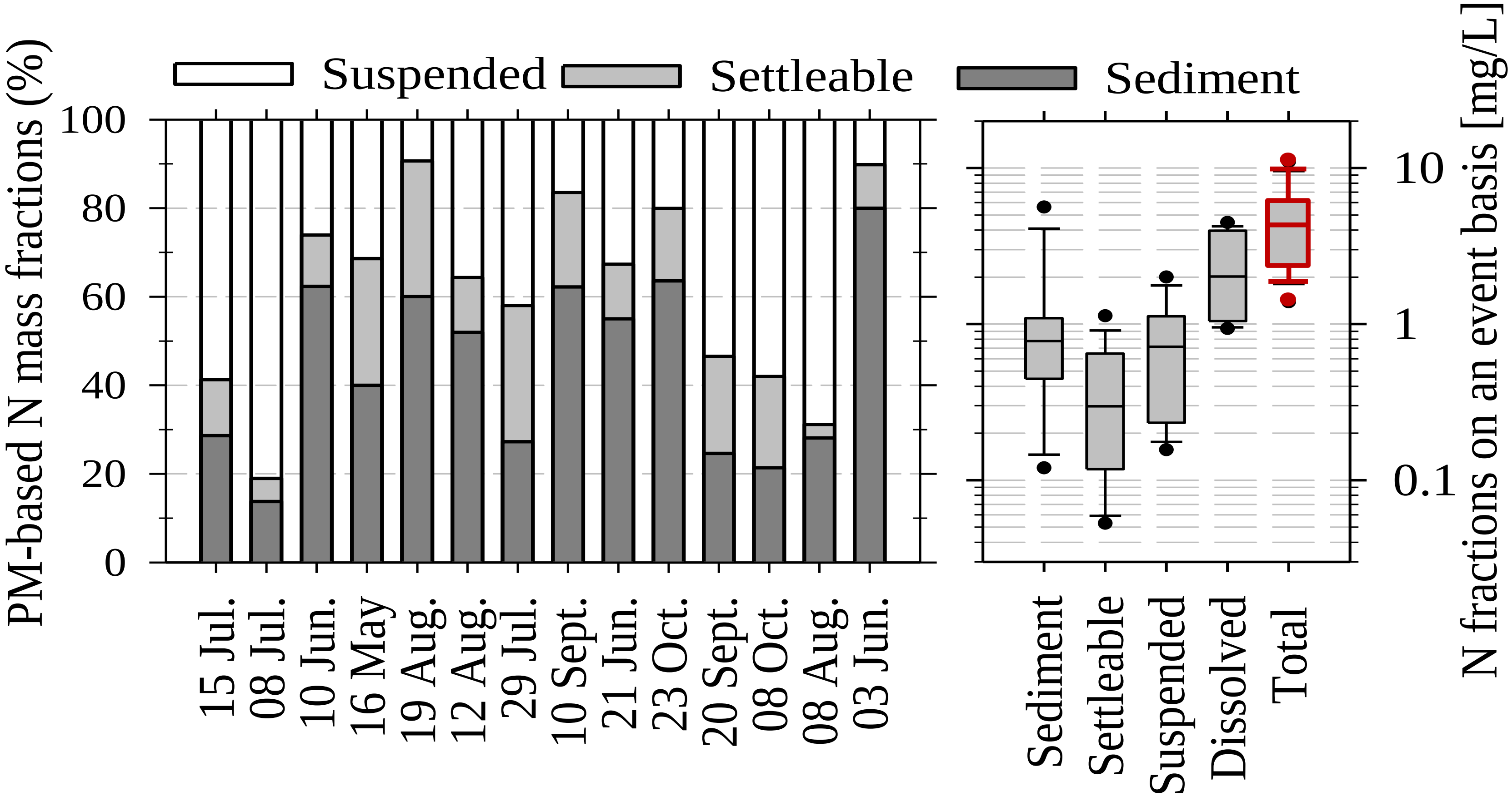
V_t *: cumulative volume [m³]*

M_0 *: constituent mass on the surface at the beginning of the rainfall-runoff event*

K_1 *: first-order coefficient [m⁻³]*

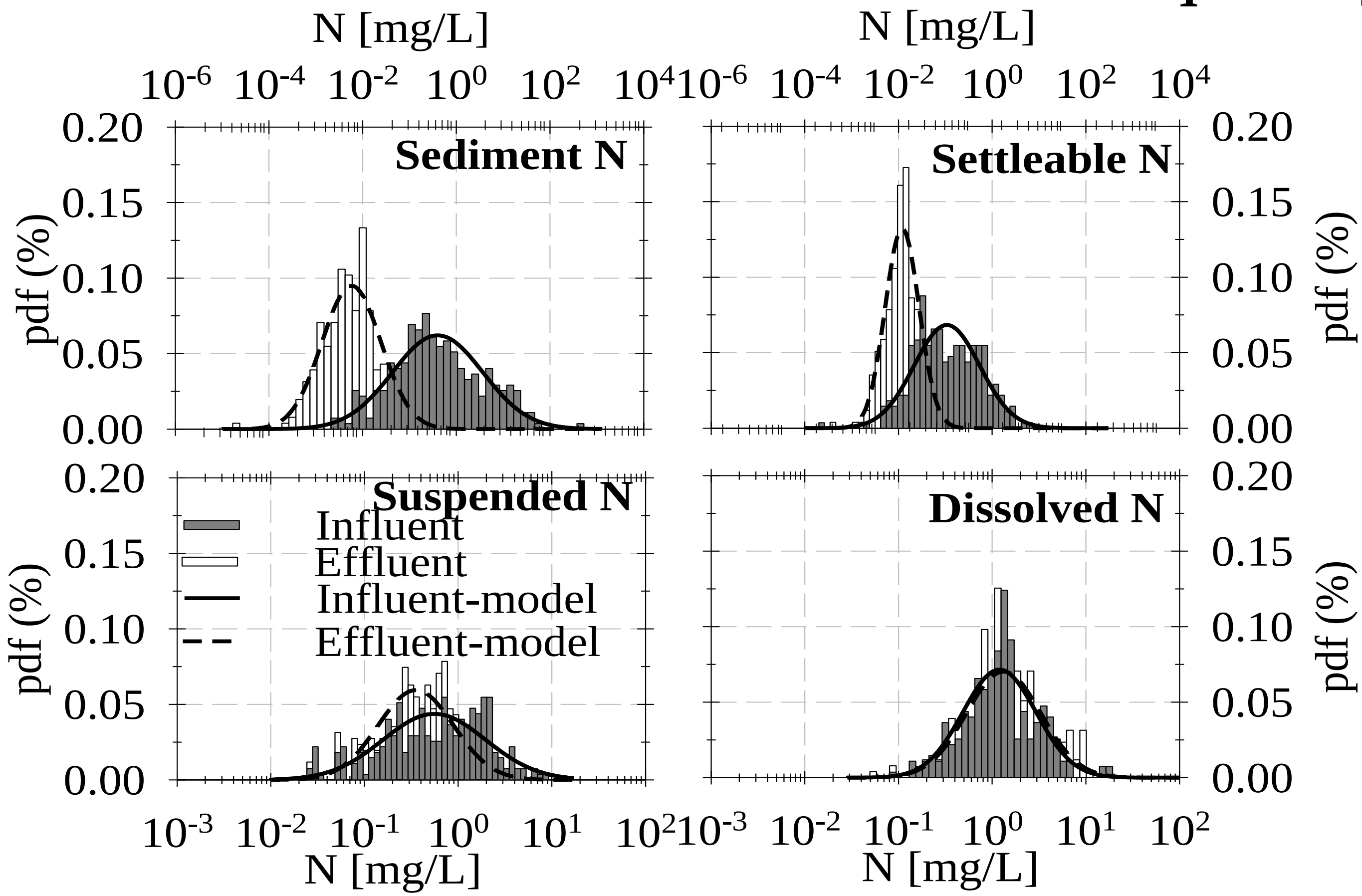
N fraction	M_0(g)	K_1(m^{-3})
Settleable	1.17	0.16
Sediment	2.86	0.12
Suspended	9.49	0.04
Dissolved	42.15	0.03

TN distribution by PM fraction (N. Central Florida)



1. There is significant intra- and inter-event variability of each TN fraction
2. The median dissolved fraction in runoff is approximately 50% of the source area TN value
3. Approximately 25 to 30% of NO_3^- in runoff is sourced directly from rainfall with the balance leached during the rainfall-runoff process or later in the UO

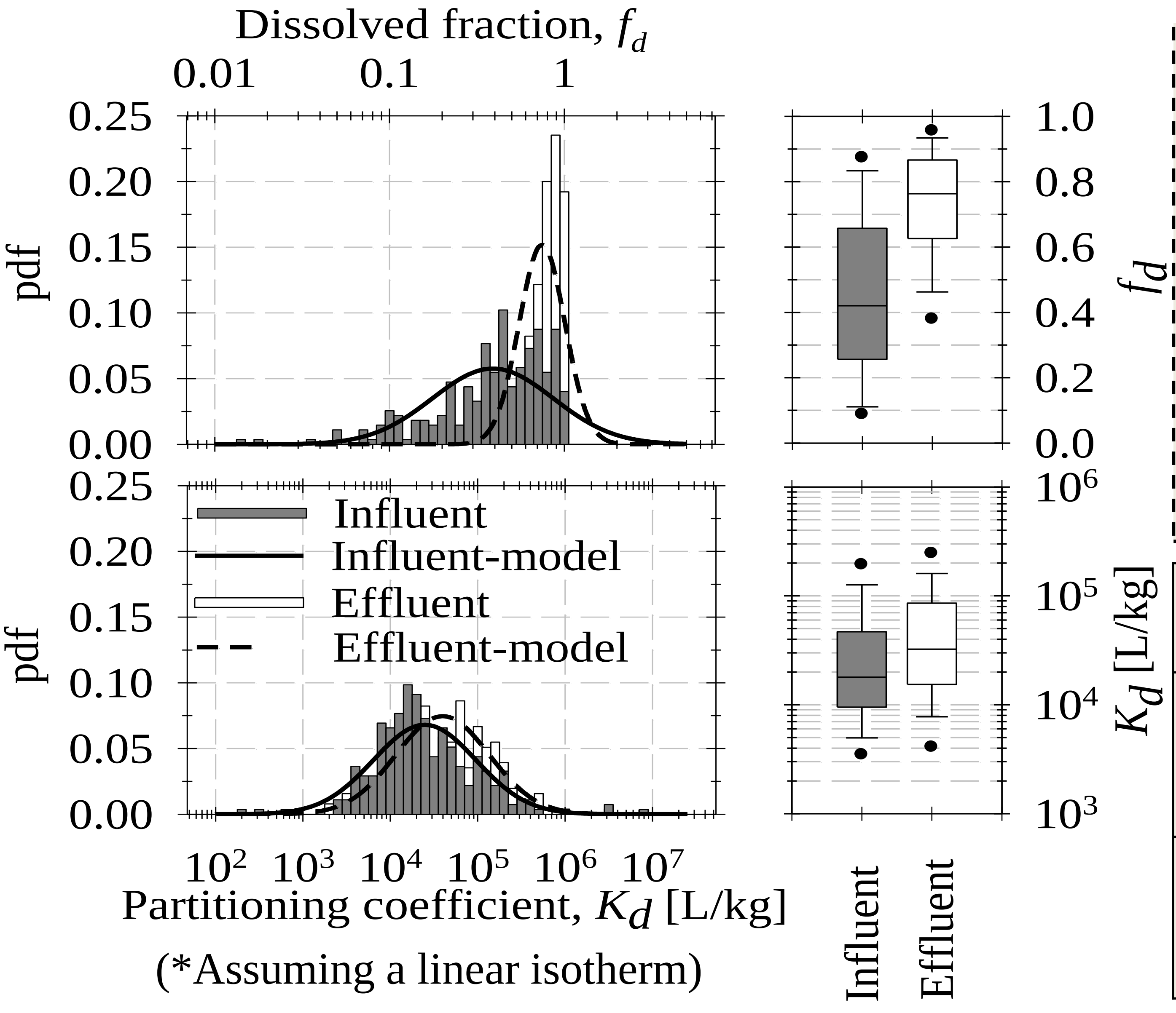
Particulate bound TN: Frequency Plots



N fraction	Influent		Effluent	
	median	std. dev.	median	std. dev.
Dissolved	1.10	2.45	1.22	2.44
Suspended	0.52	3.53	0.33	2.53
Settleable	0.09	5.00	0.01	2.29
Sediment	0.34	9.17	0.01	4.25

1. Log-normal distribution
2. Dissolved fraction has the highest N concentration, while settleable fraction held the least portion
3. High variability of N concentration due to high mobility of nitrogen species
4. N in coarser PM showed wider distribution than finer PM due to stronger first-flush effect

N partitioning (dissolved vs. PM fraction phases)

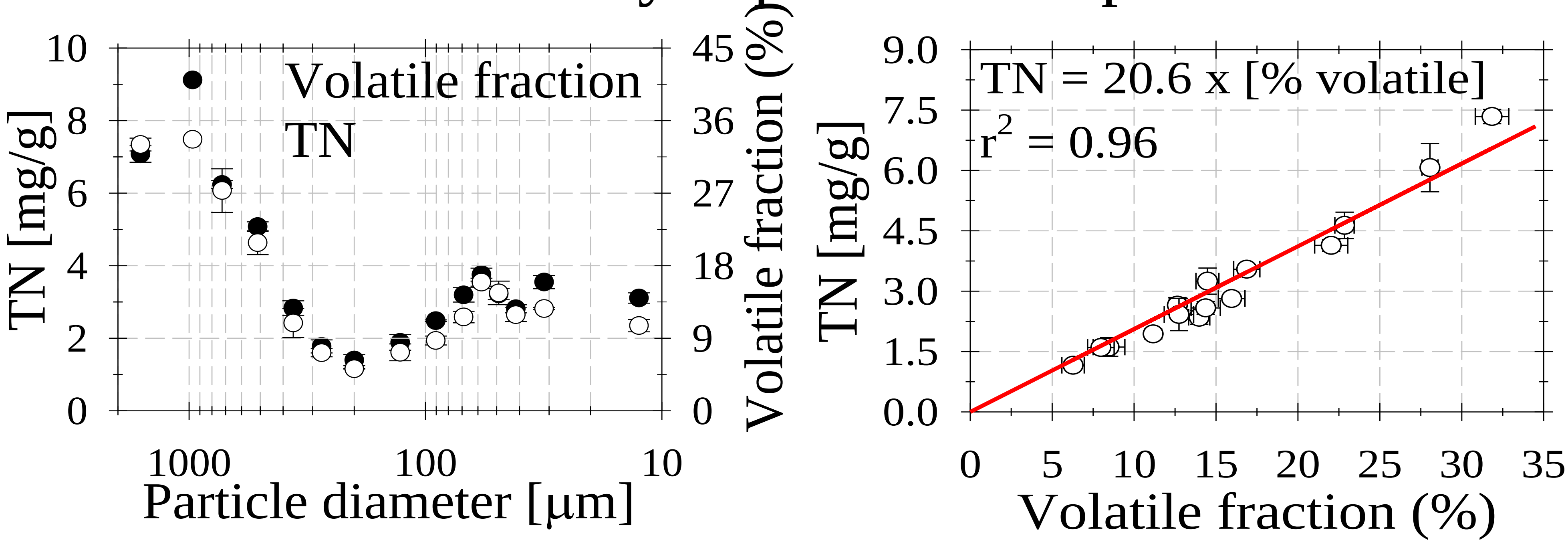


(*Assuming a linear isotherm)

1. Log-normal distributions
2. Effluent has higher f_d values due to the separation of PM by UO
3. UO is an adsorptive-media filter

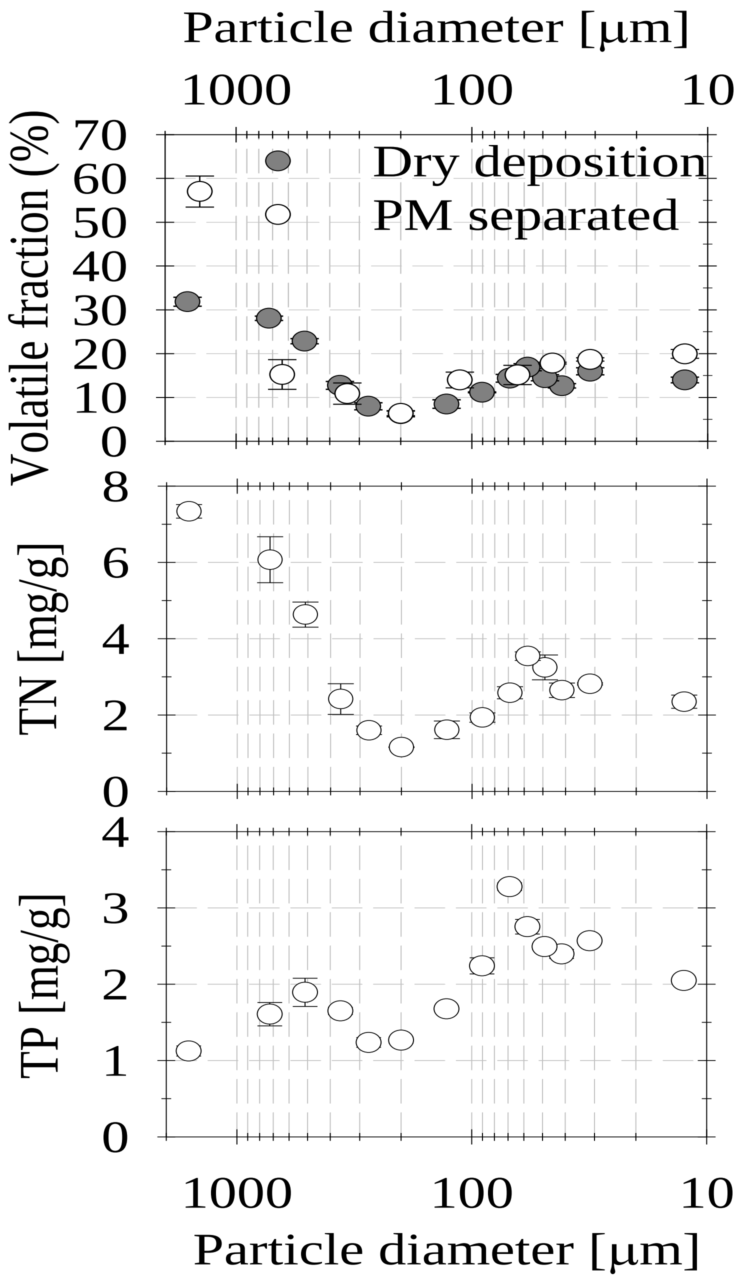
		f_d	K_d [10^4 L/kg]
Influent	μ_{50}	0.42	1.78
	μ	0.45	8.91
Effluent	μ_{50}	0.76	3.24
	μ	0.73	6.82

N distribution in dry deposition samples



1. TN concentration showed a trend of "first decrease and then increase" as particle size decreased.
2. The median value of TN in dry deposition is 1.9 mg/g.
3. N associated with PM was strongly correlated with volatile fraction, which is an index of organic content.

N distribution in PM samples

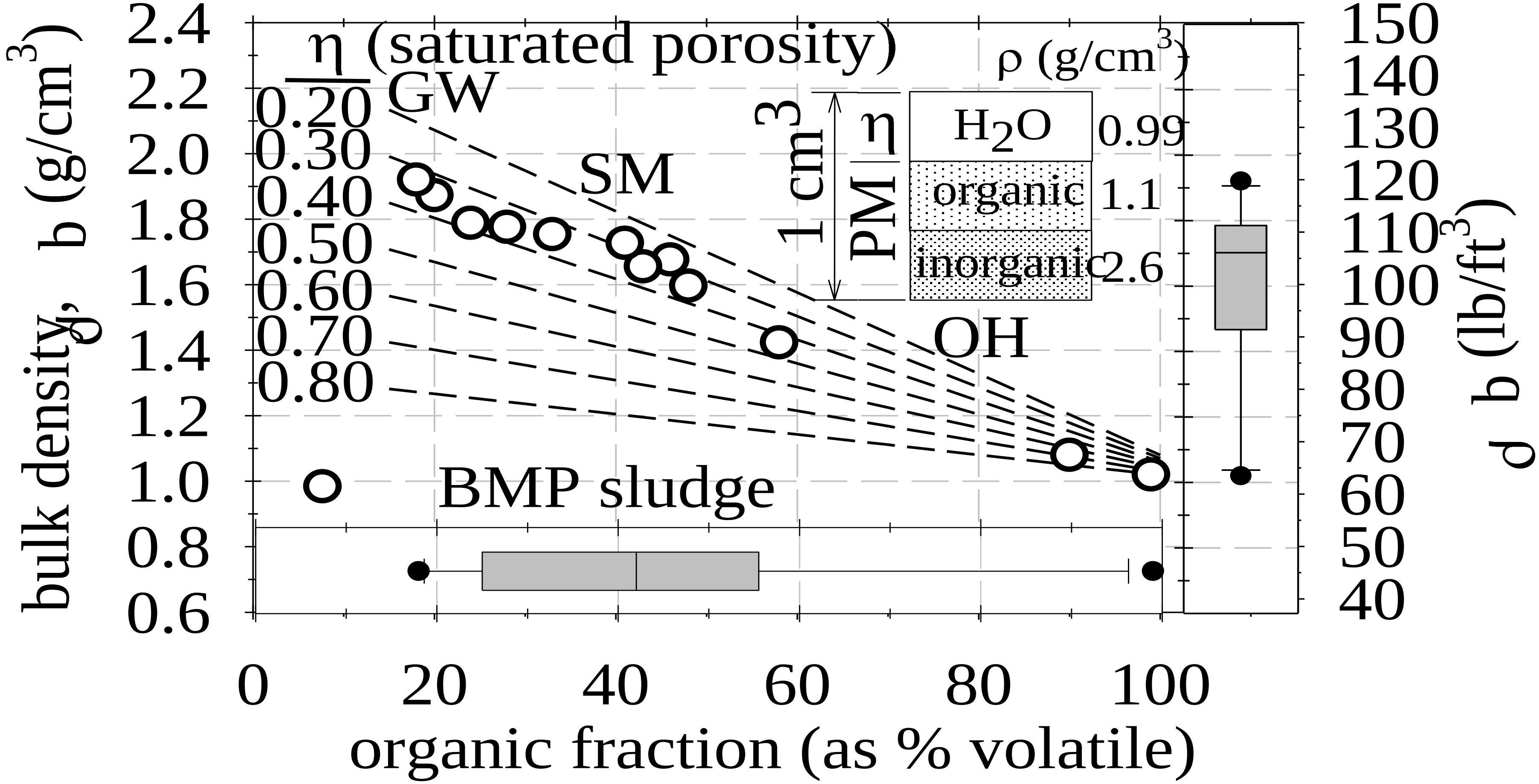


1. Dry deposition and separated PM showed similar trend for volatile fraction as a function of particle diameter.

1. TN of separated PM showed a similar trend as the dry deposition sample

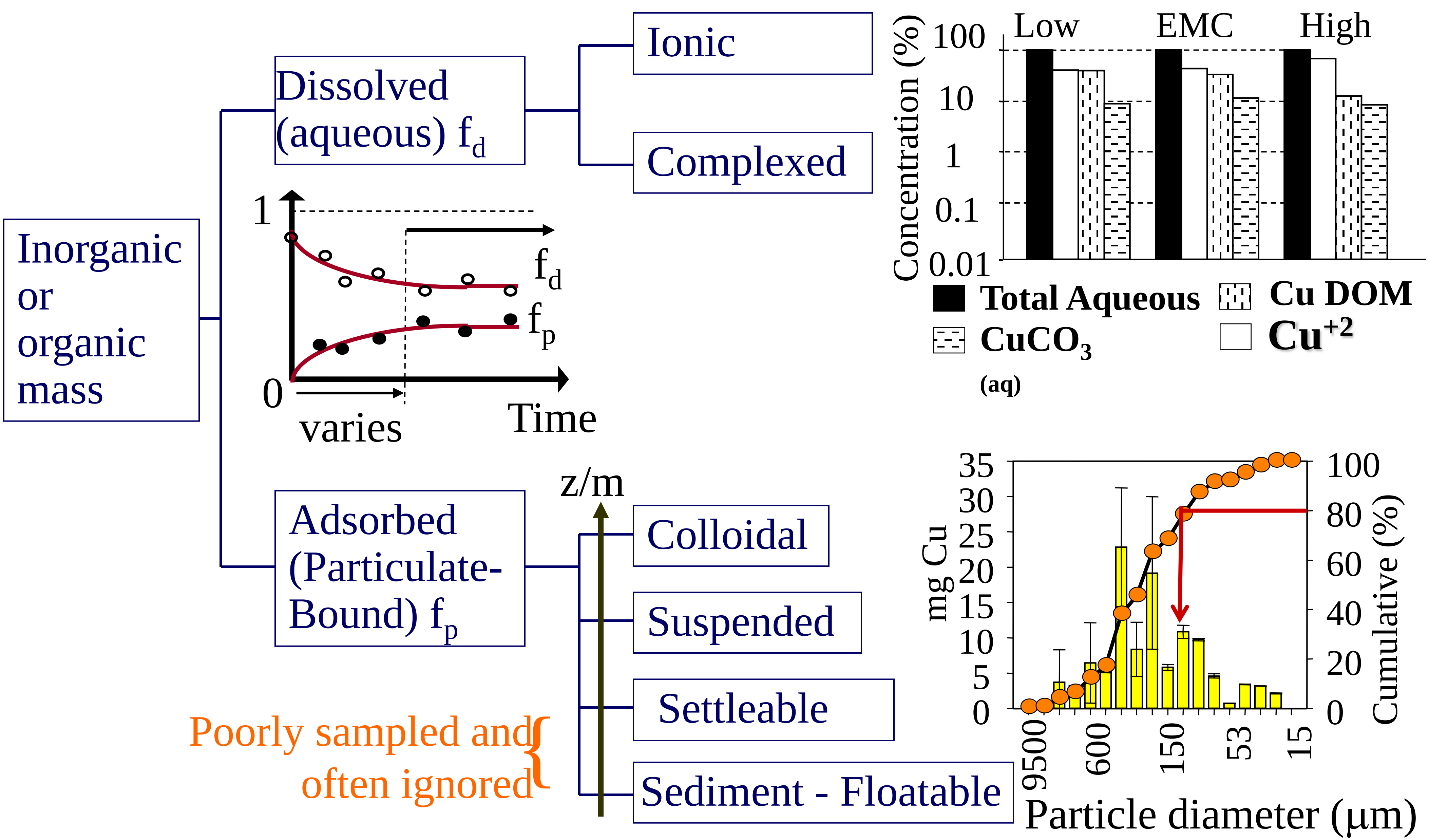
1. TP of separated PM generally increased as particle diameter decreased.

Bulk density of BMP sludge

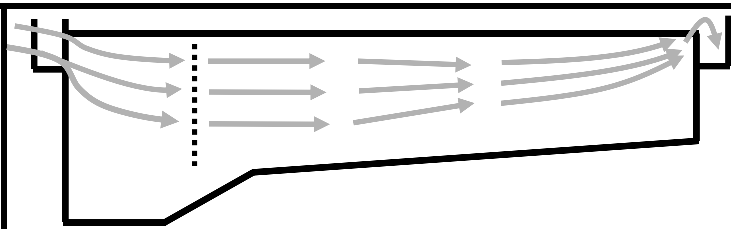
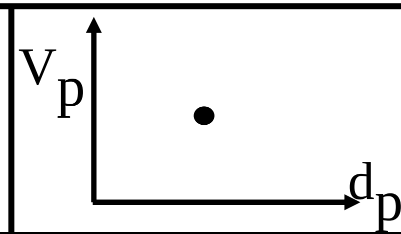
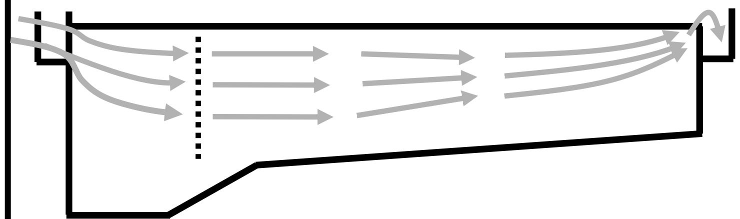
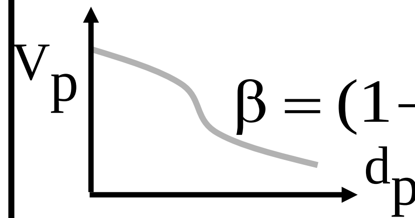
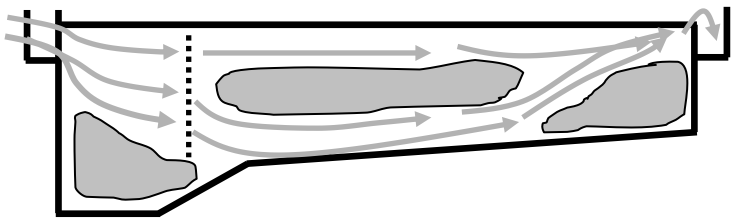
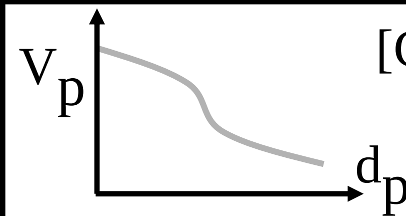
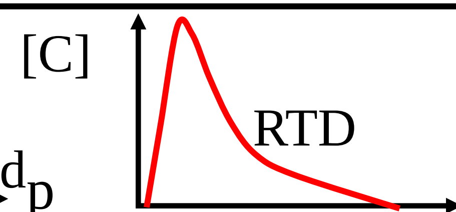
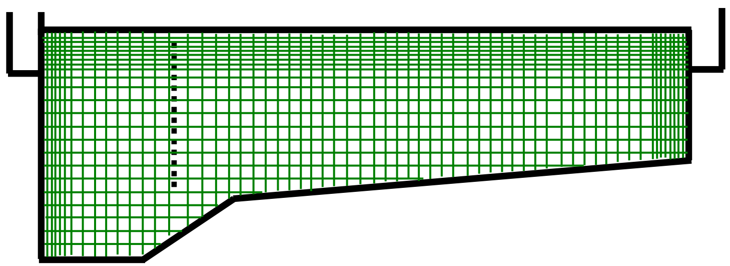
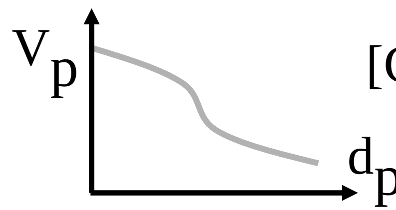
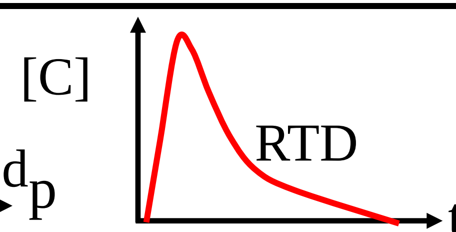


1. Bulk density is a function of organic fraction and porosity.
2. At constant porosity, bulk density tend to decrease as organic fraction increases.
3. Bulk density of BMP sludge ranged from 1.0 to 1.9 g/cm^3, with a median value of 1.7 g/cm^3.

Partitioning and distribution of mass (example – Cu)



Models for Type I Settling (Dominant Mechanism)

Ideal Overflow Model w/o PSD - *most common*		 $V_c = \frac{Q_e}{A_s}$
Ideal Overflow Model w/ PSD - *rare* (Case II)		 $\beta = (1 - X_c) + \int_0^{X_c} \frac{V_p}{V_c}\, dx$
Non-Ideal Semi-Empirical Models w/ PSD - *infrequent in USA, common in Europe*	 $N = \frac{t_{50}}{t_{50} - t_p}$	  $\beta = 1 - \left[1 + \frac{V_p A}{NQ}\right]^{-N}$
Multi-Phase CFD Models - *state of the art, rarely applied in practice* (Case IV)		  $\beta = \int_{CV} (Q, \rho, \Gamma, \varphi)\, dx\, dy\, dz\, dt$

Sedimentation Mechanisms: Type I, II, III, IV

Discrete (Type I)

- PM settles as discrete particles
- Dominant mode for urban runoff PM settling
- Primary mechanism for settleable, sediment PM

Flocculant (C/F) (and Differential) (Type II)

- Particles undergo C/F during settling
- Vs is f{floc size, PM mass concentration, PND}
- > 100 mg/L but a f (PSD)
- Type II settling impact < Type I settling

Hindered settling (Type III)

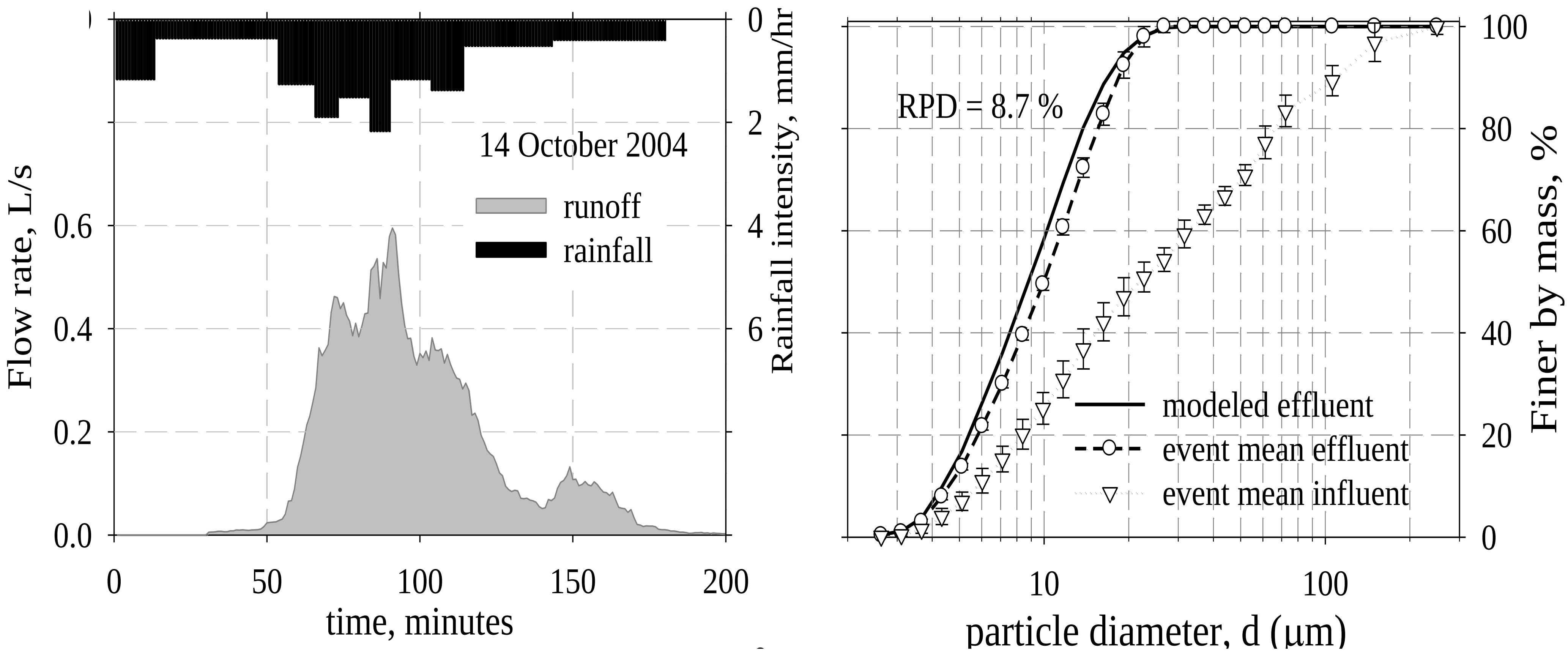
- PM-liquid interface generated with constant V_s
- PM settling as zone with no differential settling
- Mass concentrations > 1000 mg/L

Compression settling (Type IV)

- Weight of PM exfiltrates pore water
- Shear strength generation, PM now in % (v/v)
- Primary consolidation for suspended/clayey PM

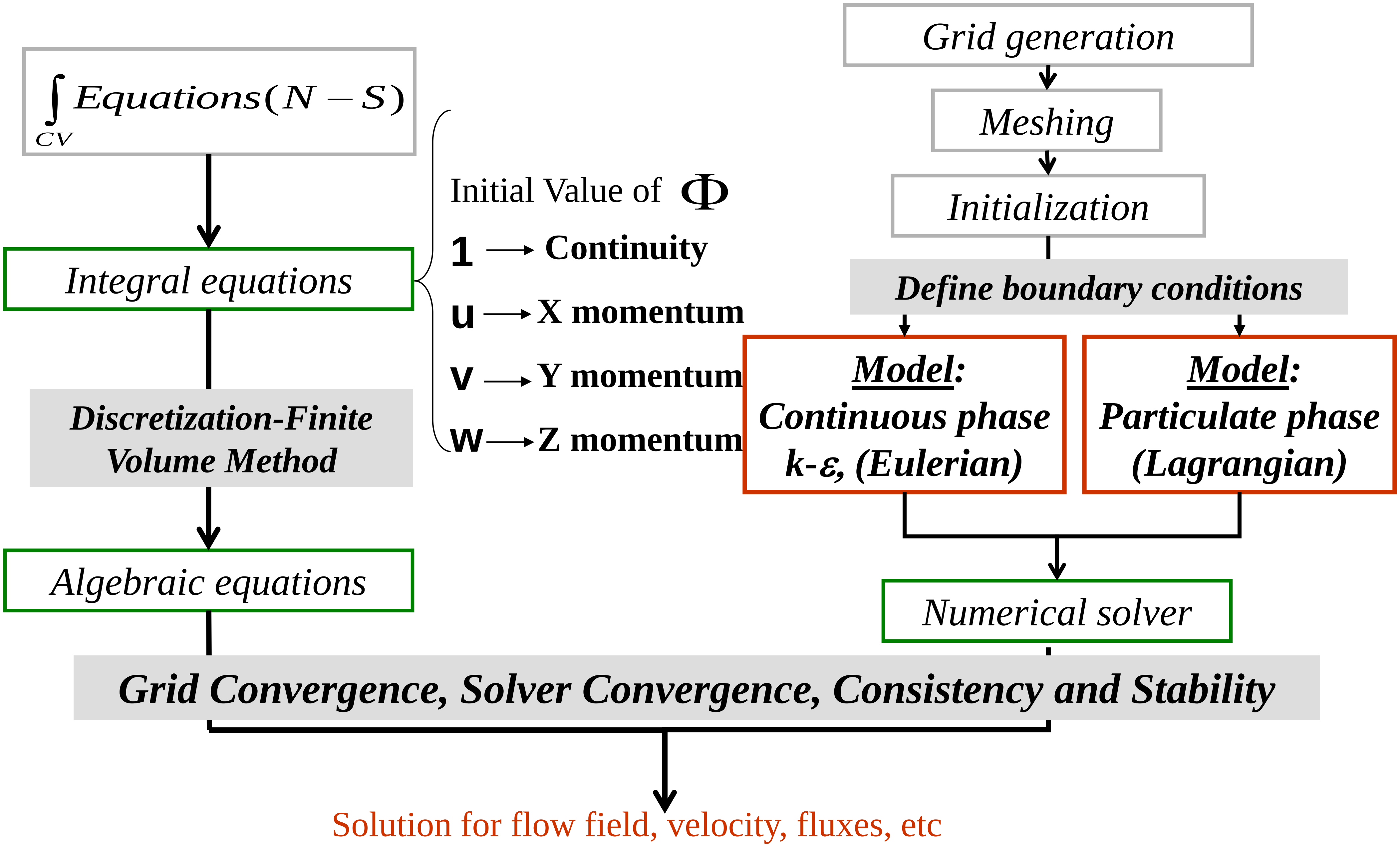
Ideal surface overflow rate can predict PM fate subject to unsteady flow w/representative PM, flow, mass balances

(1-m diameter hydrodynamic separator w/ 2400 μm screen)



Che cosa è CFD ?

CFD Processes (in this case, Navier-Stokes (N-S) Equations applied)



CFD concepts : Equations of Continuity

- The conservation equations are Continuity, Momentum and Energy is included. These are the Navier-Stokes (N-S) equations.

Continuity

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho u_j\right) = 0$$

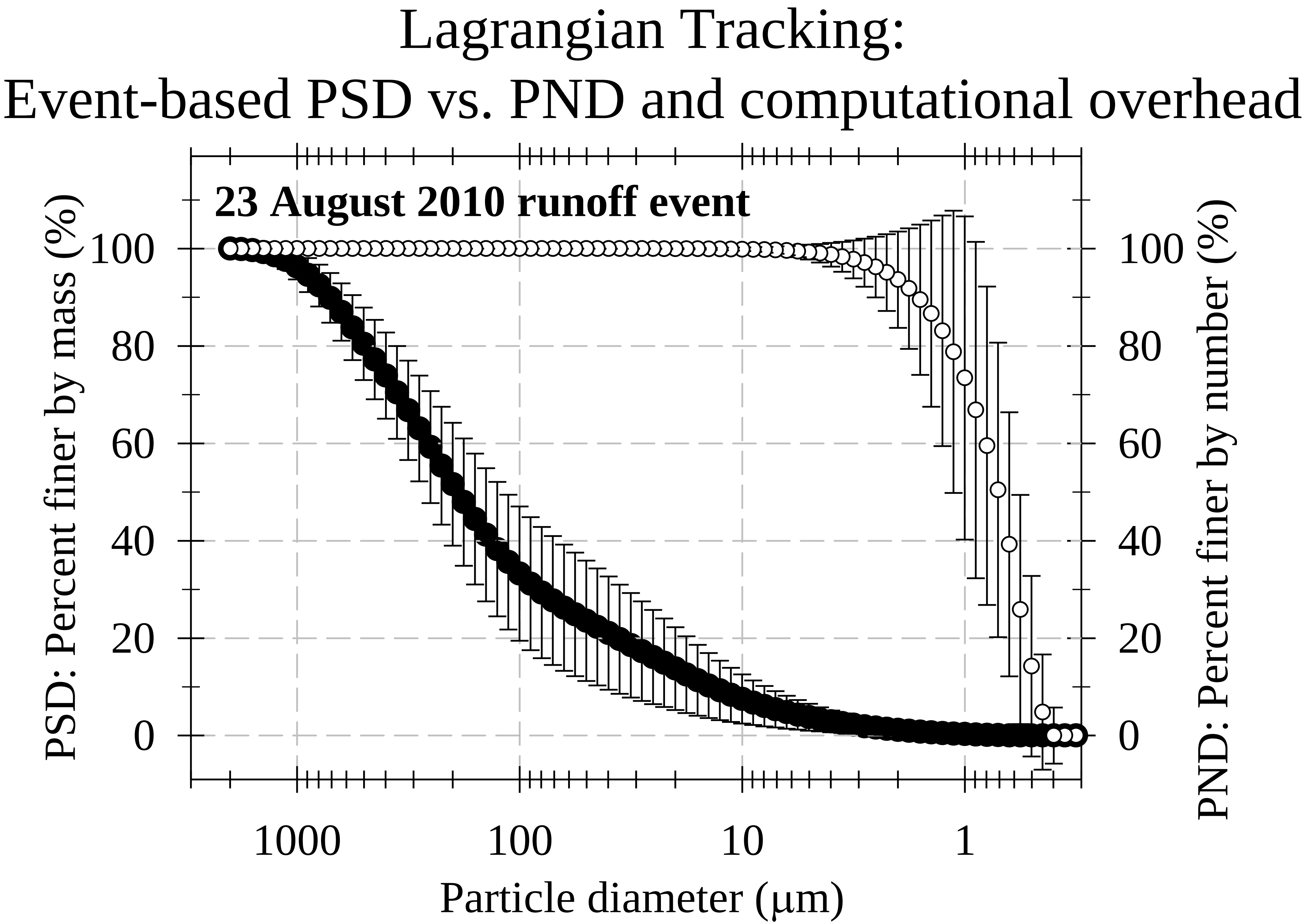
Momentum

$$\frac{\partial}{\partial t}\left(\rho u_i\right) + \frac{\partial}{\partial x_j}\left(\rho u_j u_i\right) = \frac{\partial \rho}{\partial x} + \frac{\partial \tau_{ji}}{\partial x_j}$$

Energy

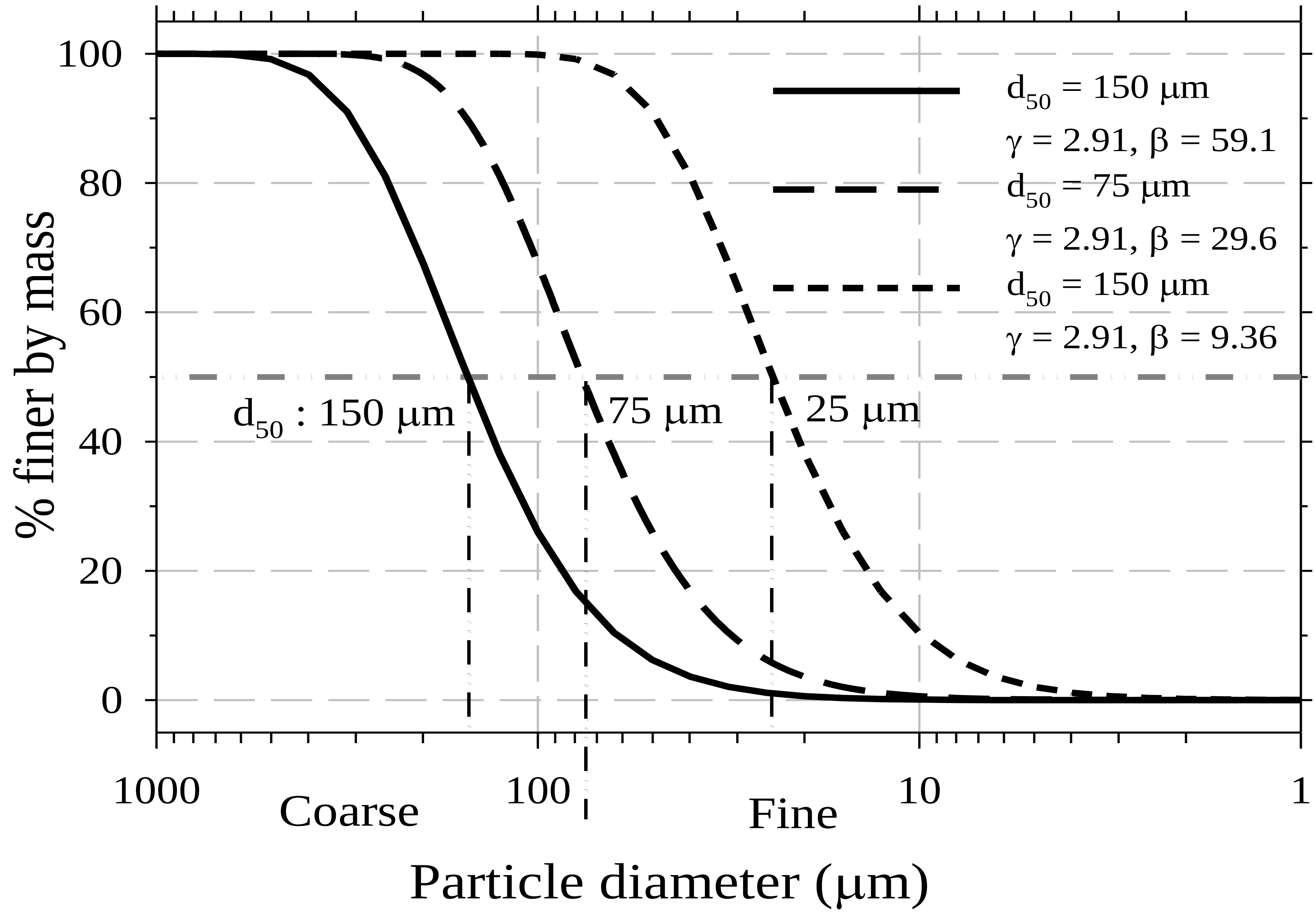
$$\frac{\partial}{\partial t}\left(\rho H - p\right) + \frac{\partial}{\partial x_j}\left(\rho u_j H\right) = \frac{\partial q_j}{\partial x_j} + \frac{\partial}{\partial x_j}\left(u_i \tau_{ji}\right)$$

ρ = density; p = pressure; x = position vector; t = time; u = velocity; τ = viscous stress tensor; q = heat flux vector; H = total enthalpy;

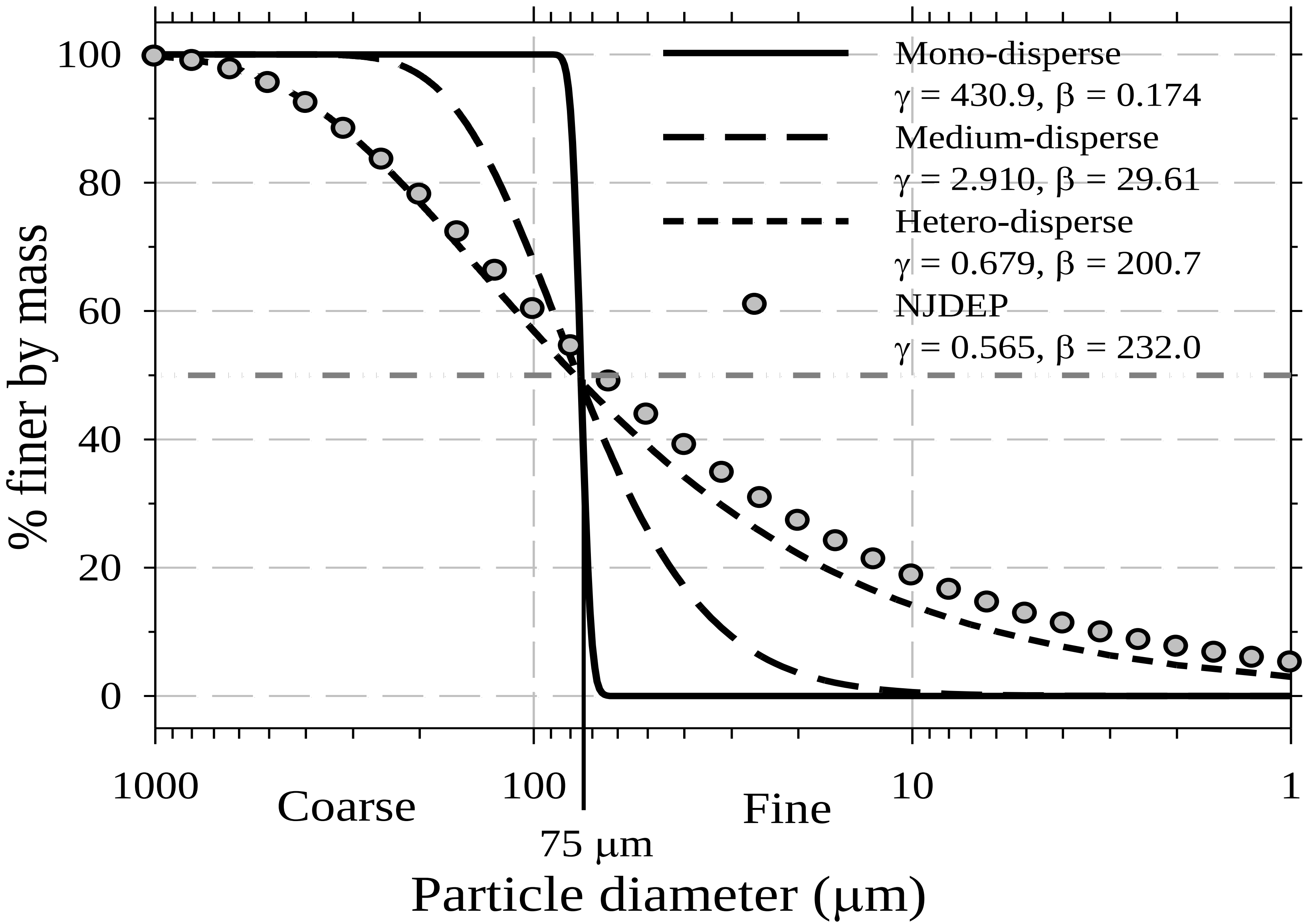


Lagrangian Tracking:
Event-based PSD vs. PND and computational overhead
23 August 2010 runoff event
PSD: Percent finer by mass (%)
PND: Percent finer by number (%)
Particle diameter (μm)
0
20
40
60
80
100
1000
100
10
1

PSDs: same uniformity and different d_{50}: both required

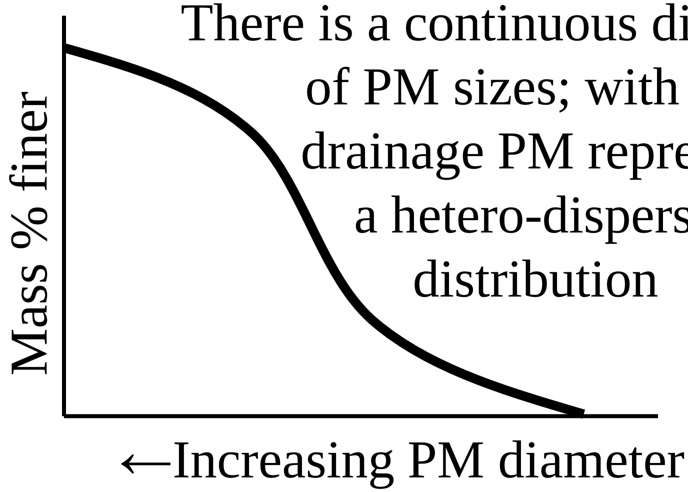


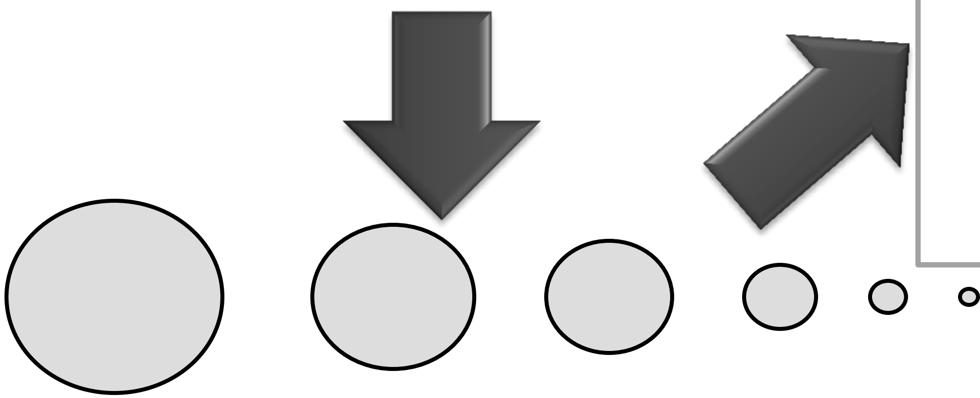
PSDs of same d_{50} but different uniformity: both required



A Discrete Phase Model (DPM): The Problem of Discretization

There is a continuous distribution of PM sizes; with urban drainage PM representing a hetero-disperse size distribution





DPM CFD Model

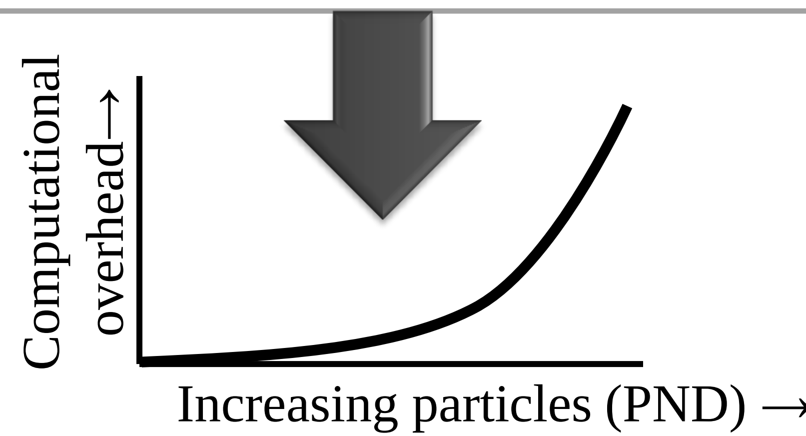
$$\frac{dv_{p\_i}}{dt} = F_{D\_i}(v_i - v_{p\_i}) + \frac{g_i(\rho_p - \rho)}{\rho_p} + F_i$$

$$F_{D\_i} = \frac{18\mu}{\rho_p d_p^2}\frac{C_{D\_i}\mathrm{Re_i}}{24}$$

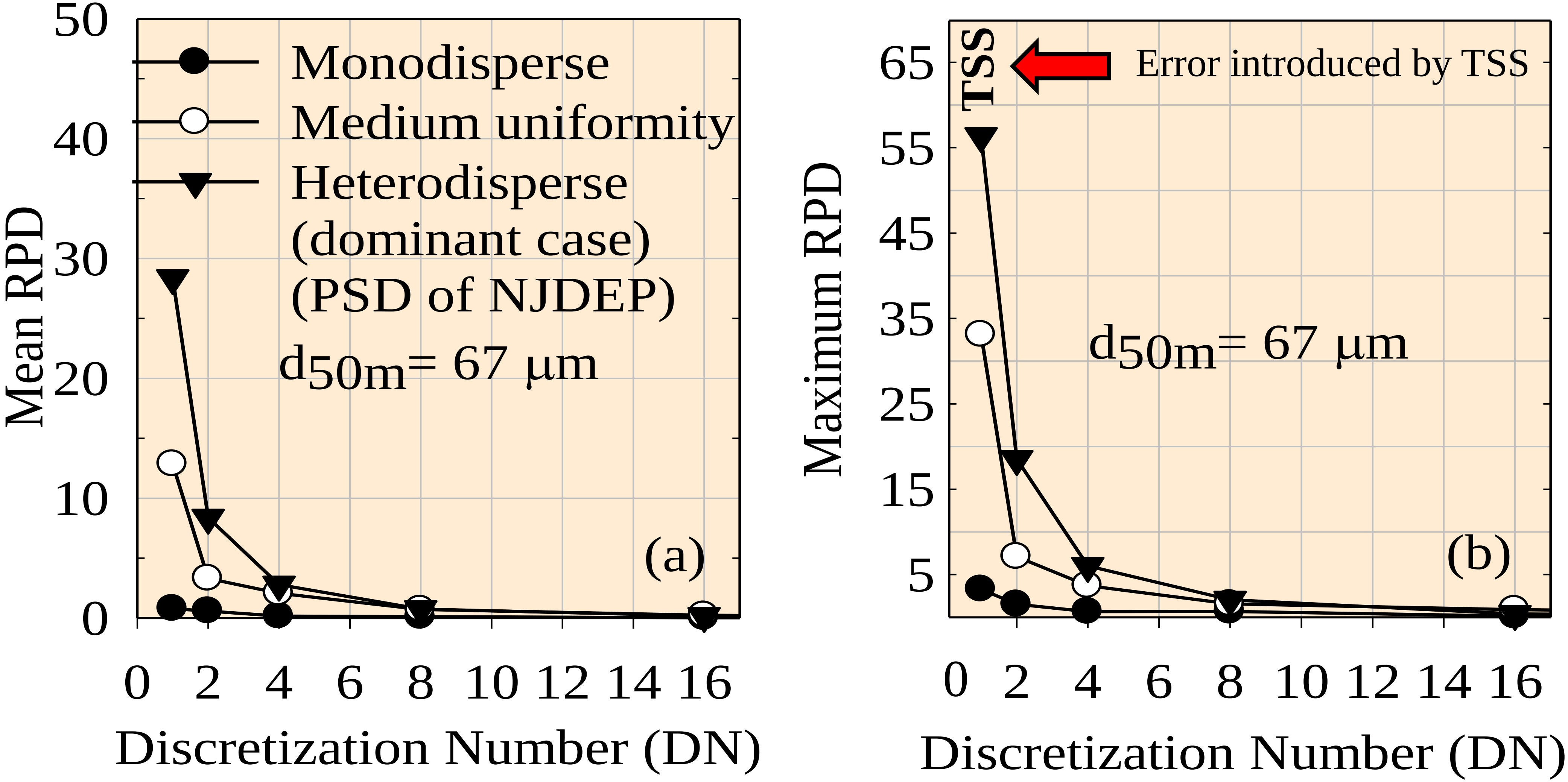
$$\mathrm{Re_i} \stackrel{\text{def}}{=} \frac{\rho d_p |v_{p\_i} - v_i|}{\mu}$$

$$C_{D\_i} = \frac{K_1}{\mathrm{Re_i}} + \frac{K_2}{\mathrm{Re_i^2}} + K_3$$

How representative are a finite number of discrete PM sizes for urban drainage hetero-disperse gradations? What error is generated when discretizing a particle size gradation?



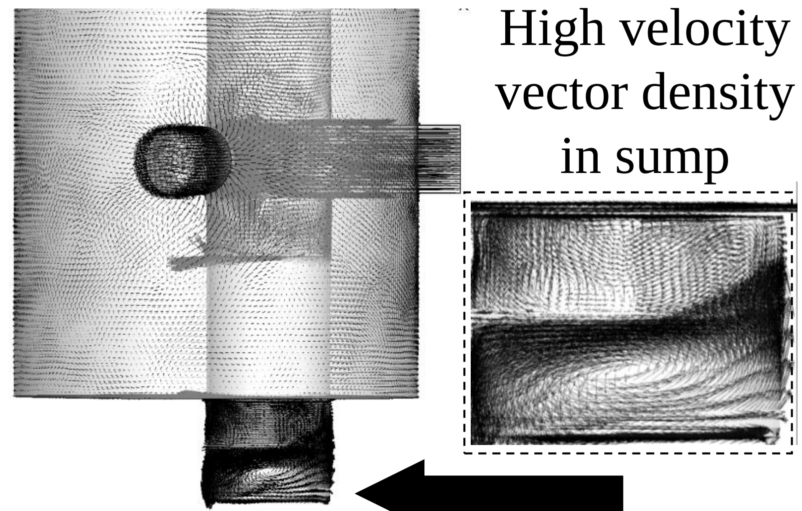
Treatment testing error as a function of PSD discretization for a hydrodynamic (OGS) unit for PSD with d_{50m} of 67μm



Two hydrodynamic separator (HS) classes illustrated

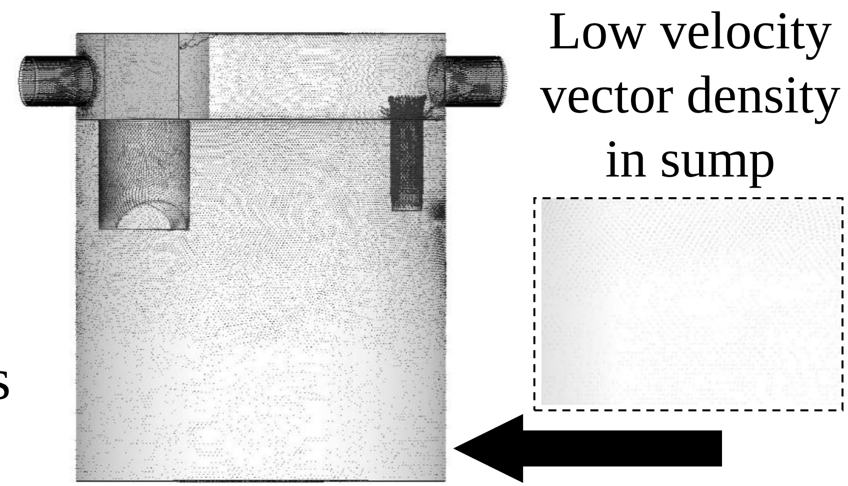
<u>Screened hydrodynamic separator (HS):</u>

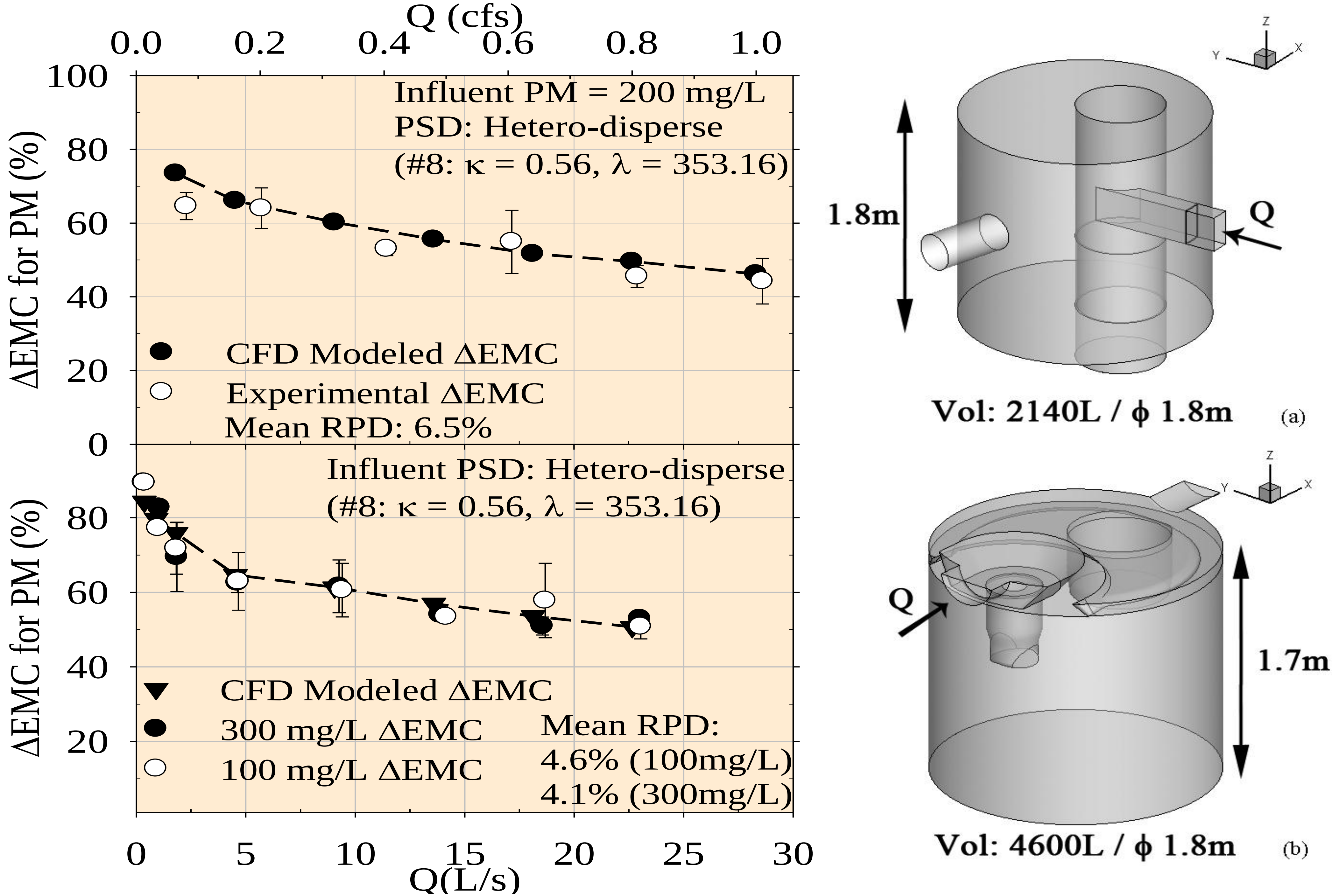
1. ***Screen separates sump from outer volute***
2. ***Sump <u>not</u> hydraulically-isolated from flow***
3. ***Higher hydraulic capacity than baffled HS***
4. PM separation similar to baffled HS at same Q
5. Type I gravitational settling of PM
6. Sump water chemistry degradation in 48 hours
7. Dickenson and Sansalone, ES&T, 2009



<u>Baffled hydrodynamic separator (HS):</u>

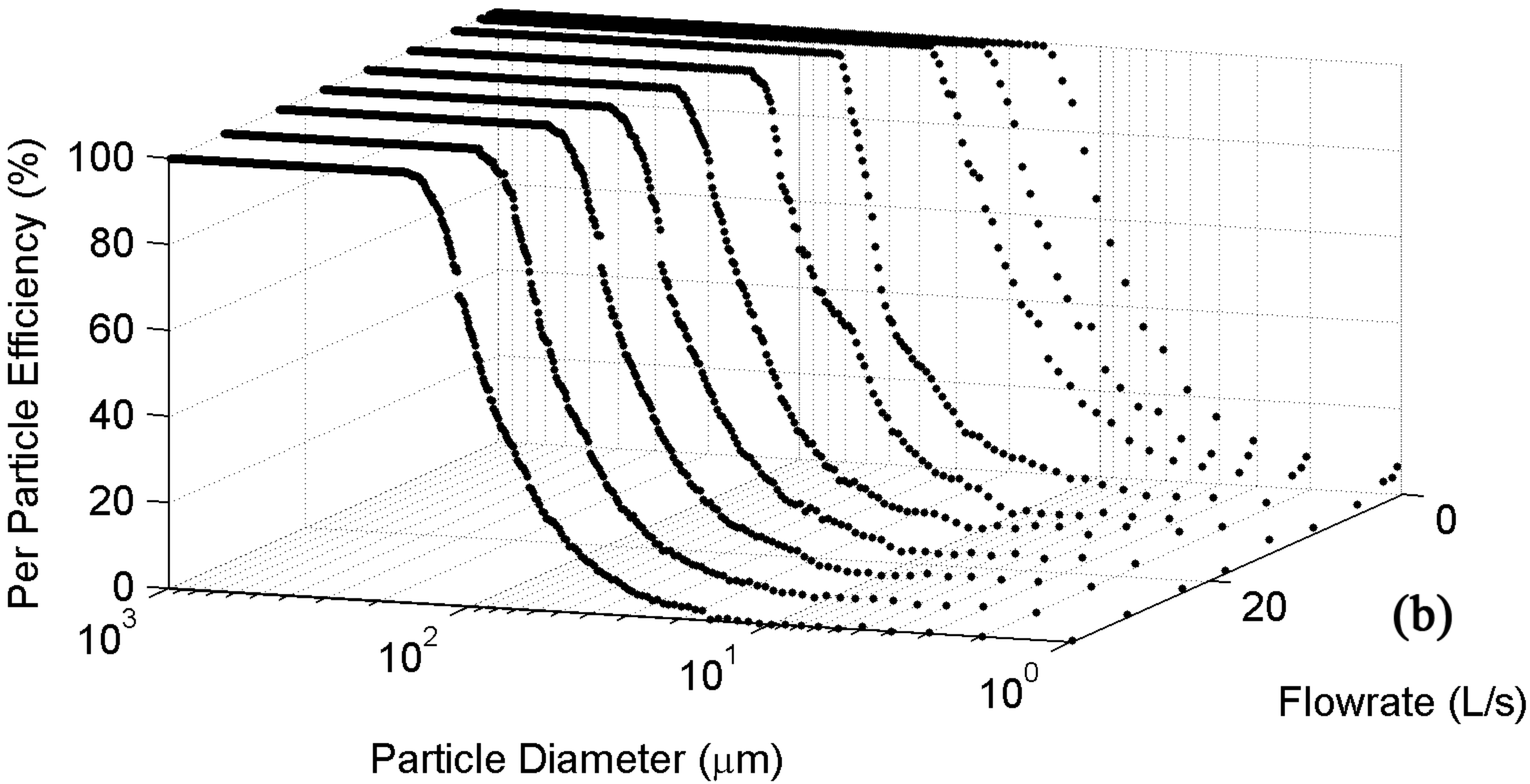
1. ***Horizontal baffle provides O&G separation***
2. ***Sump <u>is</u> hydraulically-isolated from flow***
3. ***Higher PM sump capacity isolated from flow***
4. Type I gravitational settling of PM
5. Sump water chemistry degradation in 48 hours
6. Dickenson and Sansalone, ES&T, 2009



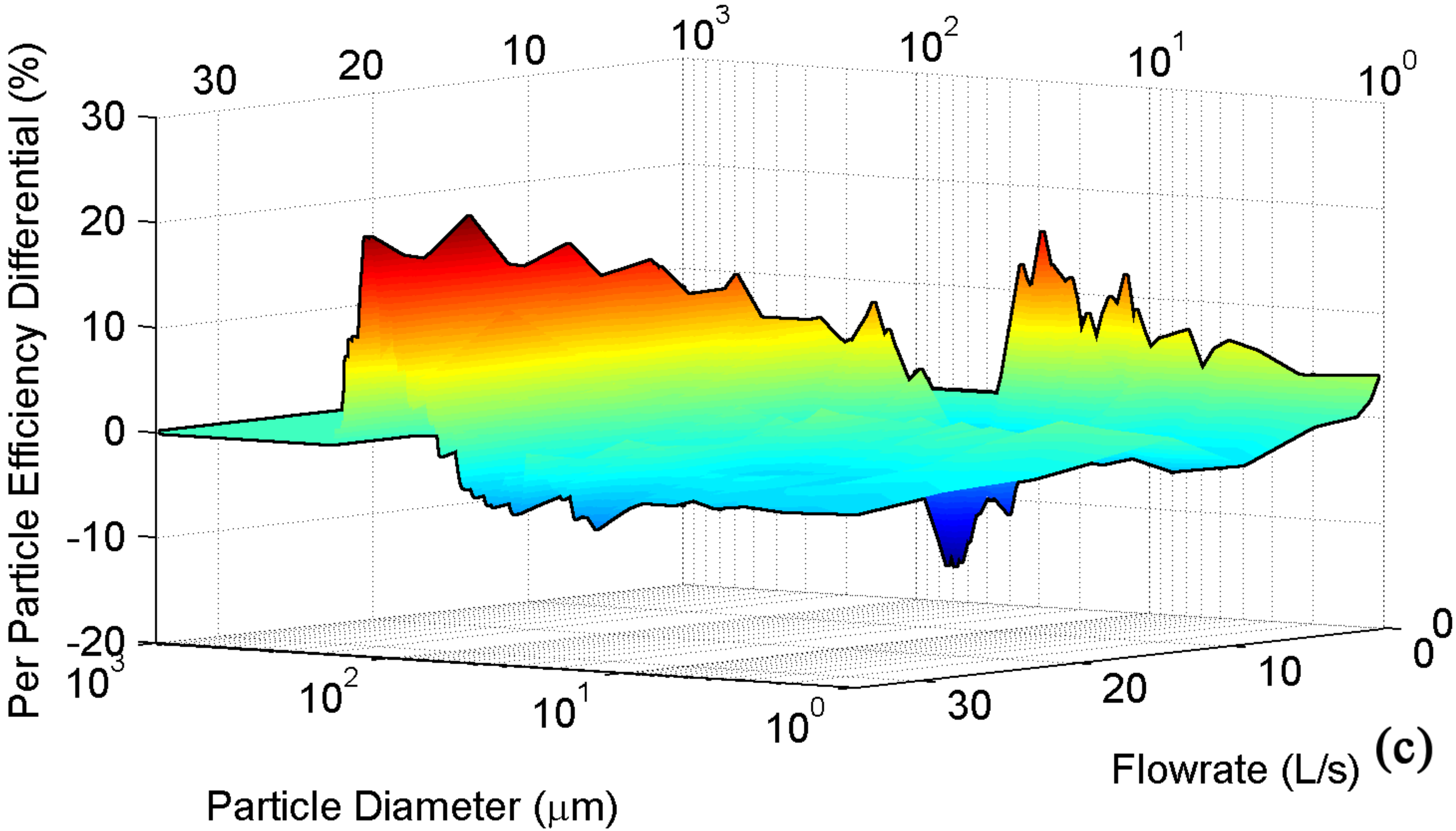


Q (cfs)
0.0
0.2
0.4
0.6
0.8
1.0
100
80
60
40
20
0
ΔEMC for PM (%)
Influent PM = 200 mg/L
PSD: Hetero-disperse
(#8: κ = 0.56, λ = 353.16)
CFD Modeled ΔEMC
Experimental ΔEMC
Mean RPD: 6.5%
Influent PSD: Hetero-disperse
(#8: κ = 0.56, λ = 353.16)
CFD Modeled ΔEMC
300 mg/L ΔEMC
100 mg/L ΔEMC
Mean RPD:
4.6% (100mg/L)
4.1% (300mg/L)
0
5
10
15
20
25
30
Q(L/s)
1.8m
Q
Vol: 2140L / ϕ 1.8m
(a)
Q
1.7m
Vol: 4600L / ϕ 1.8m
(b)

PSD-Q Domain for 1.8 m dia. Baffled HS

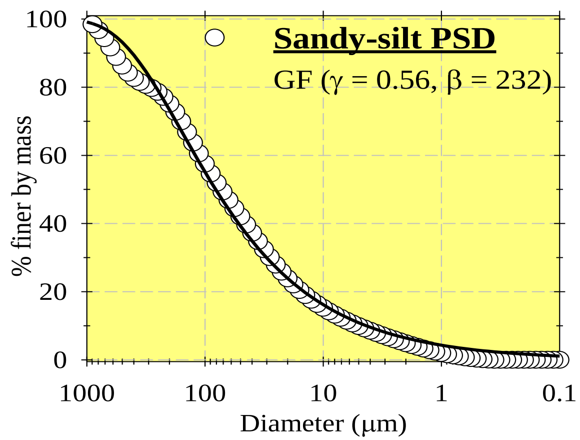


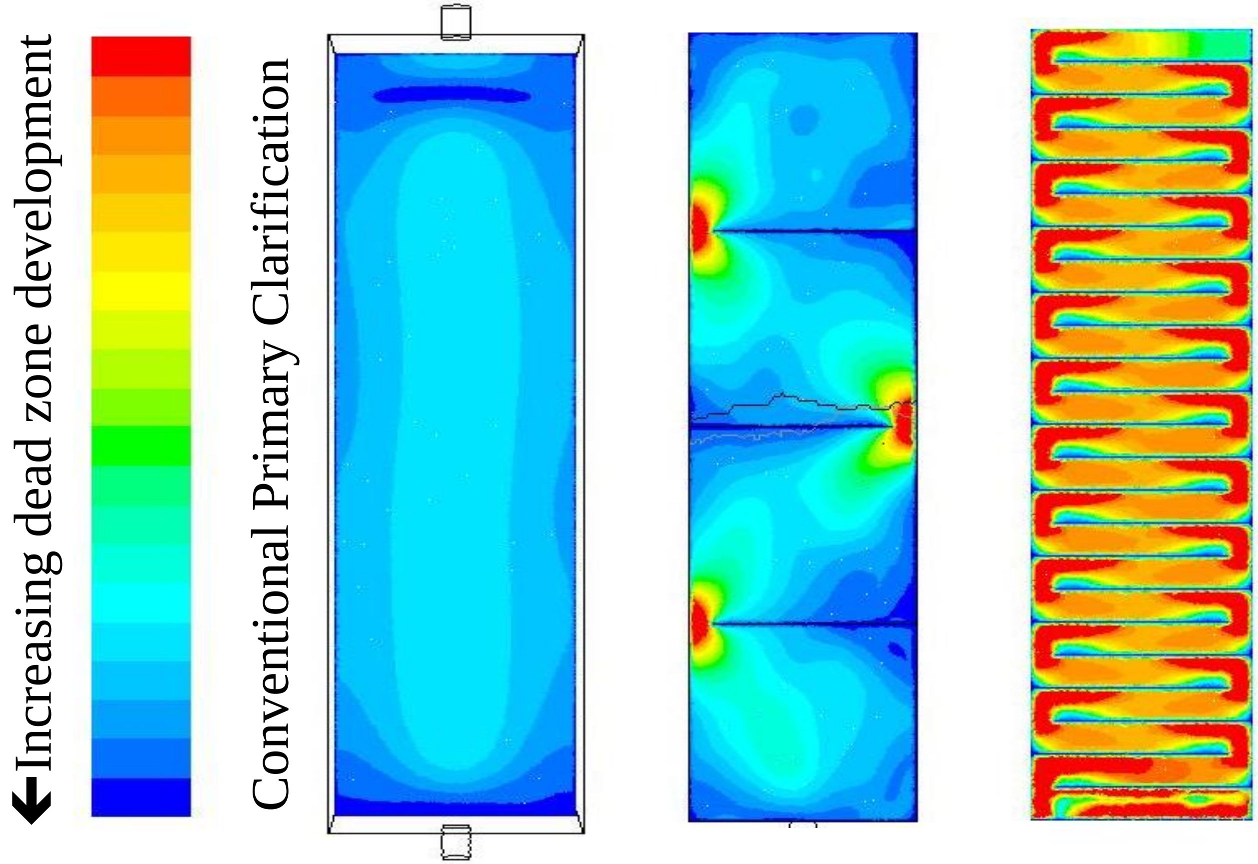
Differential HS Behavior in PSD-Q Space



Can PM clarification be optimized through baffle design with computation fluid dynamics (CFD)?

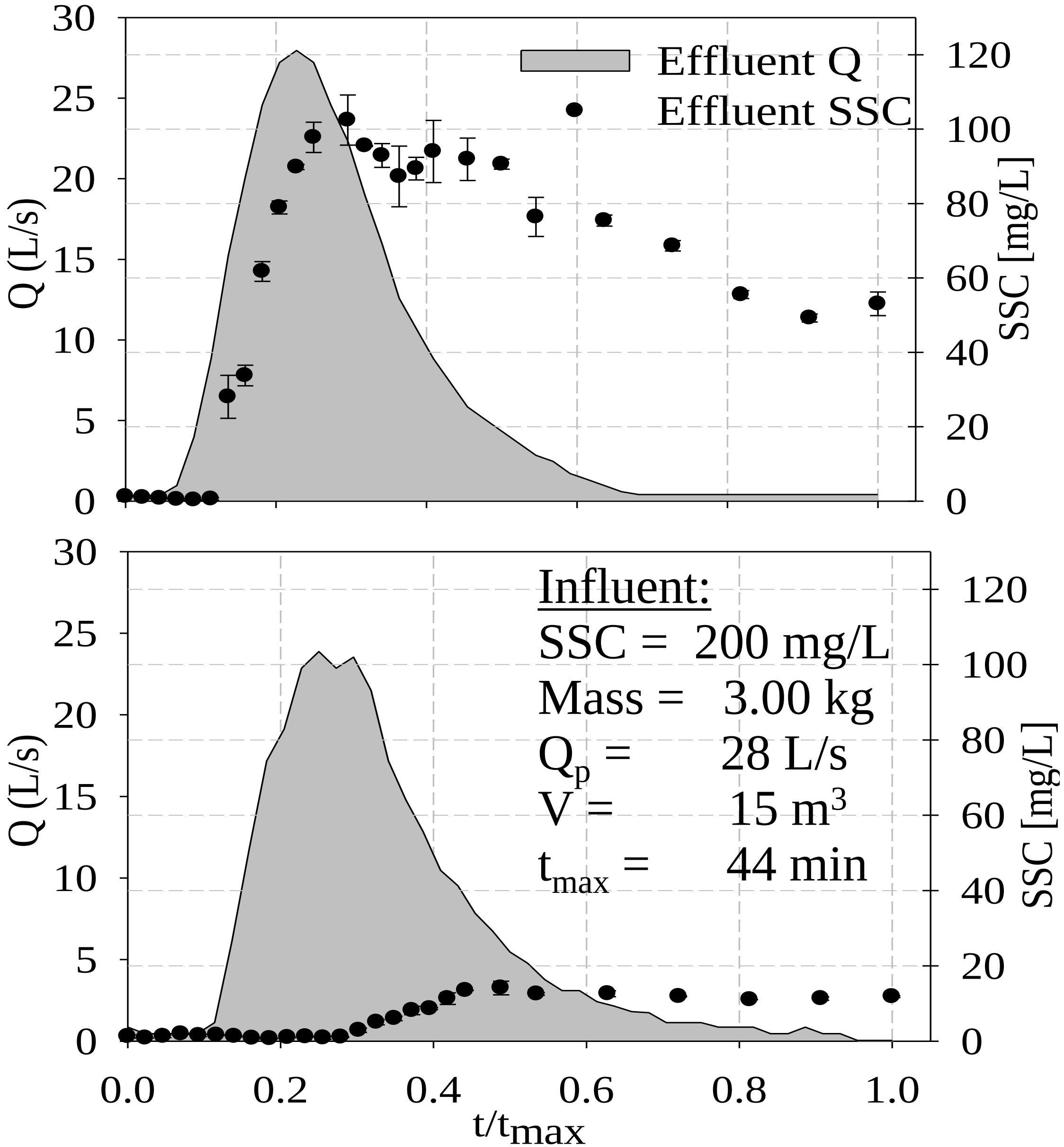
Physically-validated Model





Number of Baffles	0	3	17
Δ PM (%) (β = 0.56 , γ = 232.6)	45 to 60	60 to 70	> 95%
Volumetric Efficiency (%)	5 to 10	20 to 30	60 to 85

Physical model of TSS response to hydrograph loading



🡐 Linear trapezoidal basin

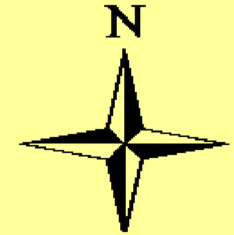
- Mean SOR: 74.8 gal./min-ft^2
- Effluent Q_p: 27 L/s
- Effluent TSS: 79 mg/L

🡐 Crenulated (baffled) basin

- Mean SOR: 74.8 gal./min-ft^2
- Effluent Q_p: 28 L/s
- Effluent TSS: 6 mg/L

With the same hydraulic capacity and surface area the baffled basin significantly outperforms the conventional basin: critical in both an airside, rural and urban context

Areal View of the ORL Basin System



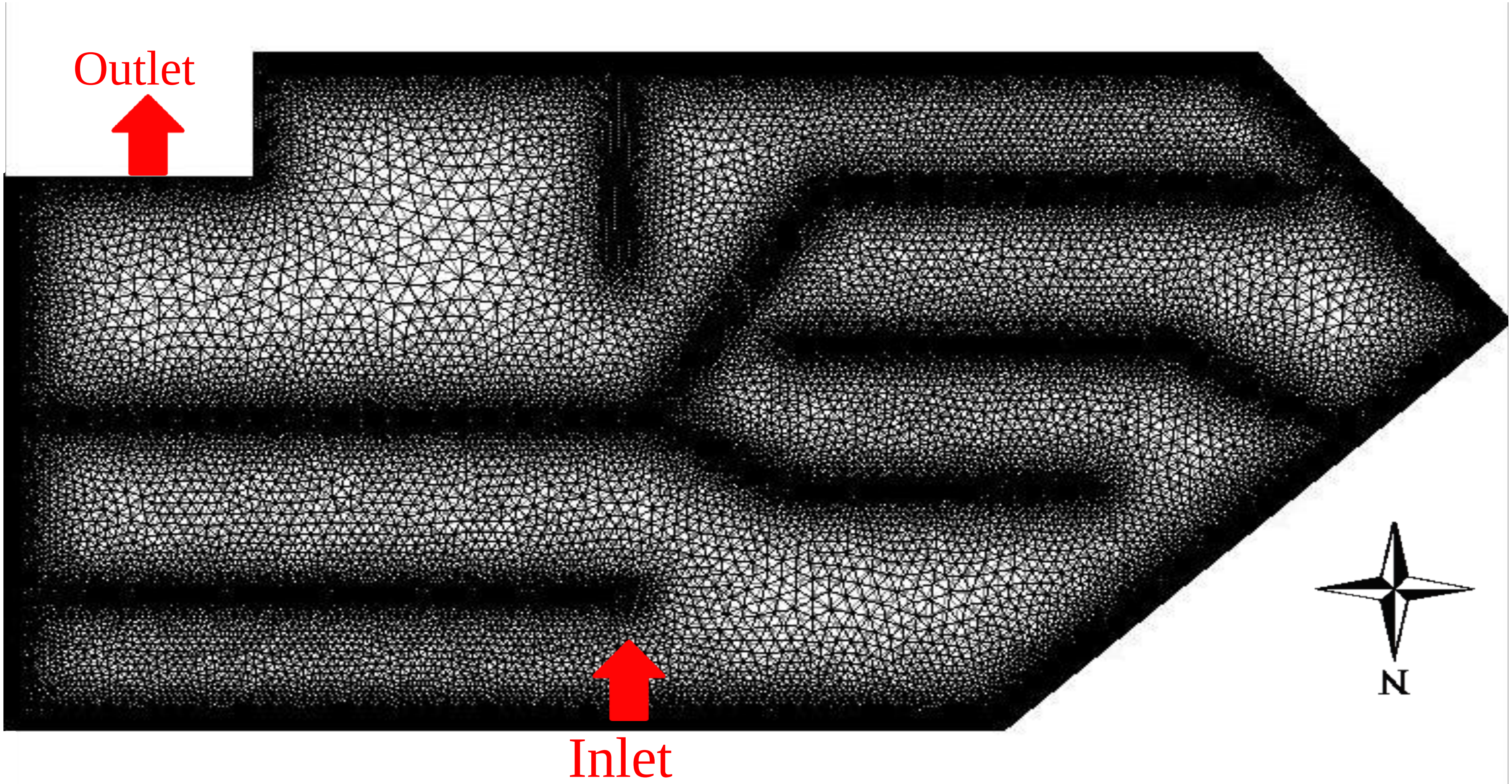
- Basin system is an ideal candidate for testing a basin design for wildlife and water quality benefits given that a baseline has been developed and the physical system is deteriorating

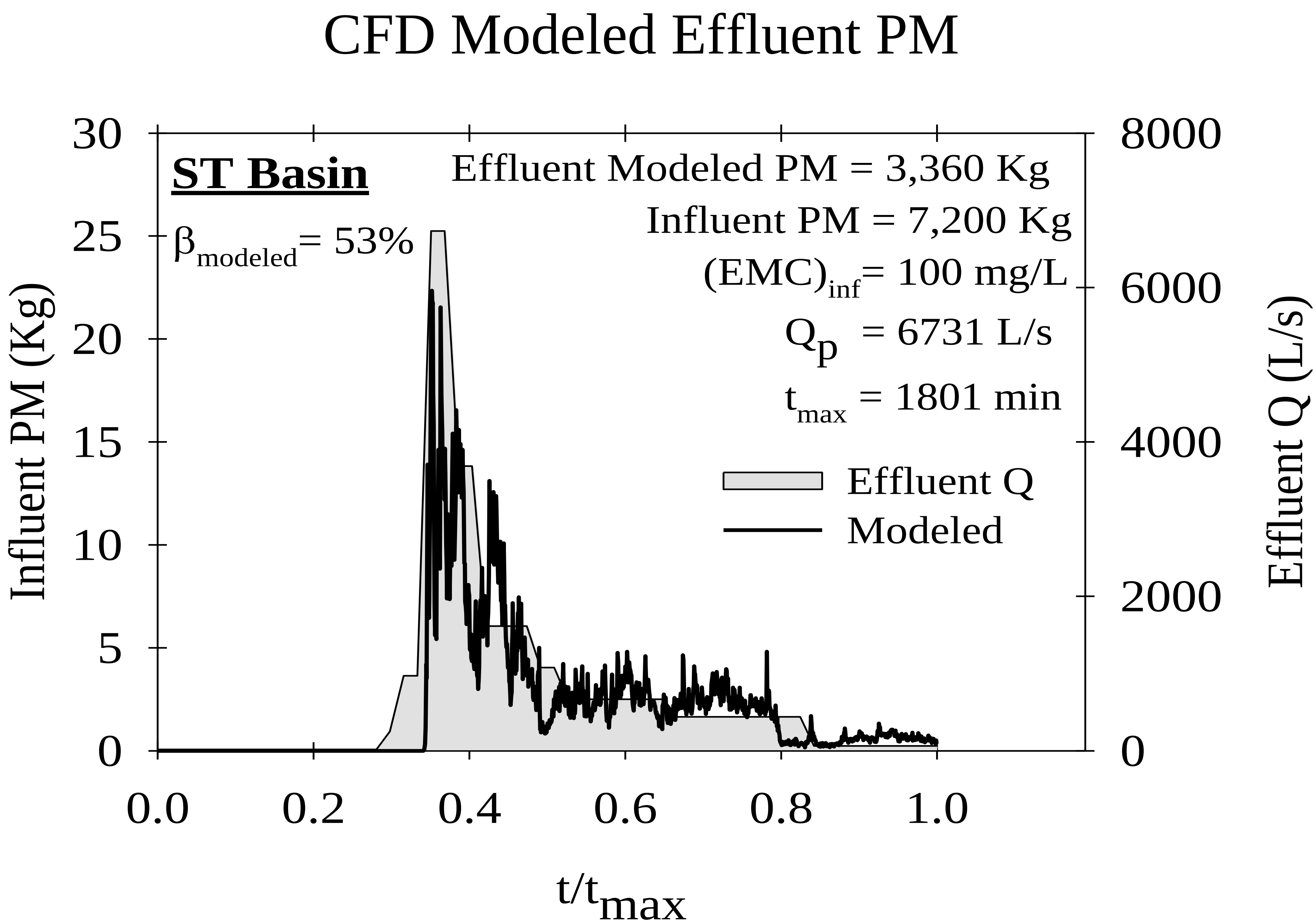
Legend

NCB =	North commercial basin
MB =	Mixing basin
STB =	South treatment basin
I =	Influent
O =	Outlet
S =	Storage

Mesh Generation for ST Basin

- To provide greater resolution in the vicinity of inlet and outlet where higher velocity gradients were anticipated, node spacing was decreased
- Completed mesh comprises approx. 4,000,000 cells (Cell $V_{mean} \approx 12$ L)

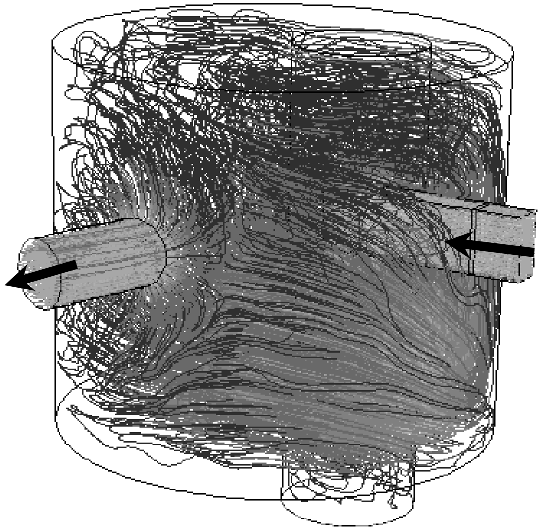




CFD Modeled Effluent PM
ST Basin
βmodeled= 53%
Effluent Modeled PM = 3,360 Kg
Influent PM = 7,200 Kg
(EMC)inf= 100 mg/L
Qp = 6731 L/s
tmax = 1801 min
Effluent Q
Modeled
Influent PM (Kg)
Effluent Q (L/s)
t/tmax
0
5
10
15
20
25
30
0
2000
4000
6000
8000
0.0
0.2
0.4
0.6
0.8
1.0

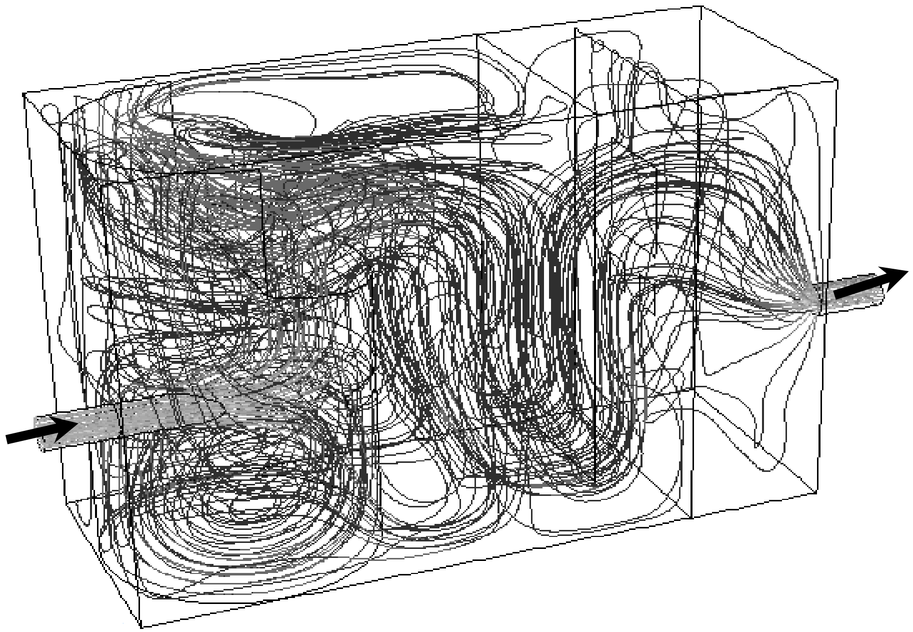
Fluid pathlines at 100% of hydraulic design capacity of differing models of hydrodynamic separators

Unit A

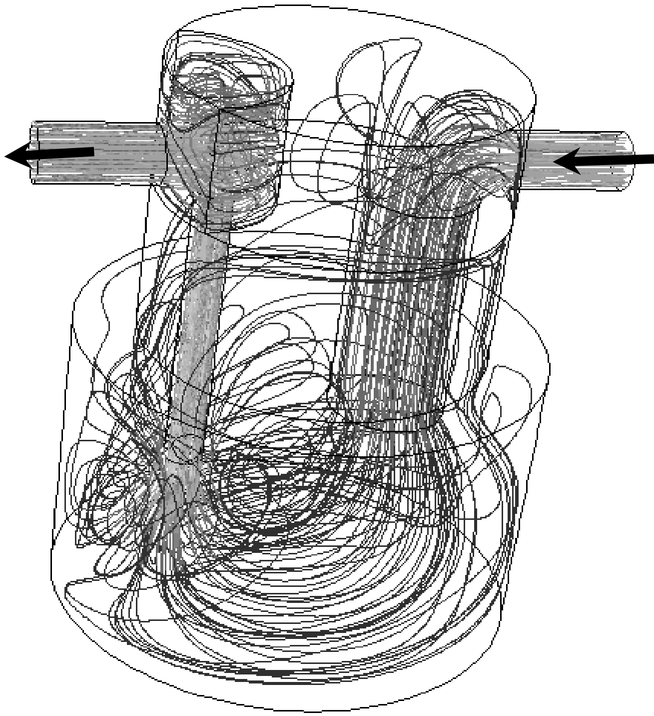


4 configurations of
this screened unit
tested in this study

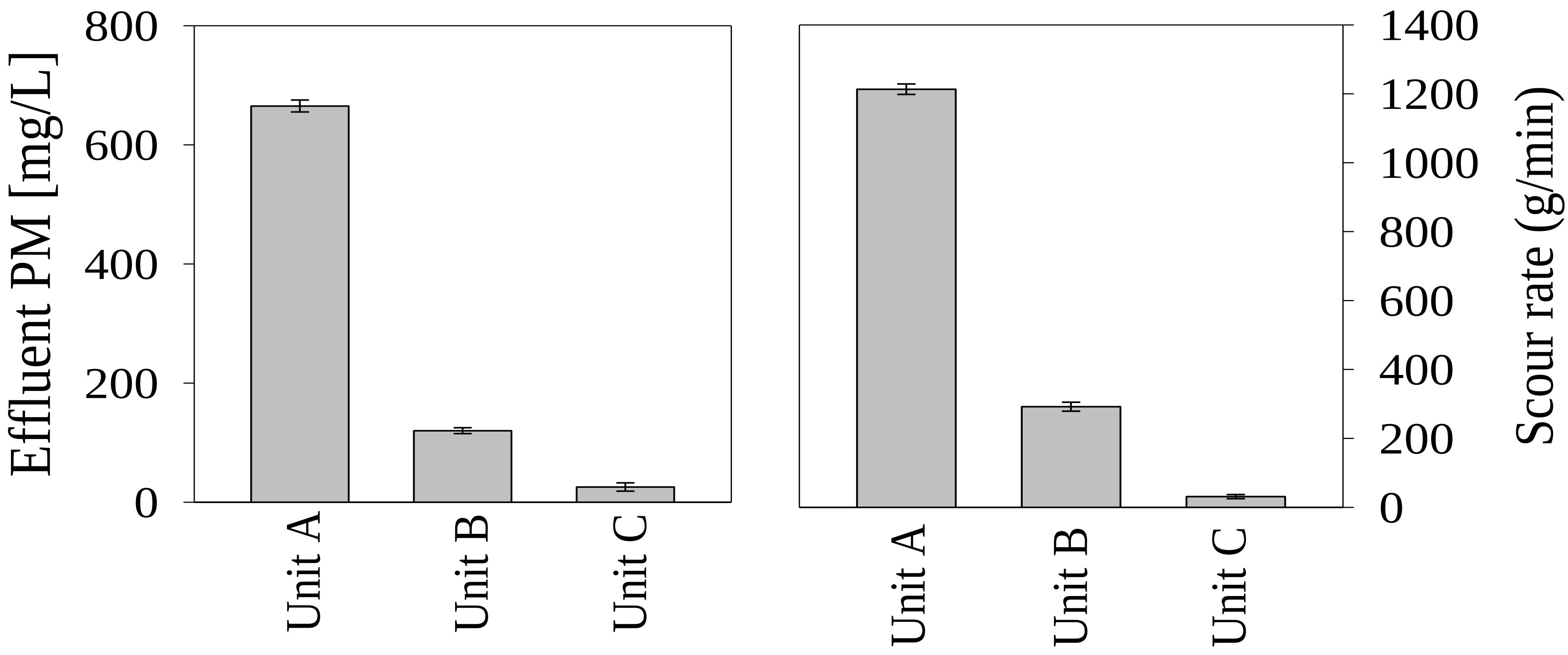
Unit B



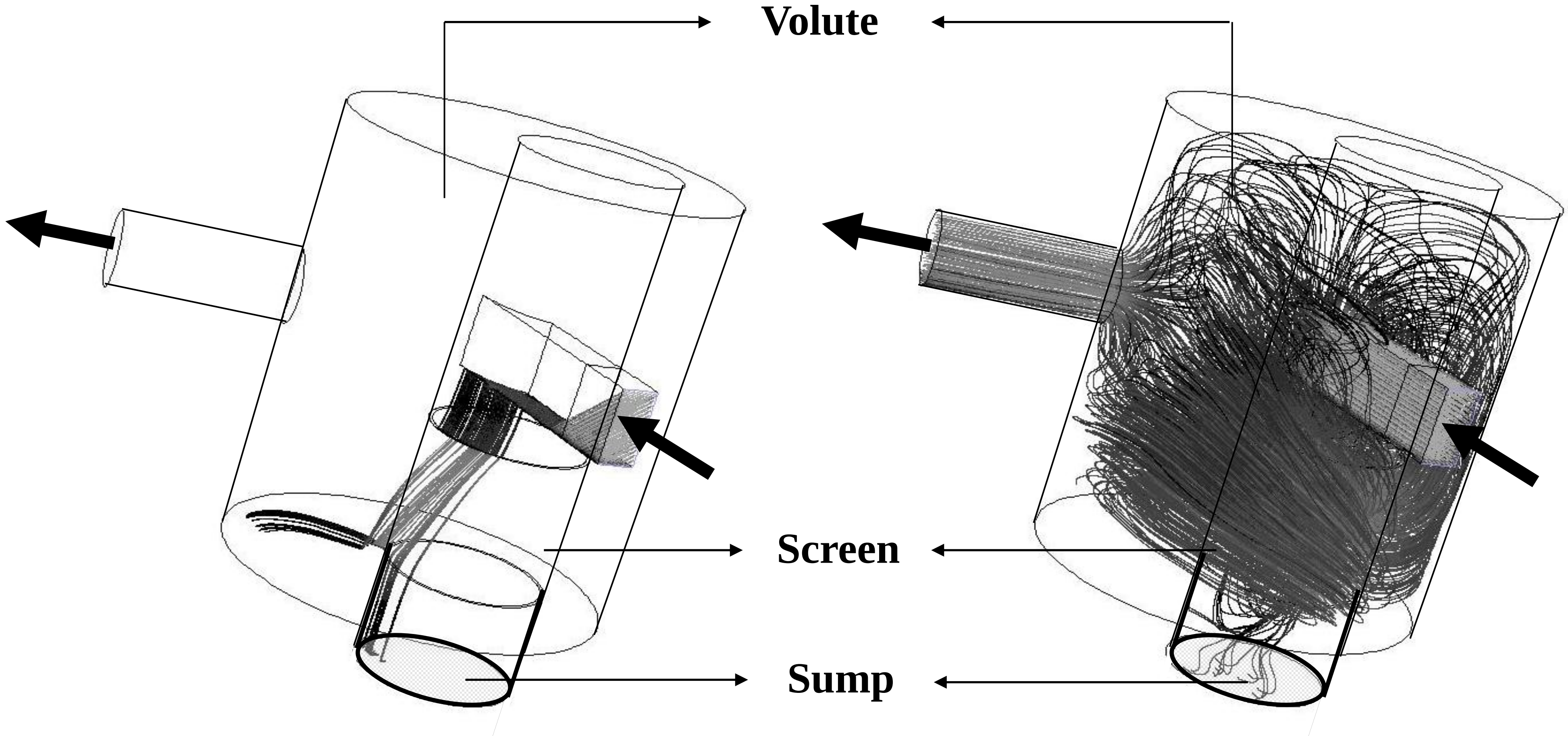
Unit C



Effluent PM and scour rate for hydrodynamic units (50% of PM capacity, 100% of design flow)



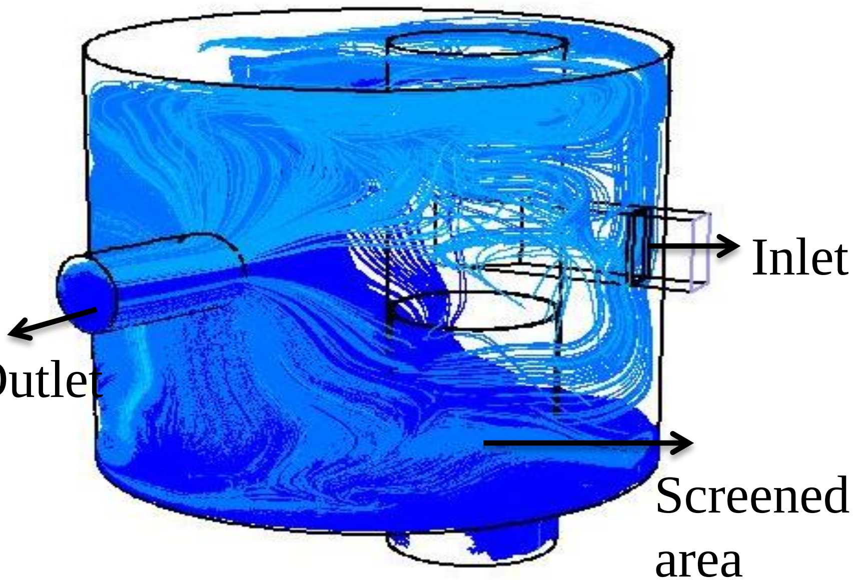
Tracking Particle Trajectories in the Screened Hydrodynamic Separator utilizing CFD

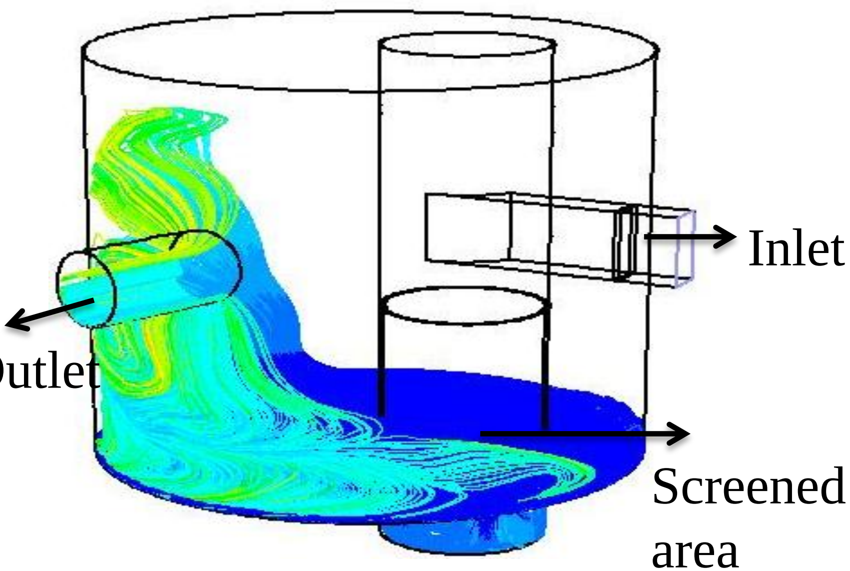


d_p = 450 μm
ρ_p = 2.63 g/cm^3

d_p = 25 μm
ρ_p = 2.63 g/cm^3

Screened HS washout of PM (Q_d = 31.2 L/s)





1. PM washout from hydrodynamic separator (HS) units is modeled with CFD, using FVM, a standard k-ε turbulence model and a Lagrangian DPM to track individual particles.
2. CFD models are physically validated for PM concentration, mass and PSDs with less than 10% of RPD.
3. Results indicate a significant washout from the HS unit; in the **suspended and settleable fractions and to some degree for sediment-size PM**.

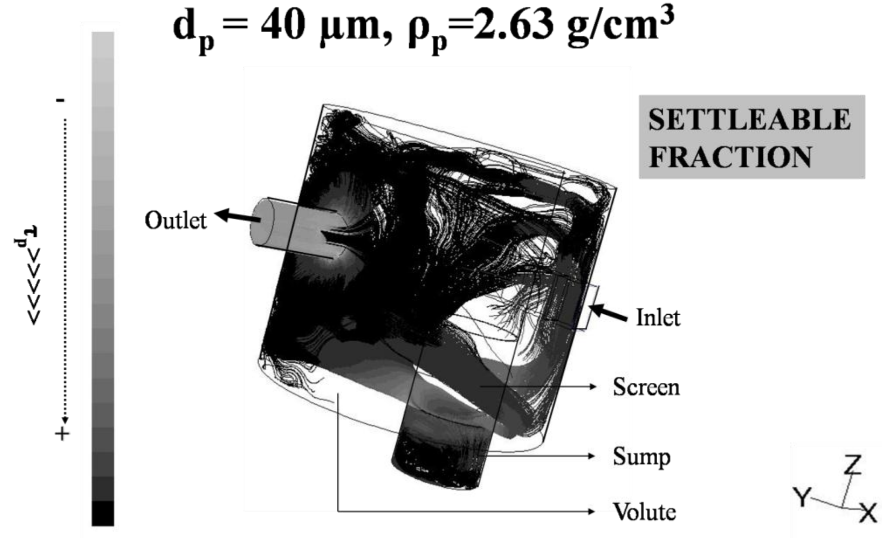
Washout PM Trajectory:

(Top figure)	*(Bottom figure)*
d_p = 25 µm	d_p = 75 µm
ρ_p = 2.63 g/cm^3	ρ_p = 2.63 g/cm^3
PM = 2607.1 mg/L	PM = 581.3 mg/L

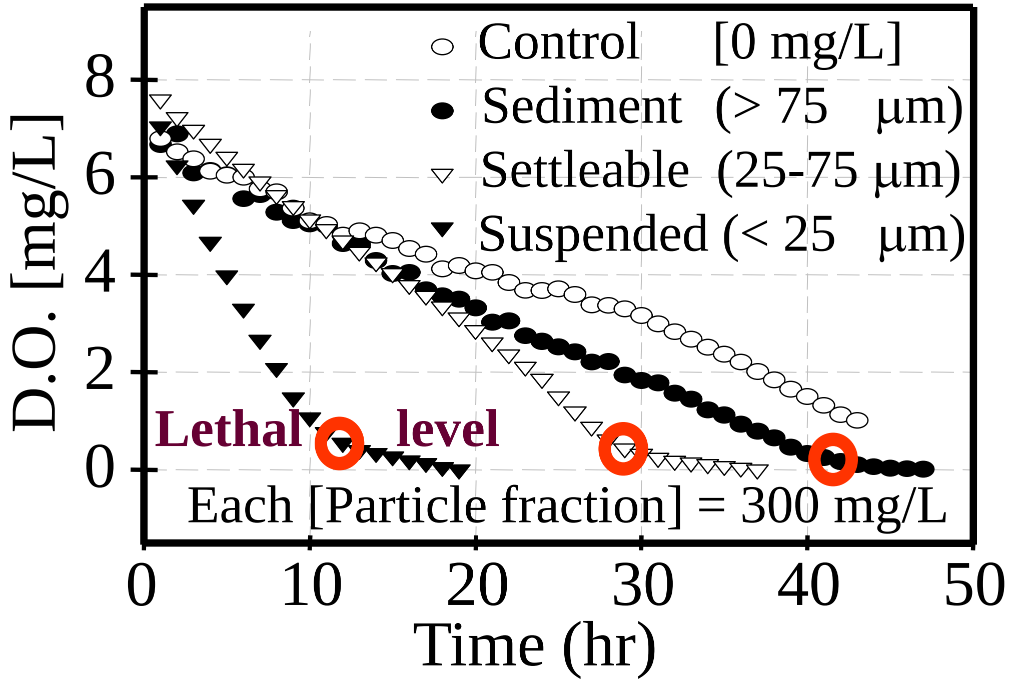
Maintenance, PM and chemical inventories: Currently the "Achilles Heel" of BMP, LID and runoff conveyance components

- The photo is a clogged stormwater catch basin inlet grate on steep slope of NW 22nd Street (Gainesville, FL)
- The challenge of microbial vectors, long-term chemical legacy, leaching, scour and clogging. How does MS4 monitor viability of hundreds of such BMPs in an MS4 or County ?

Scoured Particle Trajectories
d_p = 40 μm, ρ_p=2.63 g/cm^3



Lethality Effect Of Particles On Fathead Minnows



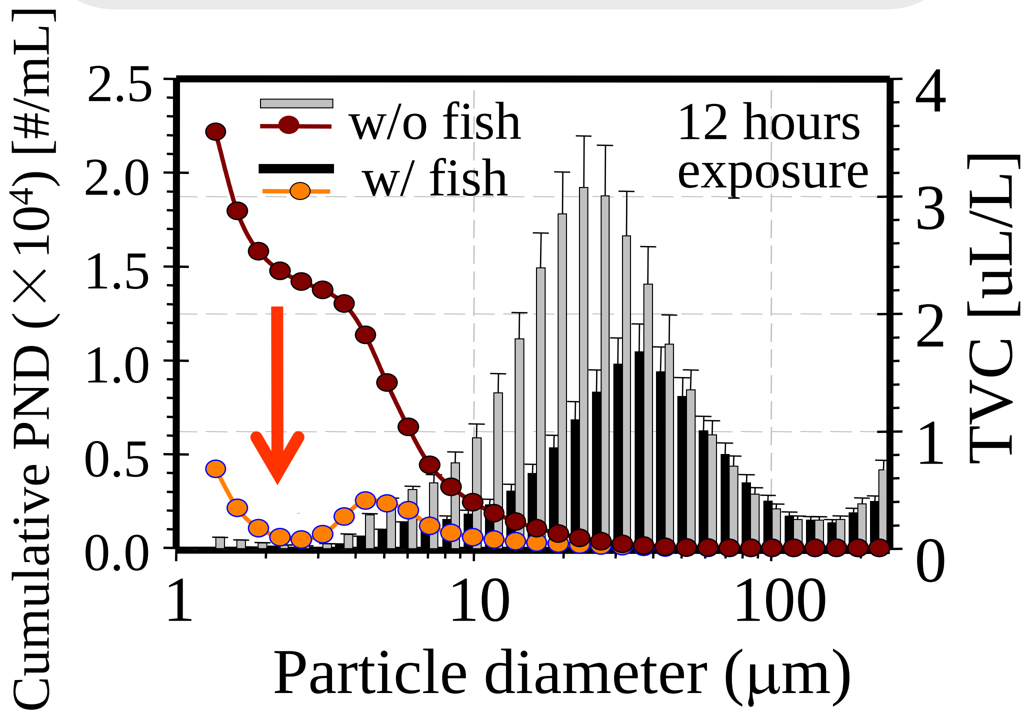
Oxygen consumption rate: mg/(g-hr)

- Amount of dissolved oxygen (D.O.) consumed in 1 hour based on the unit weight of the organism
- Sub-lethal test (gill function)

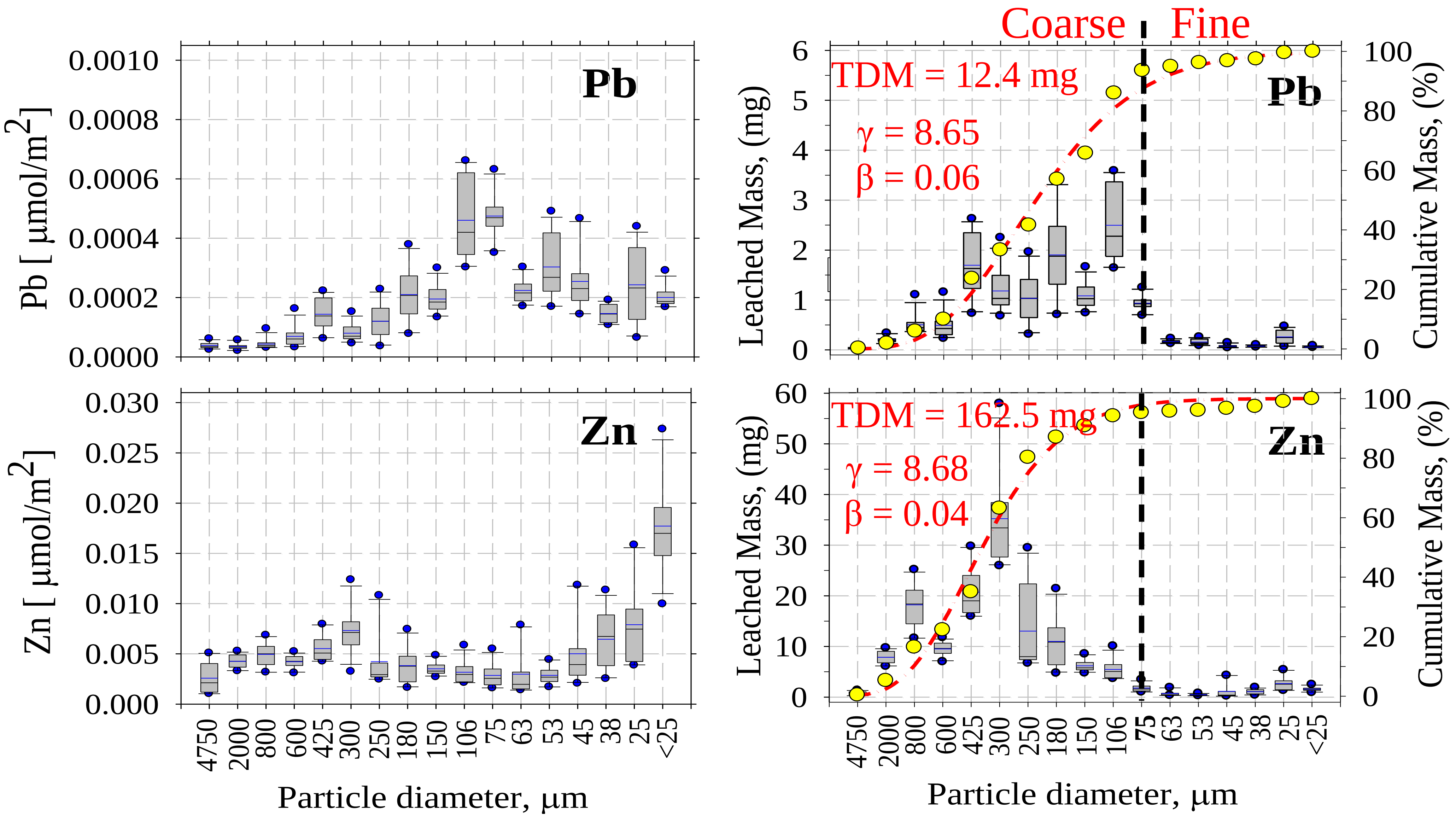
Lethal level:

- D.O. level at which gill pumping stops

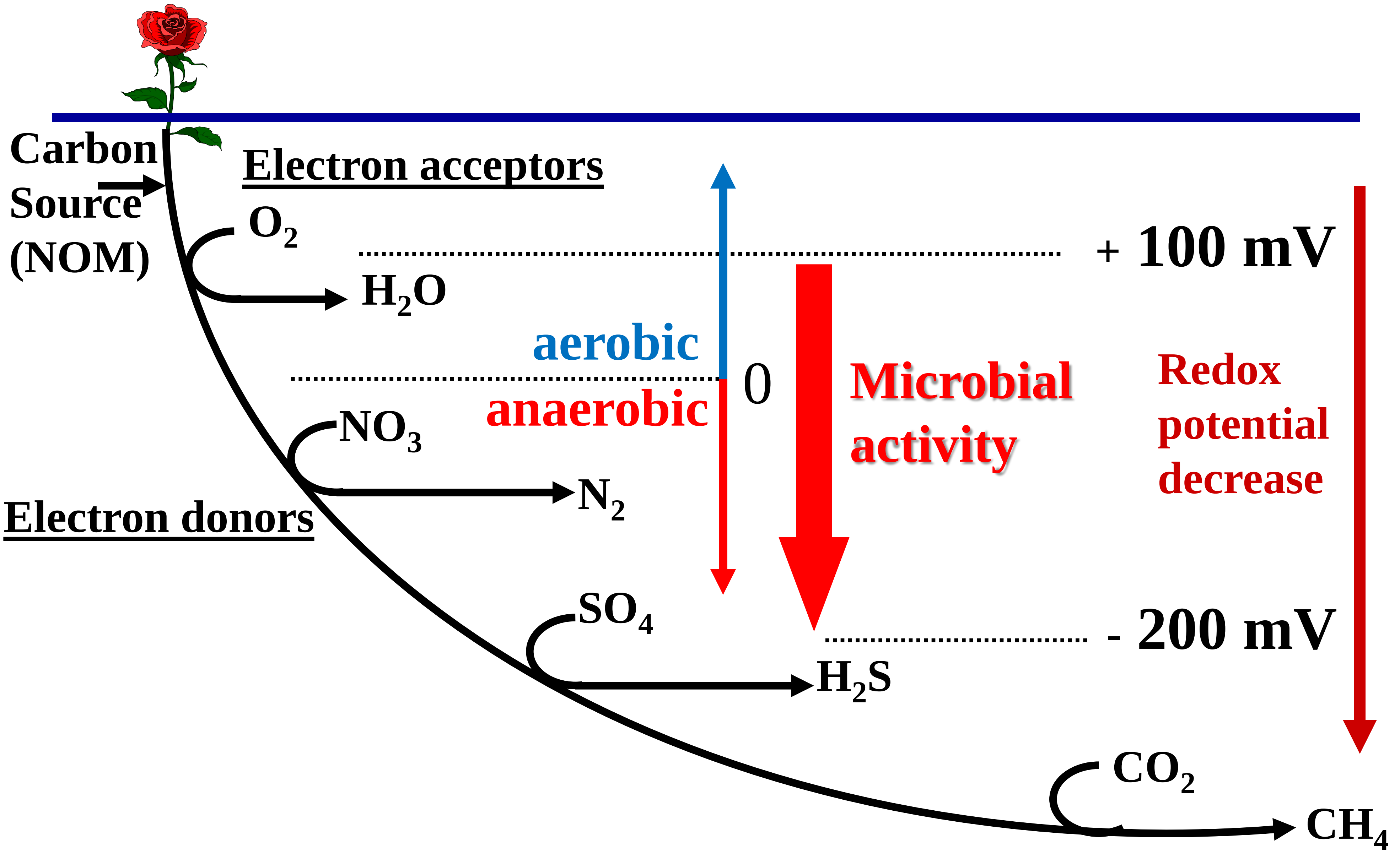
- Suspended particles trapped by gill tissue
- Settleable and sediment particles have a significantly lower effect on gill function
- Level of lethality indicated on time axis at the inflection point of each D.O.- time curve. The control generated no lethality.



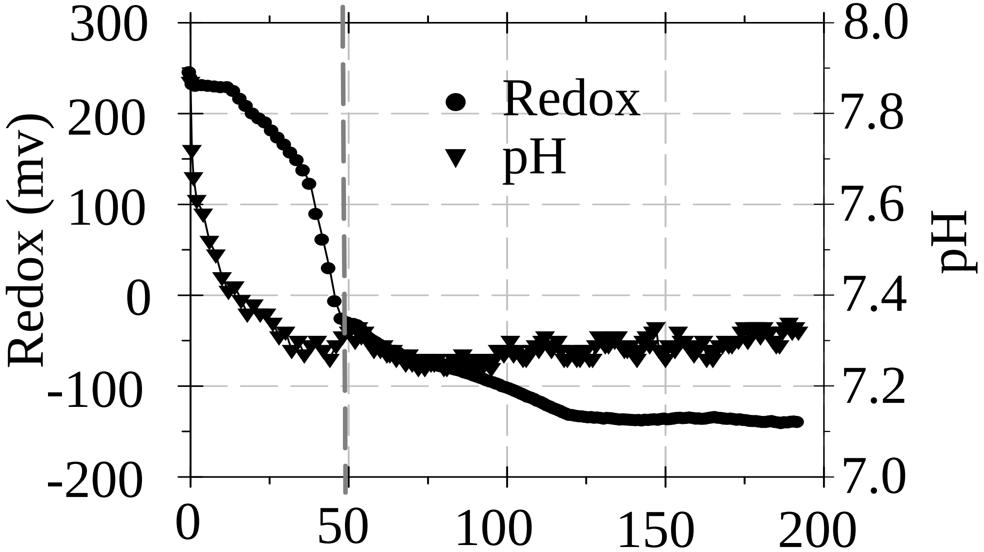
Distribution of Pb and Zn Leached from Coarse PM Separated by BMPs that are not Maintained Frequently

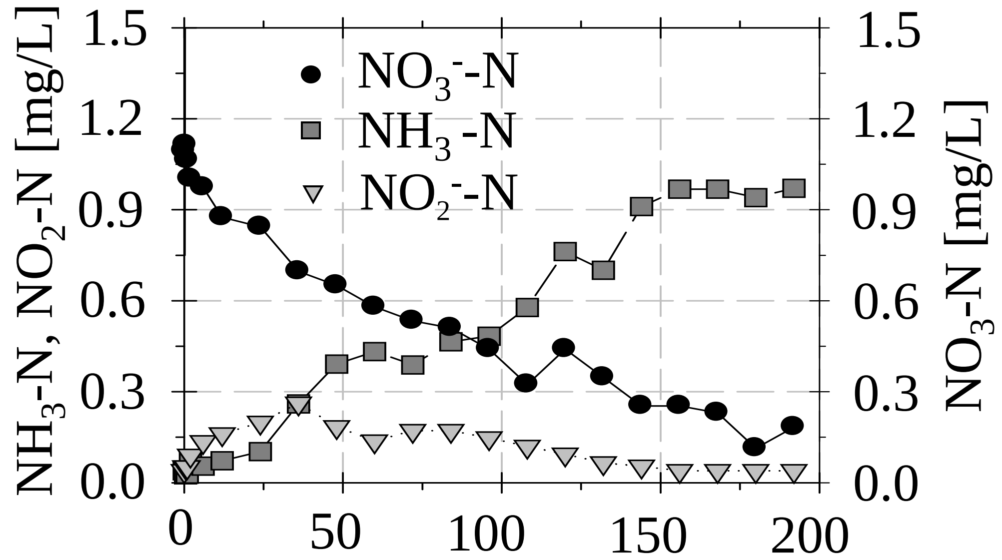


Microbial respiratory processes as a function of redox potential



Redox, pH, N and P Change over Residence Time in BMP



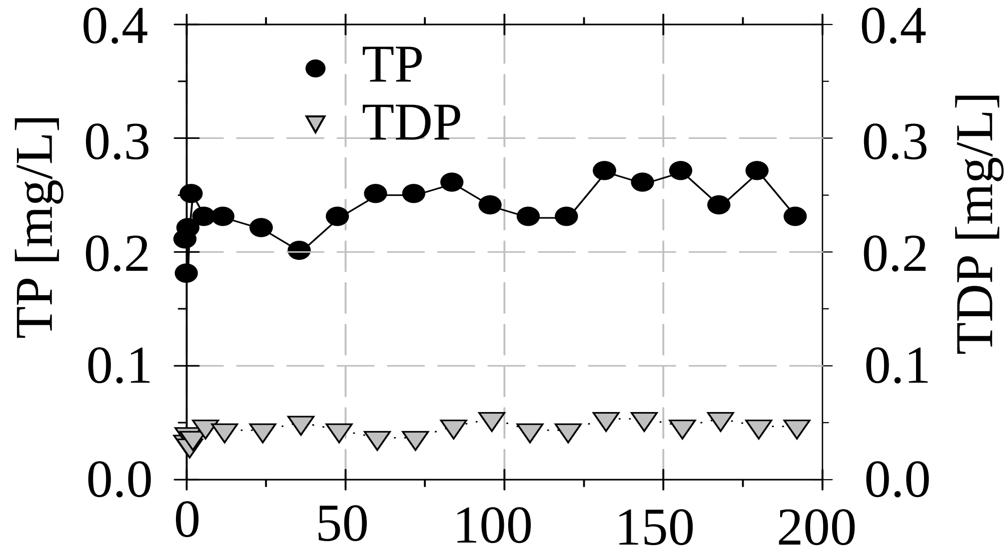


Time 0 represents the cessation of runoff from a rainfall-runoff event to a BMP

Redox significantly drop in 48 hrs residence time after 15 hrs acclimation

Transformation to anoxic/anaerobic condition for UOPs with extended periods of residence time

Nitrogen species tend to be more toxic in terms of ammonia and nitrite



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

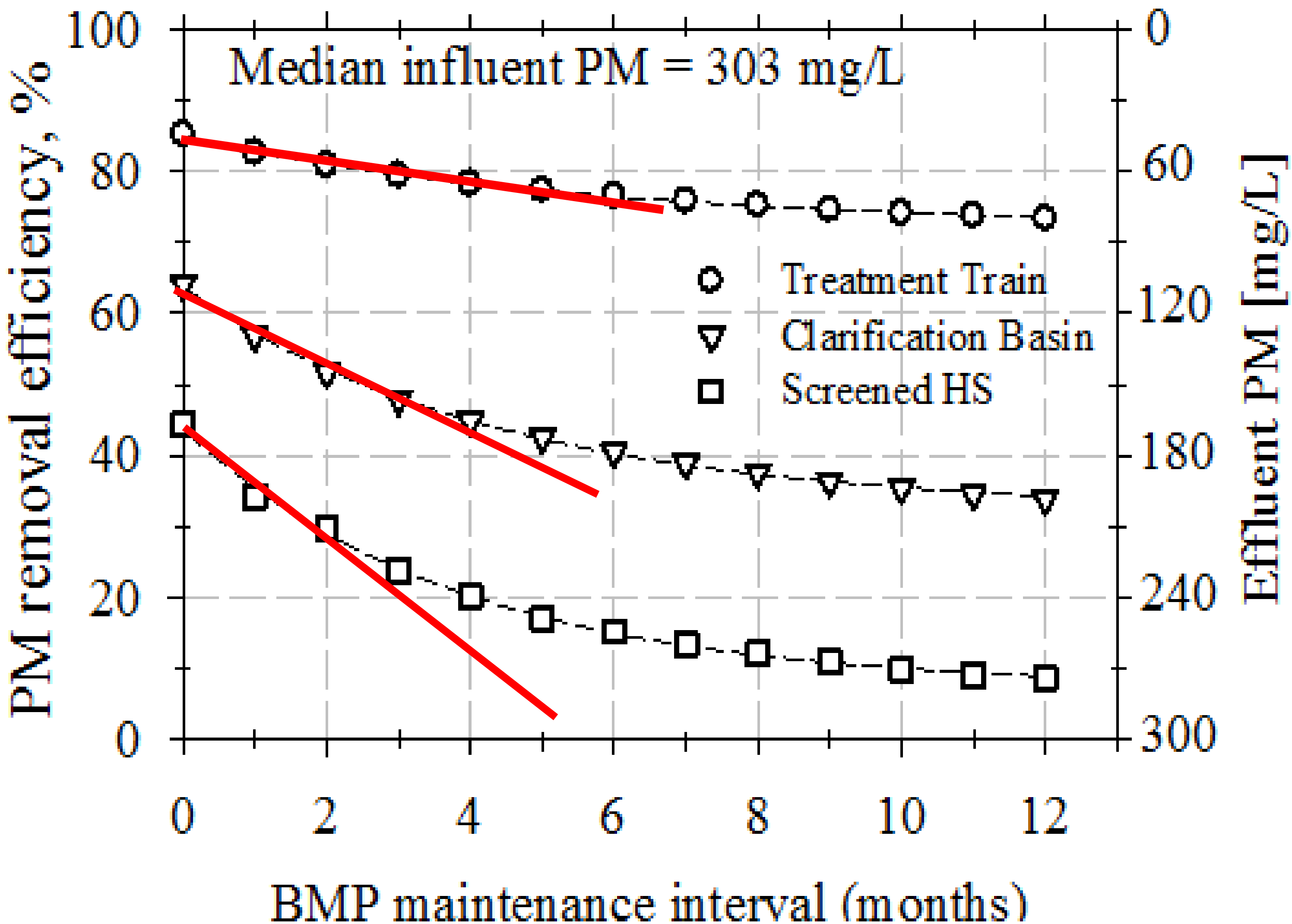
Clarification Basin:

- 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



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 ***based on clean sump conditions***

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

NNC Load Models and Treatment

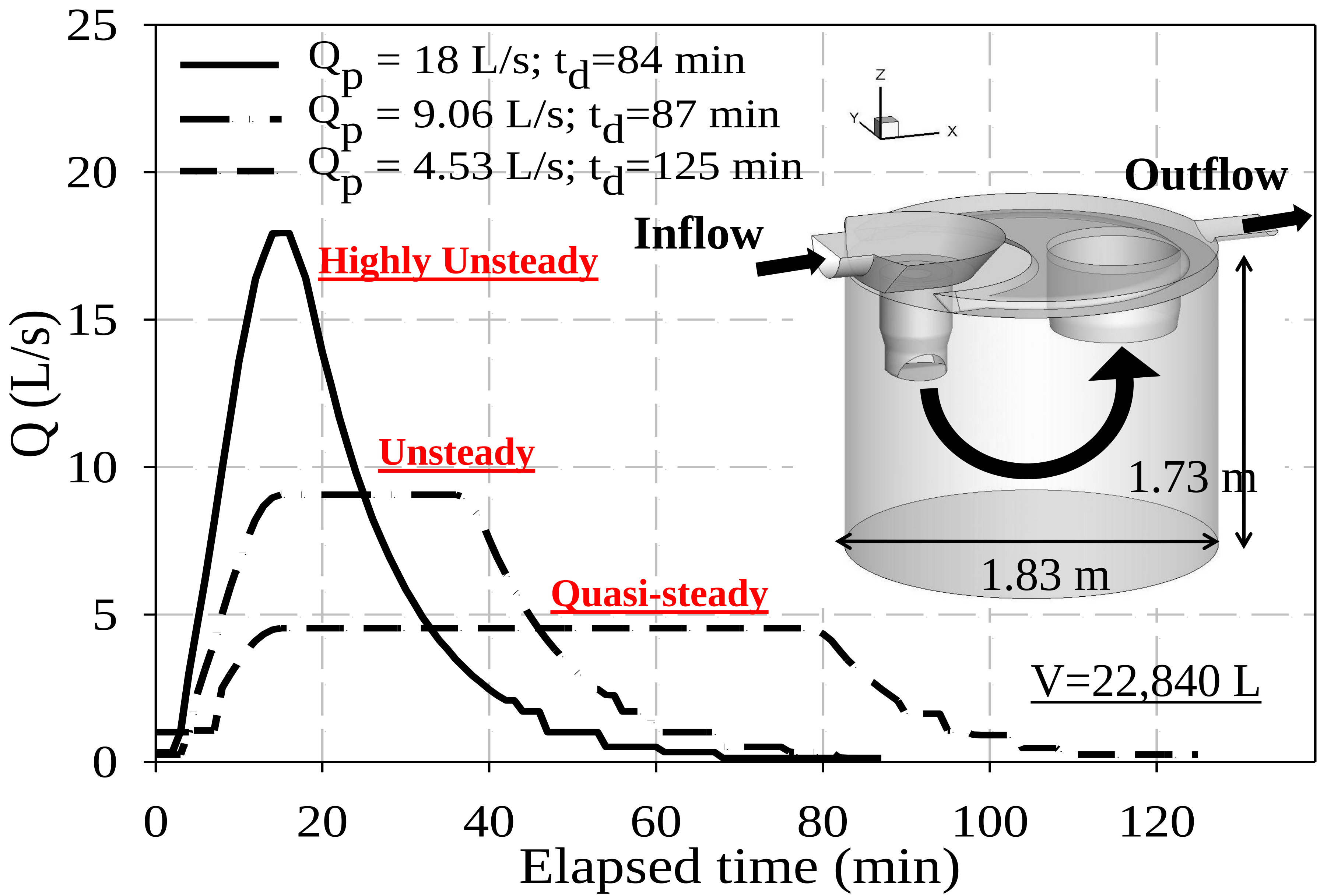
1. As opposed to black-box BMPs approaches that simply monitor in vs. out as an EMC, continuous simulation models (i.e. SWMM) and CFD are required to ensure watershed-based hydrologic restoration as well as transport and fate tools for PM and nutrients.

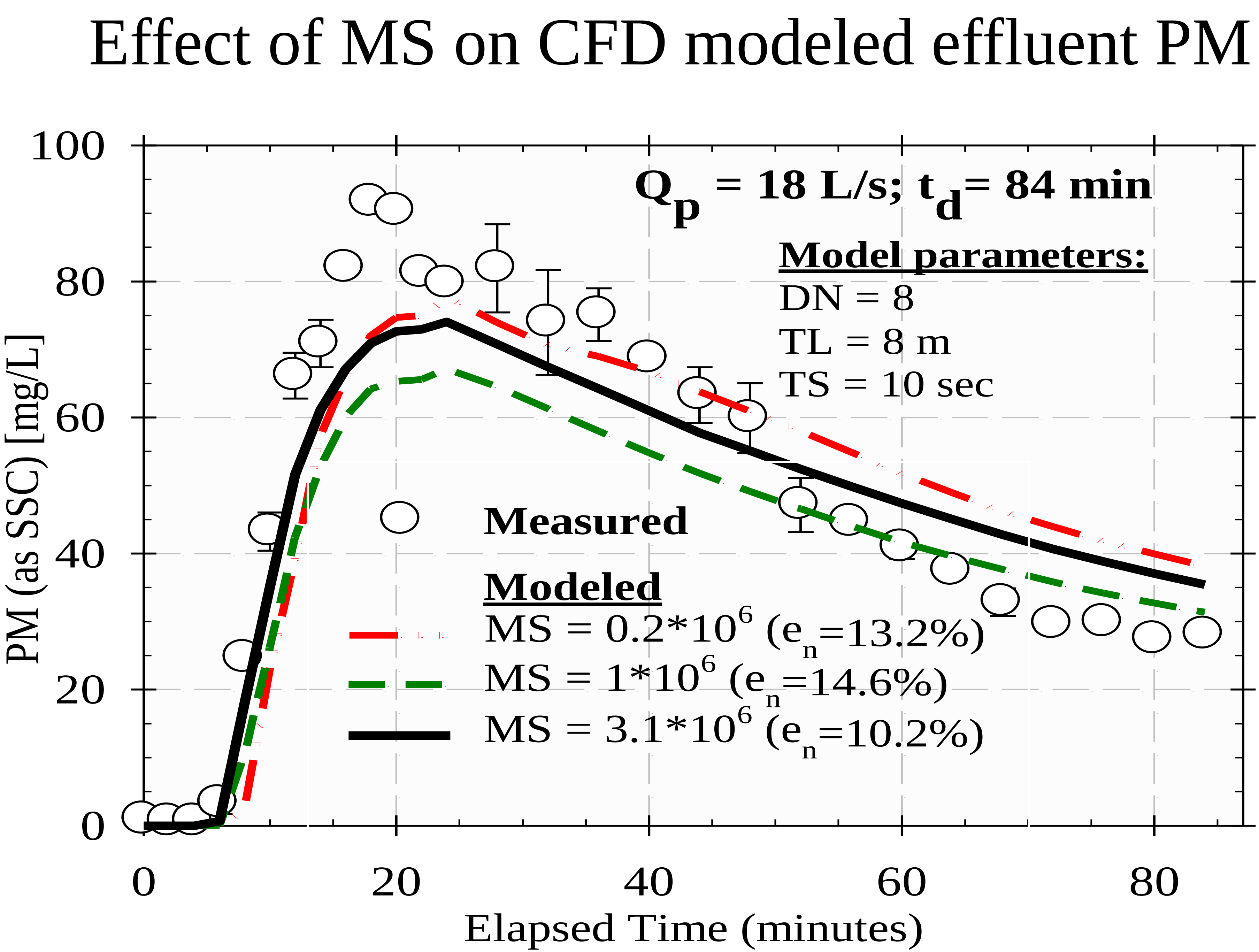
2. The current deployment of "BMPs" for example screened hydrodynamic separators and the plethora of black box BMPs that are not maintained are not sustainable, are not economical, and serve as temporary sources of PM and chemicals as opposed to sinks; this finding is not a new finding.

3. Sustainability will require practices such as engineered biodetention and retention, cementitious permeable pavement (CPP) or <u>engineered</u> treatment systems such as engineered adsorptive media/soil filters and source control.

4. Models without validation data can be hydro-fantasy. Data without modeling and mechanistic guidance is a very inefficient use of resources.

Modeling/Measuring Runoff Loadings Hydrodynamics





Effect of MS on CFD modeled effluent PM
Qp = 18 L/s; td= 84 min
Model parameters:
DN = 8
TL = 8 m
TS = 10 sec
Measured
Modeled
MS = 0.2*10^6 (en=13.2%)
MS = 1*10^6 (en=14.6%)
MS = 3.1*10^6 (en=10.2%)
PM (as SSC) [mg/L]
Elapsed Time (minutes)
0
20
40
60
80
100