Treatment and Maintenance of Stormwater Hydrodynamic Separators: A Case Study

Cosenza, Italia looking upstream on Busento River flowing from Monte Cocuzzo, near San Giovianni in Fiore

J-Y Kim, S. Pathapati, B. Liu, J. Sansalone
Environmental Engineering Sciences
University of Florida
Acknowledgements

The authors would like to acknowledge the research and efforts of all of my students, research collaborators, supporting agencies and reviewers over the last decade. Without them, this presentation would not be possible.
Treatment Control BMP Requirements

- Any in-situ control, LID, Unit Operation/Process (UOP), BMP, or MS4 conveyance requires proper maintenance, operation and knowledge. These systems are no longer black boxes.

- Performance and mass inventory evaluations require: (1) data collection and mass balances, and (2) a calibrated model, and (3) independent verification/monitoring.

- These control systems are a combination of unit operations and process (UOP) phenomena. We would never operate a wastewater or drinking water system without operation and maintenance (O&M) guidance. Why do we think that stormwater control systems, which are more complex, are any different?

- Sustainable stormwater treatment systems combine hydrologic restoration, load reduction benefits, residuals management and effluent reuse. Any BMP that do not include these attributes, in particular integration of hydrologic restoration is likely not sustainable.
Process Flow Diagrams for “Treatment Trains” (we do not have to think of UOPs as “black boxes”)

We have the tools and flexibility to predict the behavior of treatment trains, LID/SUD at every point in the process w/basic hydrologic, water chemistry fundamentals and constitutive UOP relationships, in simple spreadsheets. Rules of thumb are strengthened by physical and statistical bases.
Methodology

• Full-scale field set-up in source area MS4
  – Uncontrolled storm loadings
  – Controlled “regulatory” testing

• Computational Fluid Dynamics (CFD) modeling
**“Separation” UOPs:**
- Structural systems
- Hydrodynamic Separators
- Swirl Concentrators
- Vortex Systems
- Do not provide volumetric, flow, thermal or hydrologic control

**ADVANTAGES:**
- Small footprint, low land costs
- Trash, debris control
- Coarse particle-bound control
- Effective at beginning of WWTP
- Functions as preliminary treatment
- Many designs, multiple mechanisms

**DISADVANTAGES:**
- Little independent testing and QA/QC
- Few peer-reviewed publications
- Moderate initial cost, cost of upkeep ??
- Effectiveness ↔ Cleaning !!!
- Proper sampling and monitoring rare
- To date, conflicting information
- Systems will fail without maintenance
- Small footprint, must examine scour !!
Baton Rouge site characteristics for stormwater treatment

- Location – I-10 City Park lake overpass
- Watershed – Portland cement concrete
- Mean annual precipitation 1460 mm/year
- Total span – 270 m
- Average Daily Traffic – 70,400
- MSA population of 450,000
- NPDES Phase II region

Storm drain inlet to experimental system
- Direct runoff discharge to City Park Lake
- 2.02% slope
Calibrated flow measurement devises: 6-inch Parshall flume, ultrasonic sensor, and data logger.

Tested influent particle gradations:
ML and SP gradations

20 discrete replicated 2-L effluent samples at a constant sampling interval
Plan and side view of the screened hydrodynamic separator (HS) with dimensions

<table>
<thead>
<tr>
<th>Operational parameters</th>
<th>Diameter of the full-scale screened HS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60-inch</td>
</tr>
<tr>
<td>Screened area, cm²</td>
<td>3,310</td>
</tr>
<tr>
<td>Annular area, cm²</td>
<td>14,922</td>
</tr>
<tr>
<td>Total surface area, cm²</td>
<td>18,232</td>
</tr>
<tr>
<td>Screen/Annular area</td>
<td>0.22</td>
</tr>
<tr>
<td>Volume of unit, L</td>
<td>1436</td>
</tr>
<tr>
<td>Screen openings (μm)</td>
<td>2400</td>
</tr>
</tbody>
</table>

- Design flow capacity for 72”-unit = 34-L/s
Influent particle size distributions (PSDs) of ML and SP

- Calibration: 200 mg/L of ML (sandy silt, non-uniform gradation) NJCAT
- Validation: 200 mg/L of SP (sand, uniform gradation) OK-110

Granulometric parameters:

<table>
<thead>
<tr>
<th></th>
<th>Sandy Silt</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_{50}$</td>
<td>66.7 $\mu$m</td>
<td>111.6 $\mu$m</td>
</tr>
<tr>
<td>Central tendency</td>
<td>very fine sand $(3 &lt; \Phi_{50} &lt; 4)$</td>
<td>very fine sand $(3 &lt; \Phi_{50} &lt; 4)$</td>
</tr>
<tr>
<td>$d_{25}$</td>
<td>16.4 $\mu$m</td>
<td>97.8 $\mu$m</td>
</tr>
<tr>
<td>$d_{75}$</td>
<td>175.0 $\mu$m</td>
<td>121.4 $\mu$m</td>
</tr>
<tr>
<td>Uniformity</td>
<td>V. poorly sorted $(2 &lt; \sigma_i &lt; 4)$</td>
<td>V. well sorted $(\sigma_i &lt; 0.35)$</td>
</tr>
</tbody>
</table>

![Graph showing particle size distributions](image)
Initial sediment preloading conditions in the screened HS for scouring tests with SP gradation

A- (100%, 0 inch)
- 100% particle preload in Sump
- 0 inch particle preload in Volute
- 100%, 125% of $Q_d$

B- (50%, 0 inch)
- 50% particle preload in Sump
- 0 inch particle preload in Volute
- 100%, 125% of $Q_d$

C- (100%, 1 inch)
- 100% particle preload in Sump
- 1 inch particle preload in Volute
- 100%, 125% of $Q_d$

D- (50%, 1 inch)
- 50% particle preload in Sump
- 1 inch particle preload in Volute
- 100%, 125% of $Q_d$
Mass balance and QA/QC

Mass balance error (%) = \frac{[(\text{Influent Load}) - (\text{Effluent Load} + \text{Mass of HS particles})]}{(\text{Influent Load})} \times 100

Particle separation efficiency (%) = \frac{(\text{Mass of HS particles})}{(\text{Influent particle Mass Load})} \times 100

(\text{HS particles} = \text{Screened particles} + \text{Annular section particles})

A mass balance analysis was conducted after every event to ensure mass conservation and QA/QC.

QA/QC

Effluent mass load based on flow measurement and measured concentrations

Calculated Estimation!!

Injected influent particles mass

Recovered mass in the sump and volute chamber

Actual measurement.
Methodology

• Computational Fluid Dynamics (CFD) modeling

  – CFD is a very powerful tool when combined with defensible field data and mass balances to produce a calibrated/validated model of a BMP for treatment or scour examination and BMP selection-optimization

  – However, as with any powerful tool there is responsibility and defensibility. A CFD model that is not calibrated/validated is hydro-fantasy or worse.
Summary of CFD concepts

- Conservation of mass, momentum, energy, reactive species.
- Generalized conservation equation, in three dimensions

\[
\frac{\partial \left( \rho \Phi \right)}{\partial t} + \text{div} \left( \rho \Phi \mathbf{U} \right) = \text{div} \left( \Gamma \text{grad} \ \Phi \right) + S_\Phi
\]  

(1)

<table>
<thead>
<tr>
<th>Rate of increase of $\Phi$</th>
<th>+</th>
<th>Net rate of outflow of $\Phi$</th>
<th>=</th>
<th>Rate of increase of $\Phi$ due to diffusion</th>
<th>+</th>
<th>Rate of increase/decrease of $\Phi$ due to sources/sinks</th>
</tr>
</thead>
</table>

$\Phi$ = Fluid property per unit mass
$\Gamma$ = Diffusion Coefficient
$\rho$ = Density
$S_\Phi$ = Source/Sink

\[
\text{div} \left( \mathbf{U} \right) = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}
\]
Grid-HS

The volume of the HS ($\Phi=5'$) was divided into **1.96 million cell structure**.
Results

- Regulatory testing
- Storm event
- Scour
- CFD Modeling
Calibration, verification and prediction by a particle separation efficiency (PSE) model at influent $[C] = 200$ mg/L as SSC.
20 August 2004 storm: Hydrodynamic separator mass load reduction as a function of particle fraction

- Mass balance error = -3.5 %
- \( Q_{AVE} = 306 \text{ L/min} \)
- High suspended efficiency likely a result of shear coagulation due to event generated hydrodynamics
- \( T_{50} \) of RTD is < 2 min. \( \{f(Q)\} \)
- System physically-optimized based on RTD and mass before storm

<table>
<thead>
<tr>
<th>Particle fraction</th>
<th>( \Delta ) (mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment</td>
<td>79.0 %</td>
</tr>
<tr>
<td>Settleable</td>
<td>21.0 %</td>
</tr>
<tr>
<td>Suspended</td>
<td>14.0 %</td>
</tr>
<tr>
<td>Total SSS</td>
<td>60.0 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mass Load, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent</td>
</tr>
<tr>
<td>Effluent</td>
</tr>
<tr>
<td>Influent</td>
</tr>
<tr>
<td>Effluent</td>
</tr>
<tr>
<td>Influent</td>
</tr>
<tr>
<td>Effluent</td>
</tr>
</tbody>
</table>
Results of sediment scouring test in screened HS (7 ft diameter)

- **Non-preloaded volute area**
- **Preloaded volute area with 1 inch depth of SP**

**Effluent mass load, kg**

- 8
- 10
- 100%
- SUMP
- 50%
- SUMP

**Sediment Scouring rate, g/min**

- 400
- 600

**Flow rate** also make a significant difference on sediment scouring.

- **Total influent volume** = 27,400 L
- **HS unit volume** = 2,814 L

- **Sediment preloading condition in the sump** had the most dominant impact on the degree of scour

Proper management and clean-out schedules are critical for successful performance of the unit!!
Scour – Modeled vs. Measured (Design flow rate @ 590 gpm)

- Measured scouring rate
- Modeled scouring rate

**50% pre-loaded**
- Absolute RPD = 1.1%

**100% pre-loaded**
- Absolute RPD = 4.8%

**Effluent mass load, g**
- 0
- 2500
- 5000
- 7500
- 10000

**Scouring rate, g/min**
- -400
- -150
- 0
- 100
- 350
- 600
Scoured particle trajectories, $d_p=400 \ \mu\text{m}$, $\rho_p=2.63 \ \text{g/cm}^3$ (no scouring at design flow rate)
Scoured particle trajectories, $d_p=40$ µm, $\rho_p=2.63$ g/cm³ (high scouring at design flow rate)
Scoured particle trajectories, $d_p=10 \ \mu m$, $\rho_p=2.63 \ \frac{g}{cm^3}$ (high scouring at design flow rate)
The initial time 0 starts at the end of event (runoff stop)
Conversion of nitrate to ammonia as a function of BMP holding (residence) time with early life stage toxicity
Conclusions

• Hydrodynamic separators used for debris and coarse particle treatment control must be maintained on a frequent basis, far more frequently than current practice to avoid issues of scour and changing water chemistry during dry periods between events. Anoxic to anaerobic conditions can occur within two days, with a commensurate increase in potentially toxic species such as ammonia.

• Stormwater sludge and the associated overlying liquid requires control and treatment before the next effluent-generating event from the BMP system.

• CFD represents a very powerful tool that removes BMPs from the category of “black boxes” and allows a more complete understanding of design, O&M, and performance.

• However, CFD without field data, mass balance testing and calibration/validation is hydro-fantasy.