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 from watershed to molecular; temporal scales from seconds to years. An overview and case study are presented.
The “first-flush” misconception

• The pollutant first-flush or water quality volume (WQV) for urban watersheds is challenged by a complex reality

• As smaller source area catchments of differing times of concentration combine into more complex and larger urban watersheds, a pollutant first-flush is greatly diminished to non-existent
First Flush: Intuitive Misconception vs. Reality

**Concept:** 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*)

**Reality:** “First-flush” delivery can be proportionate delivery (flow-limited), may not be initial, and is dependent on: method of measurement, the goal, the constituent phase, the geometry of the watershed, location in the watershed; and is never known a-priori. WITH WASTEWATER REUSE, FIRST FLUSH REGULATIONS ARE DATED
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?

- \( C/C_{\text{max}}, M/M_{\text{max}} \) and \( Q/Q_{\text{max}} \)

- \( M(t) \): Mass (SSC)  
  \[ M_{\text{max}} = 41,460 \text{ mg} \]

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

- \( Q \): Flow  
  \[ Q_{\text{max}} = 244 \text{ L/minute} \]

SSC: suspended sediment concentration

- 300 m² paved source area urban catchment

- In part, acute toxicity is associated with concentration and time; chronic toxicity with mass and time
Mass Transport Patterns: Differentiation Criteria

**First-order mass depletion**  
Mass-limited, ML

\[
\frac{dM}{dt} = -KM \\
K = k_1Q
\]

\[\Delta M_t = M_0 \left(1 - e^{-k_1 V_t}\right)\]

**Zero-order mass depletion**  
Flow-limited, FL

\[
\frac{dM}{dt} = -K \\
K = k_0Q
\]

\[\Delta M_t = k_0 V_t\]

*Motivation*: High correlation between \( \Delta M_t \) and \( V_t \).

*Assumption*: Mass depletion = Mass delivered.

- PM mass depletion is generally first-order but with k-values that are a function of PM size.
- Dissolved mass depletion is generally zero-order but depends on partitioning kinetics with PM.

\( \Delta M_t \): cumulative mass delivered [M];  
\( V_t \): cumulative volume [L^3];  
\( M_0 \): constituent mass on the surface at the beginning of the rainfall-runoff event [M]; (difficult to measure, now can be estimated)  
\( k_1 \): *first-order* coefficient [L^{-3}].  
\( k_0 \): *zero-order* coefficient [ML^{-3}].  
\( M \): instantaneous mass remaining on the watershed surface (M);  
\( K \): transport rate coefficient.
The “automated sampling” misconception

- **Representative monitoring is one of the most challenging aspects of stormwater science**

- **The complex reality of stochastic storm arrival times, highly unsteady flows and complex, heterogeneous-heterodisperse pollutant transport and fate results in a very challenging condition for representative sampling**
The Need and Challenge of Representative Sampling

**Automatic (Automated) Sampling:**
- Standard North American practice for stormwater EMCs
- Adopted from wastewater sampling without modification to account for significant storm and wastewater differences
- Inaccurate and non-representative for stormwater loads !!!
- Reduces labor and decision-making; equipment costly
- Compromised by lack of real-time intelligence to balance sample timing and #, while capturing entire storm duration!

**Manual Sampling:**
- Accurate and representative, allows for material balances
- Labor and intelligence intensive, not convenient or common
- Provides real-time flexibility and decision-making throughout the entire storm to balance sample timing and #
- Coupled with real-time radar imagery and geo-referencing to match sampling with spatial and temporal storm scales
- Allows significantly reduced sample holding times- critical!
Example: Automatic Sampler Liability on Storm Basis Liability for treatment evaluations, load assessment, maintenance

PM (as suspended sediment concentration, SSC) [mg/L]

(1) Untreated Stormwater Influent

(3) Secondary Effluent (after filtration)

Manual composite
Automatic sampler composite

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400 410 420 430 440 450 460 470 480 490 500 510 520 530 540 550 560 570 580 590 600

0 100 200 300 400 500 600

Manual
Automatic

299 237

33 34

Primary sedimentation
Filtration
Parameters for Uncontrolled (Field) Physical and Numerical Modeling of a Control Strategy

1. Watershed: cover, slope, geometry, anthropogenic/biogenic activities …
2. Matching unit operation hydraulic/volumetric capacity to watershed loads
3. Granulometric: PSDs, $\rho_s$, [C], …
4. Rainfall: frequency distributions (embrace variability !!)
5. Hydrodynamics: Q, RTD, regimes, transience, …
6. Sufficient event monitoring for statistical or probabilistic evaluation of unit operations (20 to 25+); examine wrt historical continuous simulations
7. Representative sampling and material balances required (challenging !!)
8. Quantitative impact of O&M (or lack thereof) during campaign
9. Parameter integration for unit operation mathematical modeling
10. A standard regional/national rigorous physical modeling field protocol
Urban Particulate Matter (PM)

- **PM is the predominate urban sink and source of chemicals**
- **Myths regarding PM as only TSS, are historical and inertial**
- **Myth perpetuation 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
- **Representative sampling/analysis is difficult**
- **Particle size distributions (PSD) required for:**
  - modeling PM, solute and microbiological fate
  - load inventories of PM and chemicals
  - urban water cycle and reclaimed water benefits
Partitioning and distribution of mass (example – Cu)

Inorganic or organic mass

Partitioning and distribution of mass (example – Cu)

Dissolved (aqueous) \( f_d \)

Ionic

Complexed

Adsorbed (Particulate-Bound) \( f_p \)

Colloidal

Suspended

Settleable

Sediment - Floatable

Poorly sampled and often ignored

\[ \text{Particle diameter (\( \mu \text{m} \))} \]

\[ \text{Concentration (%)} \]

\[ \text{Cumulative (%)} \]

\[ \text{mg Cu} \]

\[ \text{Time} \]

\[ \text{Particulate-Bound} \]

\[ \text{Suspended} \]

\[ \text{Settleable} \]

\[ \text{Sediment - Floatable} \]
Total surface area (SSA) of urban PM

Log normal distribution function

\[ SA = SA_0 + r \cdot e \]

\[ \frac{[-0.5 \cdot (\ln(d) - \ln(d_0))^2]}{t} = 1187 + 12895 \cdot e \]
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

Lethality of PM Fractions on Fathead Minnows

Particle diameter (µm)
- 1
- 10
- 100

Time (hr)
- 0
- 10
- 20
- 30
- 40
- 50

D.O. [mg/L]
- 0
- 2
- 4
- 6
- 8

Control [0 mg/L]
- Sediment (> 75 µm)
- Settleable (25-75 µm)
- Suspended (< 25 µm)

Lethal level
Each [Particle fraction] = 300 mg/L

Cumulative PND (×10^4) [#/mL]
- 0
- 0.5
- 1.0
- 1.5
- 2.0
- 2.5
- 3.0
- 3.5
- 4.0

w/o fish
- 12 hours exposure

w/ fish
TVC [µL/L]
- 0
- 1
- 2
- 3
- 4

Particle diameter (µm)
- 1
- 10
- 100

- 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 PM Separated by “BMPs”

[Graphs and data showing the distribution of Pb and Zn leached from PM separated by particle diameter.]

*Pb* leached mass (mg) vs. cumulative mass (%), Particle diameter (µm)

- **Pb** leached mass vs. cumulative mass
  - TDM = 12.4 mg
  - \( \gamma = 8.65 \)
  - \( \beta = 0.06 \)

*Zn* leached mass (mg) vs. cumulative mass (%), Particle diameter (µm)

- **Zn** leached mass vs. cumulative mass
  - TDM = 162.5 mg
  - \( \gamma = 8.68 \)
  - \( \beta = 0.04 \)
Modeling watershed & unit processes as building blocks (i.e.: Unit hydrograph and pollutograph for hydrologic functional units)

Site, Event Parameters:
- Paved, 2% slope
- Traffic loadings
- \( Q_p = 244 \text{ L/min.} \)
- \( t_{\text{max.}} = 68 \text{ min.} \)
- \( V = 2794 \text{ L} \)
- \( \text{PM} = .258 \text{ kg} \)

Calibrated Site IUH:
- \( k = 4.02, n = 0.66 \)

Calibrated Site IUP (PM):
- \( B = 0.29 \text{ min}^{-1} \)
- \((NS) R^2 = 0.93\)
Median Settling Velocities of Particles (Type I: Discrete Settling)

Particle Diameter, $D$ ($\mu$m)

<table>
<thead>
<tr>
<th>$D$ ($\mu$m)</th>
<th>1 10 100 1000 10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Settling Velocity, $V_s$ (mm/s)</td>
<td>0.001 0.01 0.1 1 10</td>
</tr>
</tbody>
</table>

Temp. : 24.5 $\pm$ 0.2 °C

SSC : 130 $\pm$ 5 mg/L

$\rho_s$ : 2.50 $\pm$ 0.06 g/cm$^3$

Newton, I., *Principia*, 1687:

\[
v_t = \left[ \frac{4 g (\rho_s - \rho) d}{3 C_D \rho} \right]^{1/2}
\]

\[
C_D = \frac{24}{\text{Re}_D} + \frac{3}{\sqrt{\text{Re}_D}} + 0.44
\]

1 ppt

10 ppt

20 ppt

1 ppt model

10 ppt model

20 ppt model
Particle Size Modification by Urban Conveyance System: Choice and location of a unit operation will influence treatment behavior

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

\[ F(D) = \frac{\Gamma_D(\gamma)}{\Gamma(\gamma)} \]

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

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

<table>
<thead>
<tr>
<th>Location</th>
<th>((\gamma, \beta))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Deposition</td>
<td>(2.06, 187.7)</td>
</tr>
<tr>
<td>q (up)</td>
<td>(1.90, 61.9)</td>
</tr>
<tr>
<td>q (down)</td>
<td>(1.23, 23.6)</td>
</tr>
<tr>
<td>q (settled)</td>
<td>(1.51, 11.1)</td>
</tr>
</tbody>
</table>

\begin{tabular}{|c|c|c|c|c|}
\hline
\textbf{DD} & \textbf{Dry Deposition} & \textbf{q (up)} & \textbf{q (down)} & \textbf{q (settled)} \\
\hline
\textbf{D}_{50m}, \mu m & 330.7 & 98.6 & 22.6 & 13.7 \\
\hline
\end{tabular}
Che cosa è CFD?
CFD Processes (in this case, Navier-Stokes (N-S) Equations applied)

\[ \int \text{Equations}(N - S) \]

- Integral equations
- Discretization-Finite Volume Method
- Algebraic equations

Initial Value of \( \Phi \)
- \( \int \text{Continuity} \)
- \( u \rightarrow X \) momentum
- \( v \rightarrow Y \) momentum
- \( w \rightarrow Z \) momentum

Grid generation
- Meshing
- Initialization
- Define boundary conditions

Model:
- Continuous phase \( k-\varepsilon \), (Eulerian)
- Particulate phase (Lagrangian)

Numerical solver

Grid Convergence, Solver Convergence, Consistency and Stability

Solution for flow field, velocity, fluxes, etc
Influent PM = 200 mg/L
PSD: Hetero-disperse
(#8: $\kappa = 0.56$, $\lambda = 353.16$)

Mean RPD: 6.5%

Influent PSD: Hetero-disperse
(#8: $\kappa = 0.56$, $\lambda = 353.16$)

Mean RPD: 4.6% (100 mg/L)
4.1% (300 mg/L)
The Problem of Discretization (the DPM)

Continuous Distribution

Increasing diameter

Discrete Representative Particles

DPM CFD Model

\[
\frac{dv_{p_i}}{dt} = F_{D,i}(v_i - v_{p,i}) + \frac{g_i(\rho_p - \rho)}{\rho_p} + F_i
\]

\[
F_{D,i} = \frac{18 \mu C_{D,i} \text{Re}_i}{\rho_p d_p^2} \frac{24}{24}
\]

\[
\text{Re}_i \overset{\text{def}}{=} \frac{\rho d_p |v_{p,i} - v_i|}{\mu}
\]

\[
C_{D,i} = \frac{K_1}{\text{Re}_i} + \frac{K_2}{\text{Re}_i^2} + K_3
\]

Computational overhead

Increasing particles →
Error reduction (as RPD) as f (DN) for settling unit loaded by a PSD w/d$_{50m} = 67 \mu$m. TSS introduces large errors

(a) Monodisperse
(b) Medium uniformity
(c) Heterodisperse (dominant case)

d$_{50m} = 66.7 \mu$m
Differential HS Behavior in PSD-Q Space
Maintenance and pollutant inventories: The “Achilles Heel” of Control Strategies, LID and stormwater conveyance components

• The photo is a clogged stormwater catch basin inlet grate on steep slope of NW 22\textsuperscript{nd} Street (Gainesville, FL)

• The challenge of microbiological vectors, long-term contaminant legacy, leaching, scour and clogging. How does MS4 monitor viability and maintenance of hundreds of such BMPs in an MS4 or County?

Scoured Particle Trajectories
\[ d_p = 40 \ \mu m, \ \rho_p = 2.63 \ g/cm^3 \]
Annualized Cost ($)/Pound for Pollutant Load Recovery (compared to pollutant separation by “BMPs”)

<table>
<thead>
<tr>
<th>Separation or Recovery Method</th>
<th>Cost ($/lb)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Separation: BMP Treatment Train(^a)</td>
<td>743</td>
<td>25,900</td>
<td>45</td>
</tr>
<tr>
<td>Separation: FL Database for BMPs(^b)</td>
<td>1,900</td>
<td>10,500</td>
<td>41</td>
</tr>
<tr>
<td>Separation: Cementitious Permeable Pavement (CPP)</td>
<td>327</td>
<td>9,550</td>
<td>10</td>
</tr>
<tr>
<td>Recovery: Street Sweeping</td>
<td>pending</td>
<td>pending</td>
<td>4</td>
</tr>
<tr>
<td>Recovery: Catch Basin Cleaning</td>
<td>pending</td>
<td>pending</td>
<td>19</td>
</tr>
</tbody>
</table>

\(^a\)Wet basin sedimentation followed by filtration
\(^b\)TMDL database for FL Best Management Practices, 2009

The conclusion is that maintenance practices can be significantly more economical than “BMPs”. However, such maintenance addresses only constituent load recovery and not hydrologic restoration, unless maintenance is combined with quantitative SUD/LID materials and models.
Infiltration, Filtration, Biofiltration: Indirect Reuse

- All systems and media are not created equal, in fact systems and media can behave very differently but we have the tools to evaluate and create the building blocks for models, monitoring and maintenance
10 yrs of Rainfall Data:
- Historical rainfall only
- August 1999 – January 2009
- "Pristine Conditions"
- North Central Florida
P, N and PM comparison between watershed studies with surface parking cover conditions (Gainesville, FL watershed)

FDEP Numeric Nutrient Criteria Plan, 2009
Nutrient Ecoregion XII Southern Coastal Plain
Existing Catchment Conditions (Post-Development)

**Problem**: Existing condition of raised vegetated islands that drain to impervious asphalt

**Hypothesis**: For given catchment constraints, we can quantitatively demonstrate PM and solute control with green infrastructure and LID.
Existing Post-Development Condition
Catchment Post-Development Hydrologic Cycle

Hydrologic Data:
- 10 yrs of continuous simulation
- Years: 1999 – 2008
- Existing Condition (as of 2009)

Evapotranspiration: 120.96 in.
Depression Storage and Evaporation: 80.94 in.
Infiltrate: 70.10 in.
Surface Runoff: 251.66 in.

Preliminary Data: Pre-development (53.8 in.)
Green Infrastructure Option (Permeable Pavement + BAR)
Cementitious permeable pavement (CPP), as an in-situ material with behavior that can be measured/modeled

Lateral Sheet Flow, $q_{lsf}$

Evaporation

CPP adsorptive-filter design:
- 11 - 15 kN/m$^3$ Unit weight
- 0.1 - 0.005 cm/s $K_{saturated}$ (clean bed)
- 25,000 – 30,000 Kpa Unconfined strength
- 20 - 50 L/min-m$^2$ Surface loading rate

Mix Design Proportions:
- varies Type II Cement
- 380 kg Sand
- 380 kg Pea Gravel
- varies Water
- 10 – 30 % Total porosity
- varies Amphoteric admixture

Unsaturated flow in AOCM media or subgrade
$K_{sat.}$ for media: 0.01 cm/s
Solids & particulates
CPP Pore and Structural Properties (function of mix design)

\[ f_{c}' = 12909(e^{-0.064\phi_t}} \]

PDF, %

CPP pore size, \( d \) (µm)

Mean = 657.7 µm
Std. Dev. = 456.8 µm

Total effective area = 775 mm²

\[ f_s = 0.55(f_{c}')^{0.833} \]

Mean = 657.7 µm
Std. Dev. = 456.8 µm

R² = 0.97
n = 160

fₙ: unconfined compressive strength
fₛ: splitting tensile strength
Filtration mechanisms of CPP
(a pre- or primary unit operation that can be maintained)

Filtration mechanism
\( \frac{d_m}{d_p} \) ratio using mass based
d_{50} of media and particulates

\[ N_T = \alpha \left( \frac{l_i}{R} \right)^{-\beta} \]

The power law function uses cumulative particle number
density (PND) of all particles larger than the reference value R
(i.e. 1 \( \mu m \)).

Surficial Straining
(\( \frac{d_m}{d_p} < 10 \))

Deep-bed Filtration
(10 < \( \frac{d_m}{d_p} < 20 \))

Physical Chemical
(\( \frac{d_m}{d_p} > 20 \))
Event- and Flow-based PM Separation by an Engineered Infiltration System: Permeable Pavement with Filtration Media Subgrade

12 June Event
System Behavior

PM separation efficiency, %

Overland flow, (L/min./meter of length)
Sustainability: Monitoring, Modeling, Maintenance (Phosphorus Adsorption Example: CPP vs. sandy silt soil)

Runoff infiltration to 2-m width of CPP

Runoff infiltration to sandy silt soil

- No breakthrough
- Breakthrough

Time = 0 years
Mass Balance Error:
Solute: 0.06%
Fluid: -0.06%

- Quantitative physical-chemical properties of any unit operation/process system (engineered or natural) are required with monitoring, modeling and maintenance.
- Qualitative approaches to decentralized controls will not permit sustainability.
Redox as a runoff storage in below-grade BMP vault/sump (BMPs contain high microbial activity for electron transfers)

Subsurface Detention Time, (t) (hours)

Oxidation-Reduction Potential [mV]

16 May 2008 (monitored event #2)
08 Oct. 2008 (monitored event #14)

Influent [C] of NO$_3^-$ (Nitrate) [mg/L]

16 May 2008 (monitored event #2)
08 Oct. 2008 (monitored event #14)

$[C] = [C]_0 e^{-k(t)}$

$[C]_0 = 3.81$
$k_0 = 0.0102$
$R^2 = 0.97$

$[C] = [C]_0 e^{-k_1(t)}$

$[C]_0 = 1.51$
$k_1 = 0.0266$
$R^2 = 0.98$
Adsorptive-Filtration Media for Phosphorus (as TDP)

Problem Statement:

1. Most media currently applied to rainfall-runoff treatment is not engineered (sand, perlite, zeolites, GAC …) for runoff solute mass transfer;
2. Most media evaluations utilize surrogate aqueous matrices in comparison to a rainfall-runoff matrix.

Media Matrix:

- **AOCM**  Reactive Aluminum Oxide
  - **AOCM\(^c\)** (clay substrate)
  - **AOCM\(^p\)** (pumice substrate)
  - **AOCM\(^{pcc}\)** (concrete substrate)
- **Z-P-G**  mixture of Zeolite, Perlite and GAC

- (1) Equilibria, (2) kinetics, (3) breakthrough parameterization required for models as illustrated in the next several slides
MnO$_x$ cementitious media surface model

Diffusion Layer

Bulk Solution

OH$^-$

Me$^{2+}$ + OH$^-$ = Me(OH)$_2$

Film layer (high pH)

OH$^-$

OH$^-$

Me$^{2+}$

Me$^{2+}$

MnO

OH$^-$

Me$^{2+}$

Me$^{2+}$

Calcite

Surface

Inner media

(MO)CM
Surrogate Aqueous Matrix:

Temperature: 20 °C;
TDP: 0.05 ~ 50 mg/L (n =7);
pH: 7;
Sorbent/Solution: 0.5 g/ 40 mL;
Ionic strength: 0.01 M
Aqueous matrix: D.I.
Equilibria is dependent on concentration illustrating the invalidity of the P-index

\[ q = \int_0^\infty \frac{C}{b' + C} N(b')db' \]
\[ N(b') = A'(b')^{\frac{1}{p} - 1} \]
\[ q = K_F C^n \]
TDP Kinetics (Potential Driving Model)

Surrogate Aqueous Matrix:
TDP: 1.0 mg/L;
pH: 7;
Ionic strength: 0.01M;
Sorbent/Solution: 20 g/2 L;
SLR: 40 L/min·m²;
Aqueous matrix: D.I.

\[
\frac{dC_t}{dt} = k(q_e - q_t)(C_t - C_e)
\]

\[
\frac{t}{C_0 - C_t} = \frac{t}{C_0 - C_e} + \frac{a}{k(C_0 - C_e)^2}
\]
Infrastructure and Design Solution: No Loss of Function

Design: 2 m of CPP (Al admix) with BAR (10 yrs of loads)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Design Option</th>
<th>Runoff (inches)</th>
<th>Phosphorus (lb)</th>
<th>Nitrogen (lb)</th>
<th>TSS (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pristine</td>
<td></td>
<td>53.8</td>
<td>7.78</td>
<td>301.61</td>
<td>296.26</td>
</tr>
<tr>
<td>Current</td>
<td>1</td>
<td>251.66</td>
<td>243.05</td>
<td>1065.83</td>
<td>61143.81</td>
</tr>
<tr>
<td>6 ft LIR + BAR</td>
<td>3(a)</td>
<td>53.63</td>
<td>2.17</td>
<td>133.18</td>
<td>239.85</td>
</tr>
</tbody>
</table>

Compared to conventional Florida BMPs:
• 13% more economical for P treatment
• 15% more economical for N treatment

Bounding clay layer allowing storage and denitrification
Restoration of CPP hydraulic conductivity

After vacuuming
$k_v/k_0 = 97.3\%$
After sonicating
$k_s/k_0 = 99.6\%$

After vacuuming
$k_v/k_0 = 96.1\%$
After sonicating
$k_s/k_0 = 99.8\%$

After vacuuming
$k_v/k_0 = 96.9\%$
After sonicating
$k_s/k_0 = 99.3\%$
Pavement Cleaning (Source Area Control)

- Arguably, the most logical and cost-effective pollutant load recovery tool of a municipality
- HOWEVER, not all pavement cleaners or street sweepers are created equal
- This is significant misapplication of street sweeper types for given conditions
- How (speed, frequency ...) a street sweeper is operated is also important
- New generation, high efficiency street sweeper are significantly more effective than older systems

It is always more economical to recover street sweeping residuals in the dry phase instead of separation of such residuals and pollutants in runoff by structural “BMPs”. Source area control critical for LID.
Urban Water Cycle Management Needs

1. The urban water cycle including quantitative control strategies is not sustainable without decentralized hydrologic restoration, source control and frequent maintenance (no different than POTWs).

2. Monitoring, analysis and models that accurately represent urban water complexity for transport, treatment, reuse (especially with wastewater superimposed) and fate of “chemicals” in engineered and natural systems.

3. Models and monitoring for control strategies that incorporate fundamental mechanistic and probabilistic phenomena in contrast to examining controls as “black boxes” using indices, or resorting to modeling hydro-fantasy.

4. Frequent quantitative maintenance for residuals/toxics. Control strategies are short-term repositories at best, the urban water cycle is much longer.

5. Acceptance of new knowledge, methods and rigor – why are we afraid?

6. Regular operation and maintenance requirements for all control strategies.