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

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Treatment Control BMP Requirements

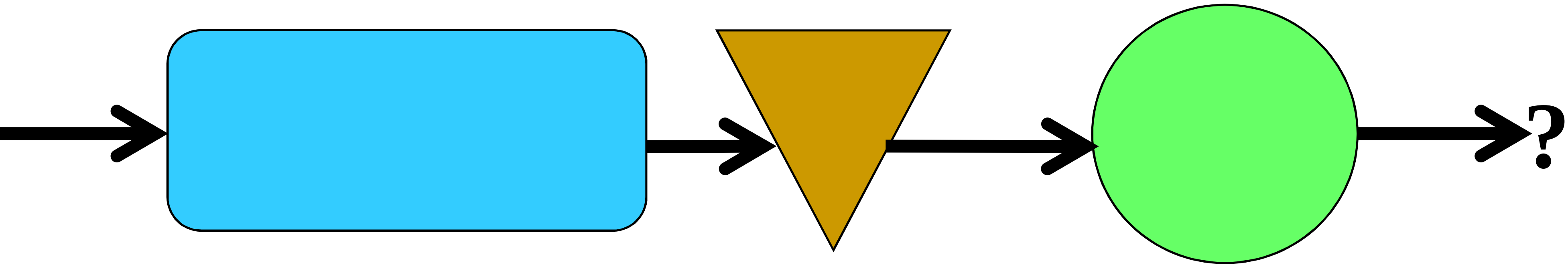
– **Any in-situ control, LID, Unit Operation/Process (UOP), BMP, or MS4 conveyance requires proper <u>maintenance</u>, operation and knowledge. These systems are no longer black boxes.**

– **Performance and mass inventory evaluations require: (1) data collection and mass balances, and (2) a calibrated - validated 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")



<u>Hydrologic control</u>

- Rainfall parameters
- Watershed parameters
- Basin parameters
- Effluent Q, V, t parameters
- ***You have tools to model***

<u>Particle separation</u>

- Granulometry parameters
- Hydrodynamic parameters
- Geometric, screen parameters
- Settling and C/F parameters
- ***You have tools to model***

<u>Adsorptive-filtration</u>

- Media parameters
- Geometric parameters
- Filtration parameters
- Mass transfer parameters
- ***You have tools to model***

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.

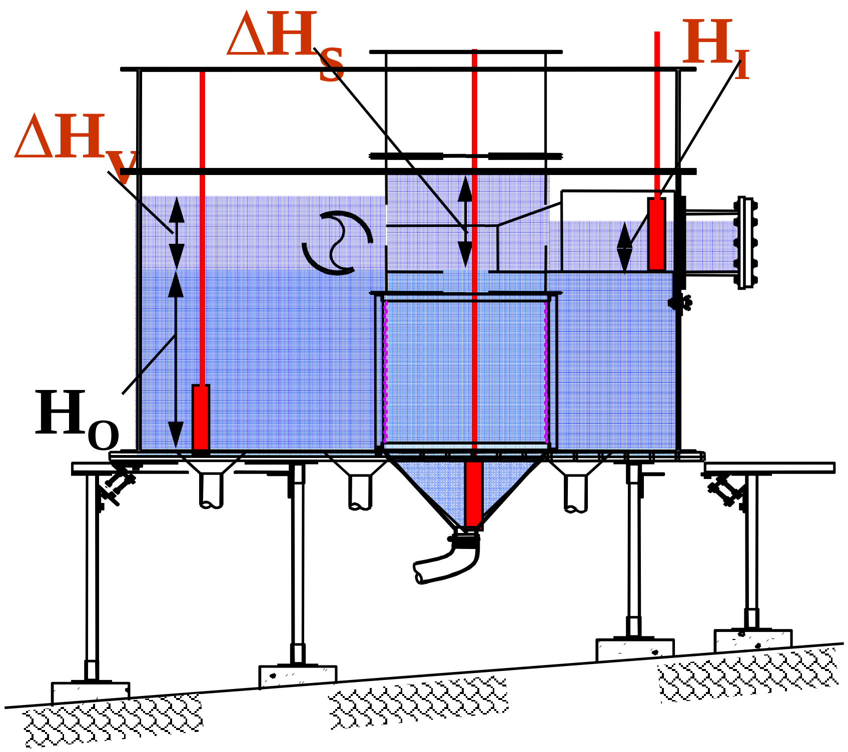
Rules of thumb are strengthened by physical and statistical bases

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



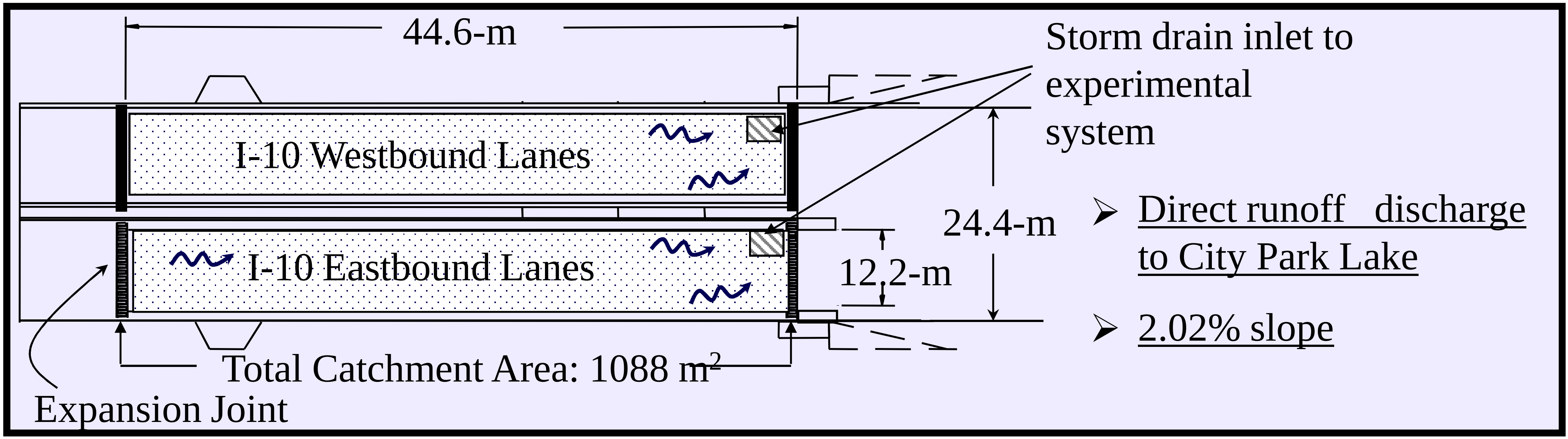
ADVANTAGES:

- 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

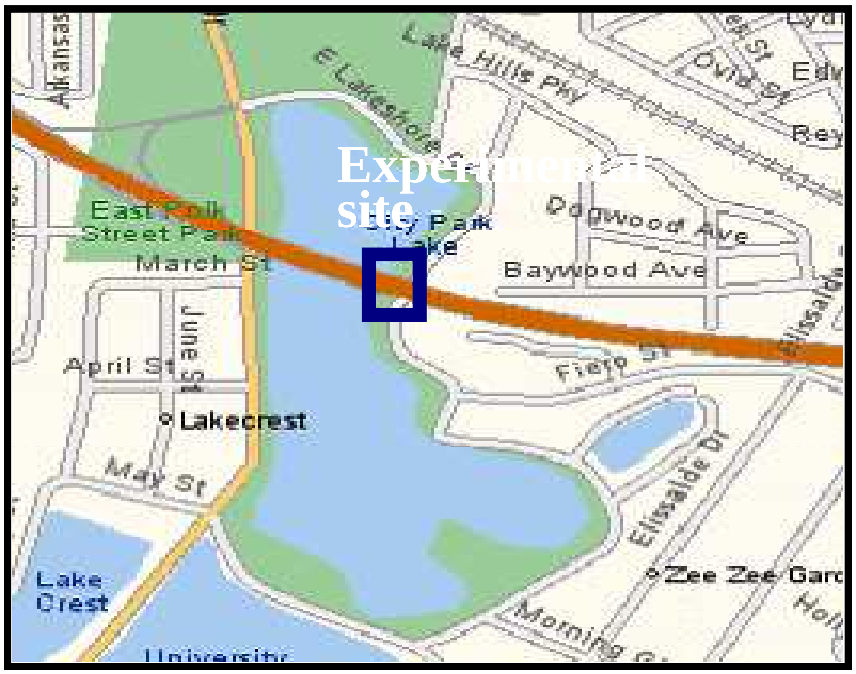
DISADVANTAGES:

- 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



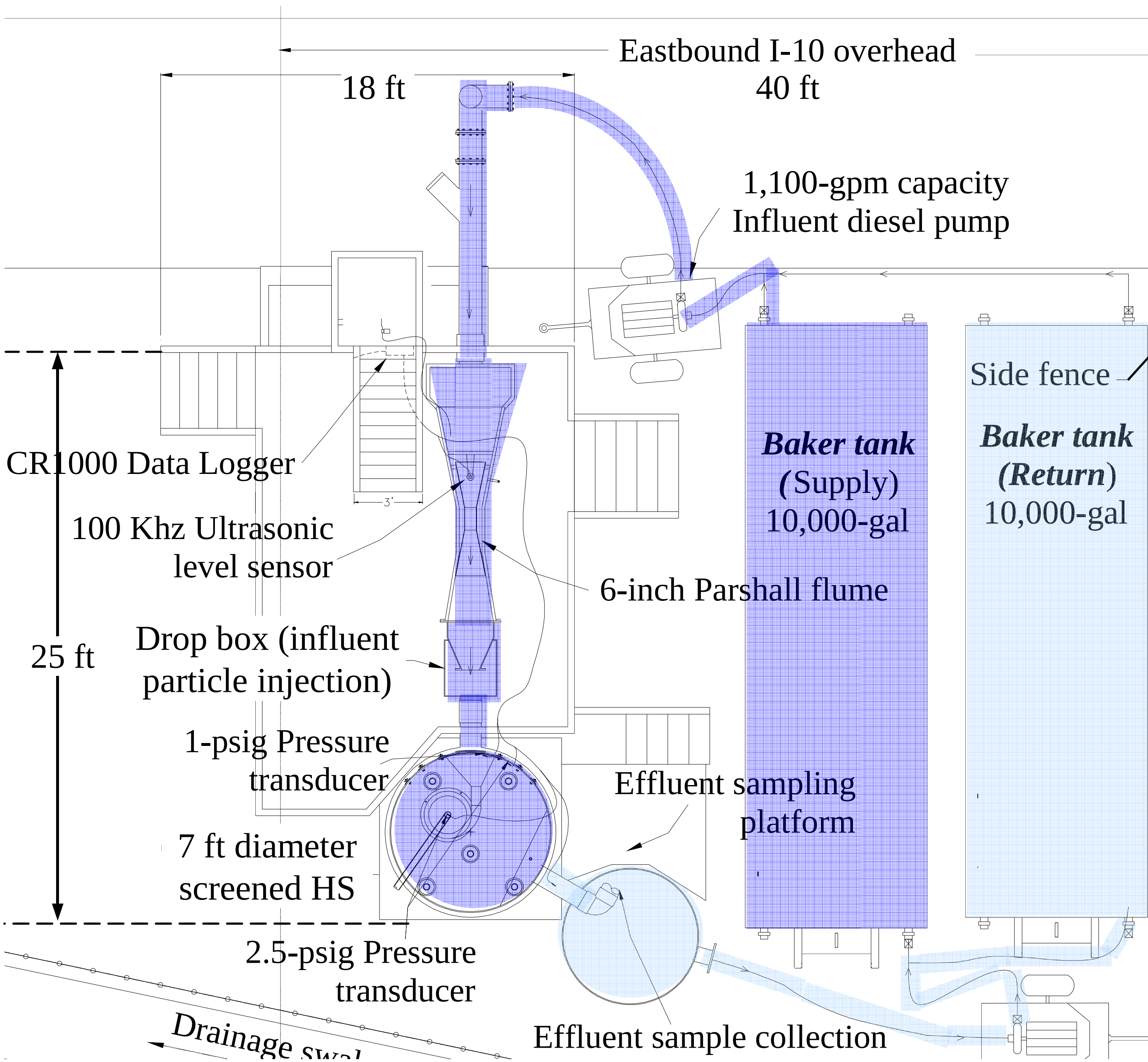
- Direct runoff discharge to City Park Lake
- 2.02% slope



- 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

Plan view of experimental setup for HS



- **Calibrated flow measurement devises :**

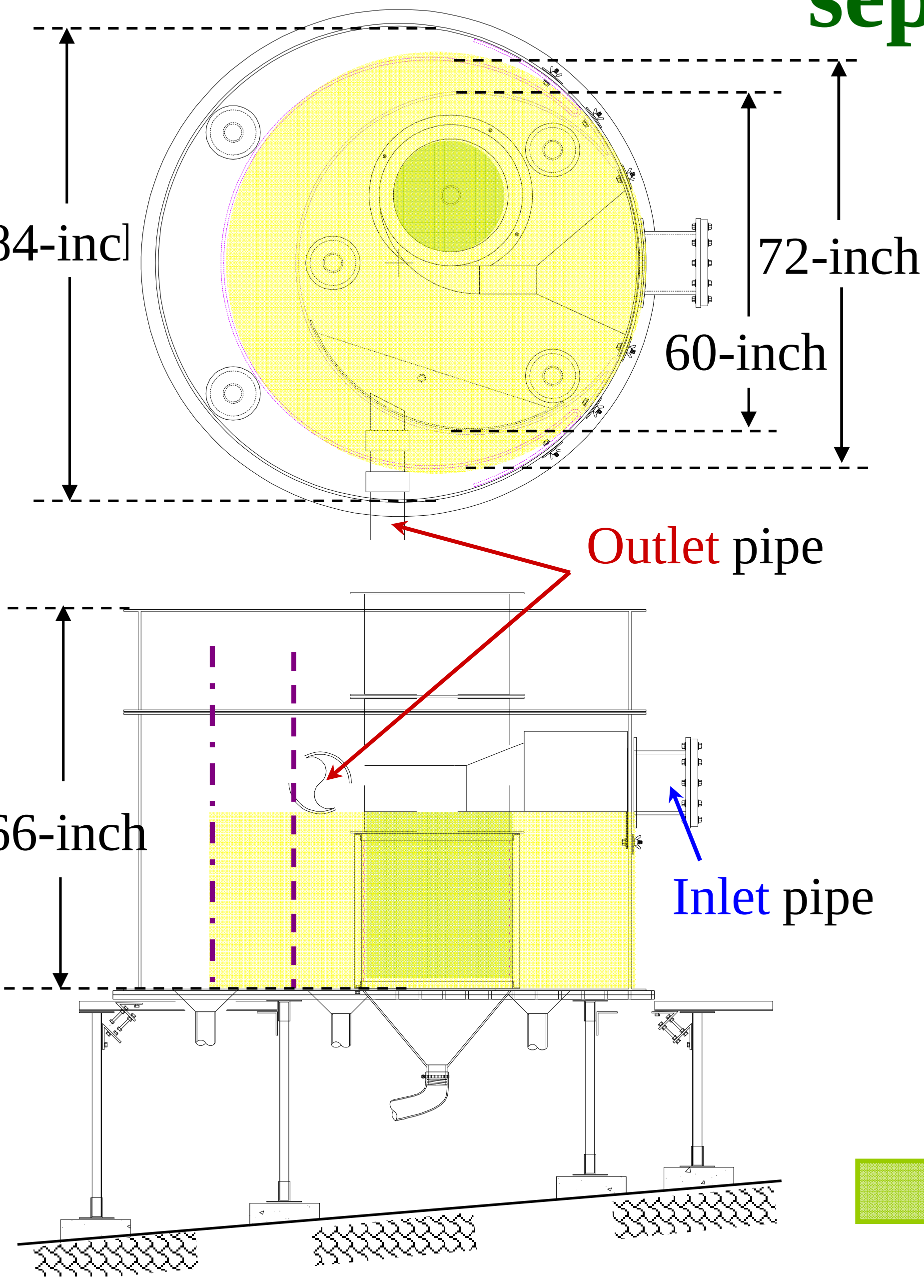
  6-inch Parshall flume, ultrasonic sensor, and data logger.

- **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



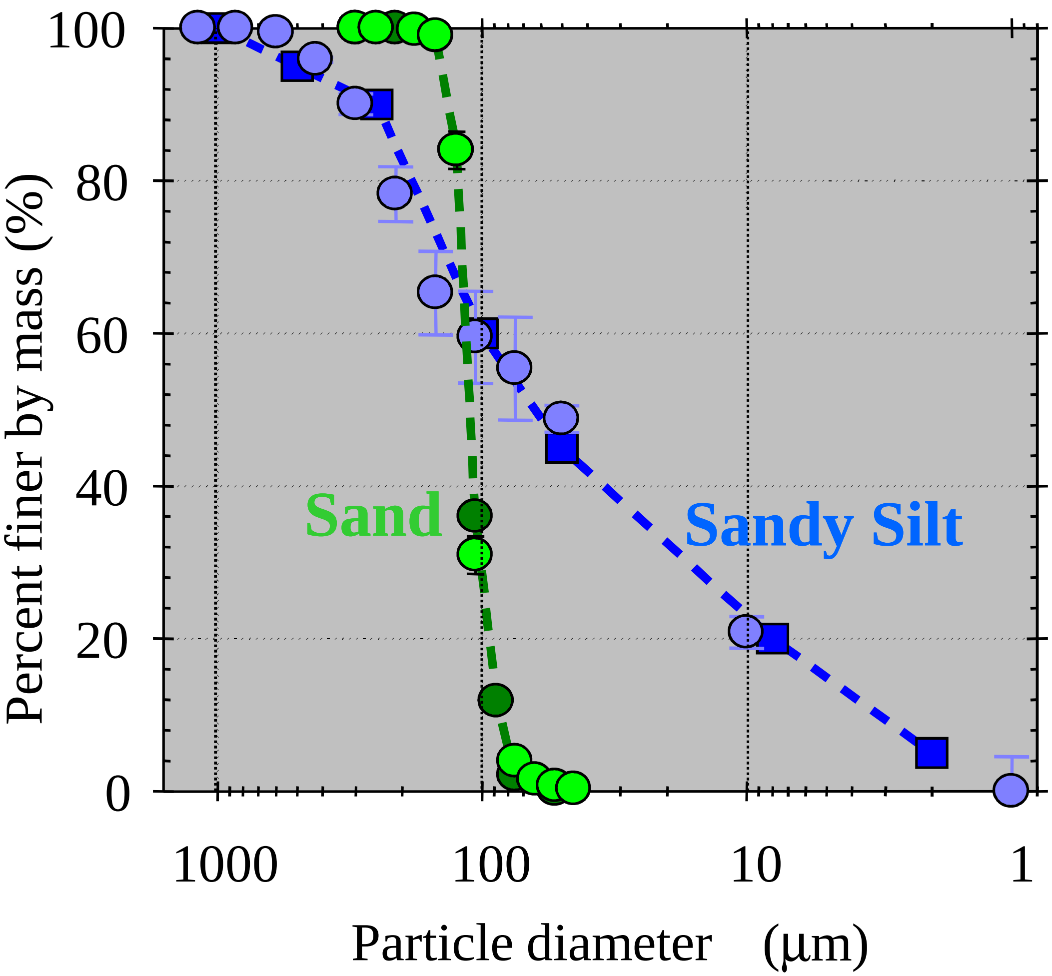
Operational parameters	Diameter of the full-scale screened HS		
	60-inch	72-inch	84-inch
Screened area, cm^2	3,310	3,310	3,310
Annular area, cm^2	14,922	22,944	14,922
Total surface area, cm^2	18,232	26,254	35,735
Screen/Annular area	0.22	0.14	0.10
Volume of unit, L	1436	2067	2814
Screen openings (μm)	2400	2400	2400

❖ Design flow capacity for 72”-unit = 34-L/s

Screened area Annular area (72inch)

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**

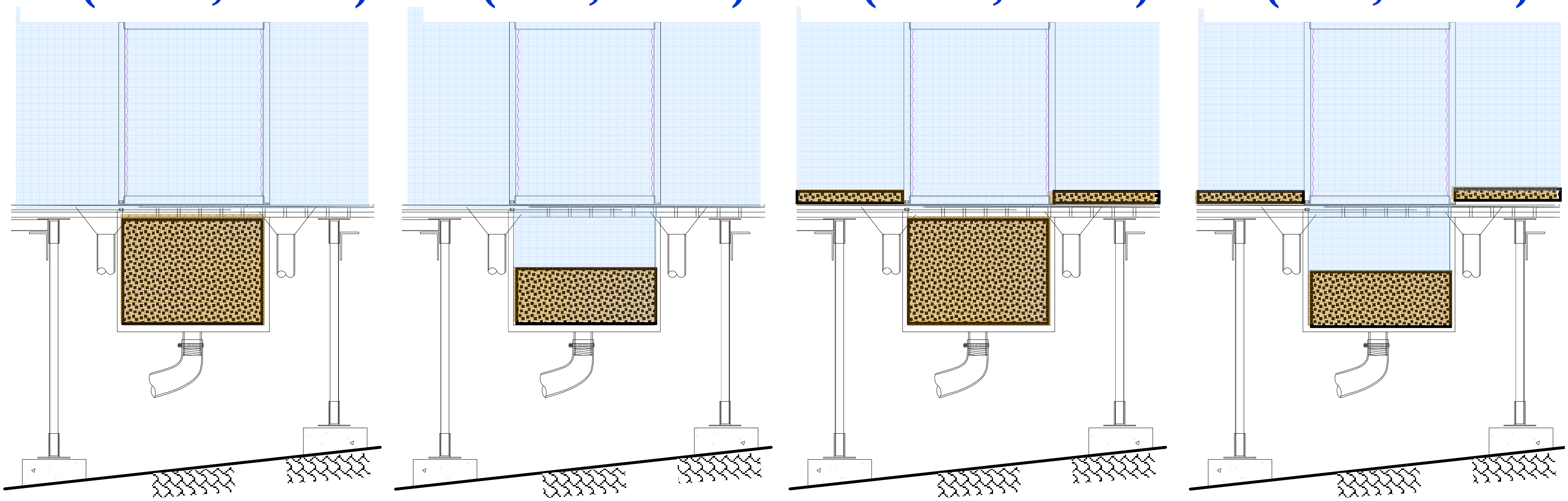


Granulometric parameters:

	Sandy Silt	Sand
d_{50}	66.7 μm	111.6 μm
Central tendency	very fine sand ($3 < \Phi_{50} < 4$)	very find sand ($3 < \Phi_{50} < 4$)
d_{25}	16.4 μm	97.8 μm
d_{75}	175.0 μm	121.4 μm
Uniformity	V. poorly sorted ($2 < \sigma_I < 4$)	V. well sorted ($\sigma_I < 0.35$)

Initial sediment preloading conditions in the screened HS for scouring tests with SP gradation

A- (100%, 0 inch) B- (50%, 0 inch) C- (100%, 1 inch) D- (50%, 1 inch)



A
- **100%** particle preload in **Sump**
- **0 inch** particle preload in **Volute**
- **100%, 125% of Q_d**

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

C
- **100%** particle preload in **Sump**
- **1 inch** particle preload in **Volute**
- **100%, 125% of Q_d**

D
- **50%** particle preload in **Sump**
- **1 inch** particle preload in **Volute**
- **100%, 125% of Q_d**

Mass balance and QA/QC

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

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

(HS particles = Screened particles + 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

$$\frac{\partial(\rho\Phi)}{\partial t} + div\,(\rho\Phi U) = div\,(\Gamma\, grad\;\Phi) + S_{\Phi} \qquad (1)$$

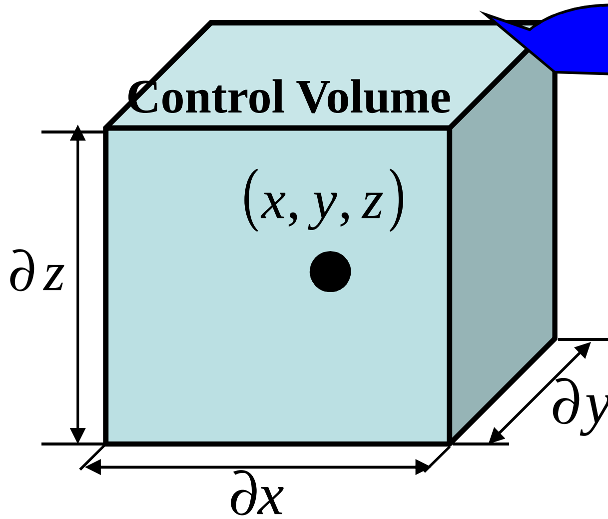
Rate of increase of Φ	+	Net rate of outflow of Φ	=	Rate of increase of Φ due to diffusion	+	Rate of increase/decrease of Φ due to sources/sinks

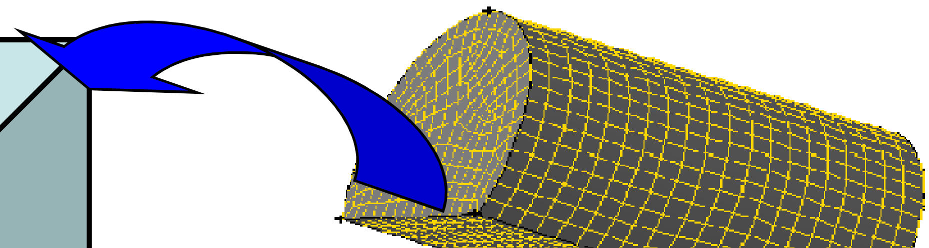
Φ = Fluid property per unit mass

Γ =Diffusion Coefficient

ρ =Density

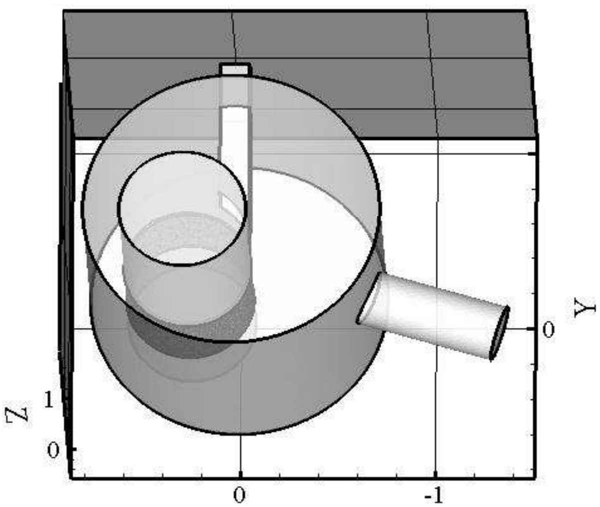
S_{Φ} =Source/Sink

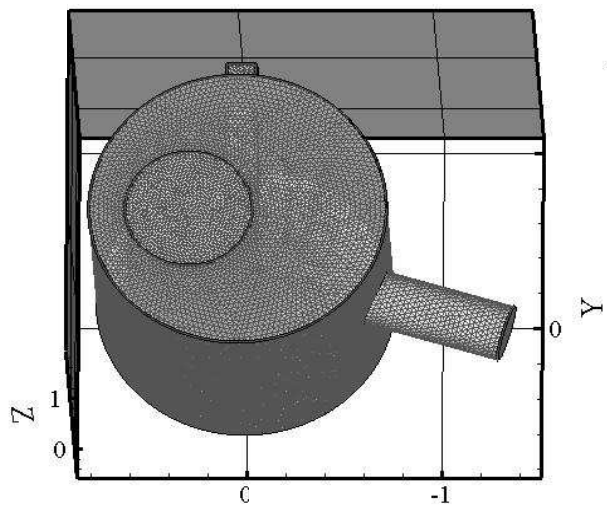




$$div\,(U) = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}$$

Grid-HS



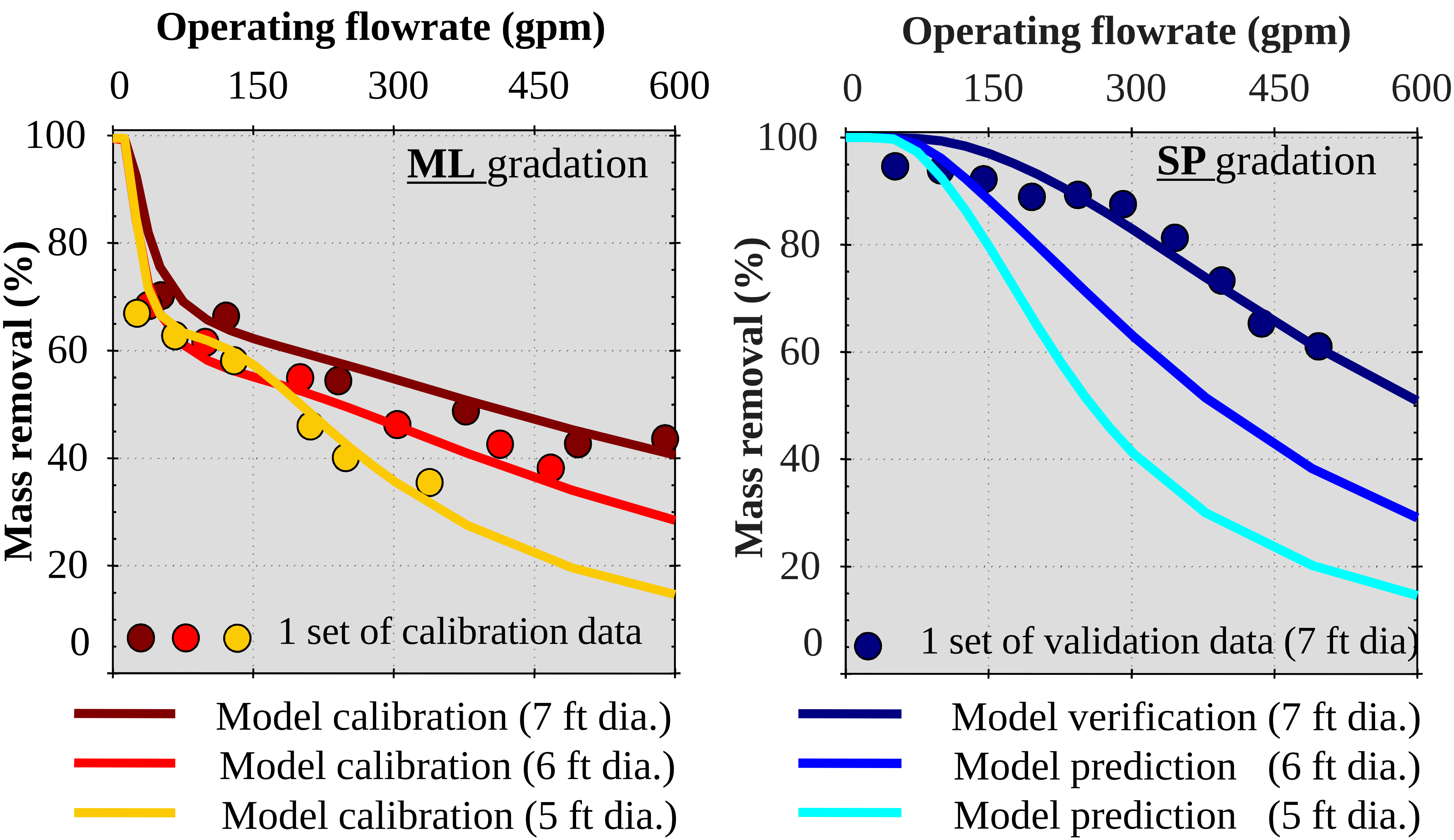


•The volume of the HS (Φ=5') was divided into **1.96 million cell structure.**

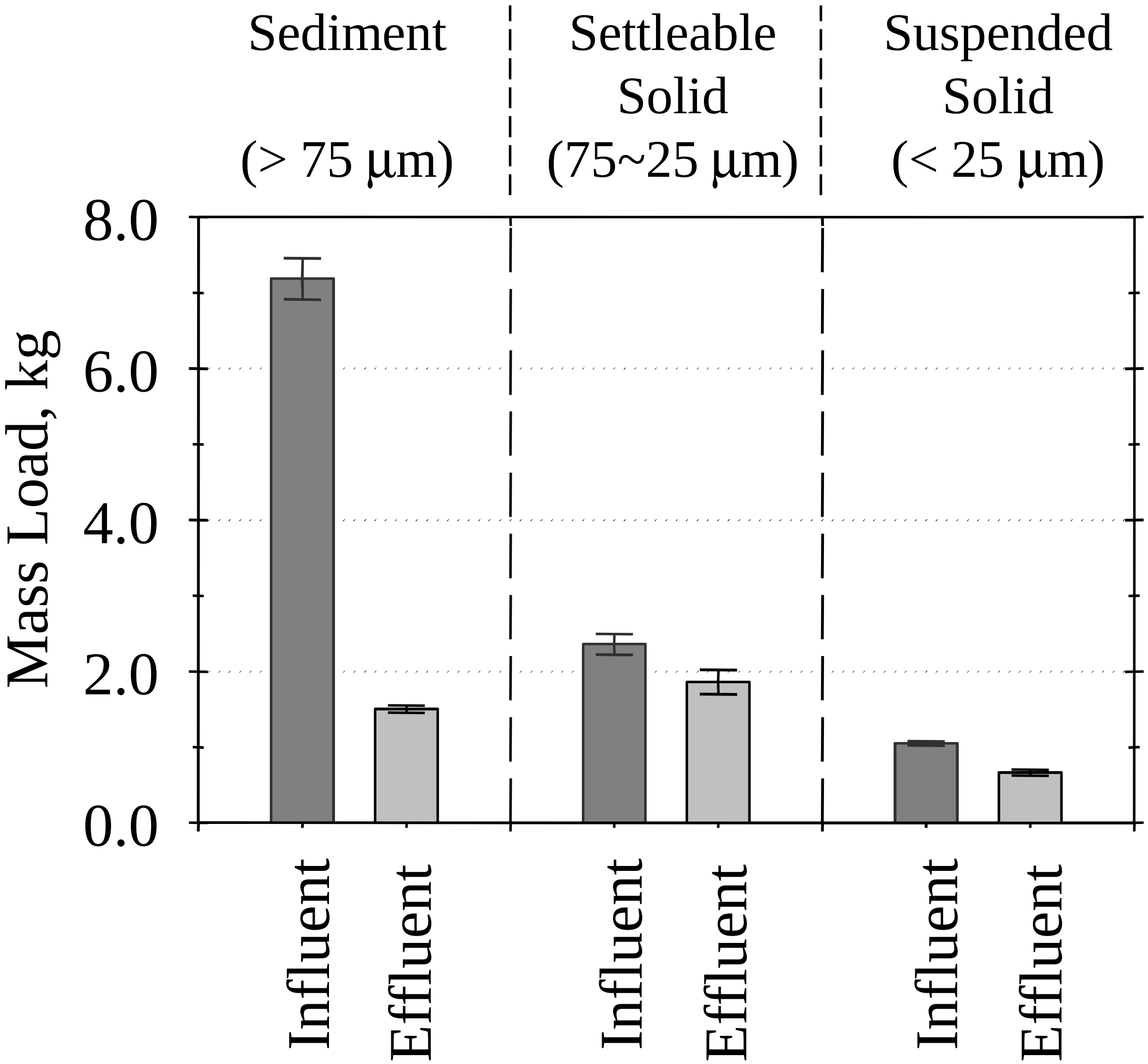
Results

- 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



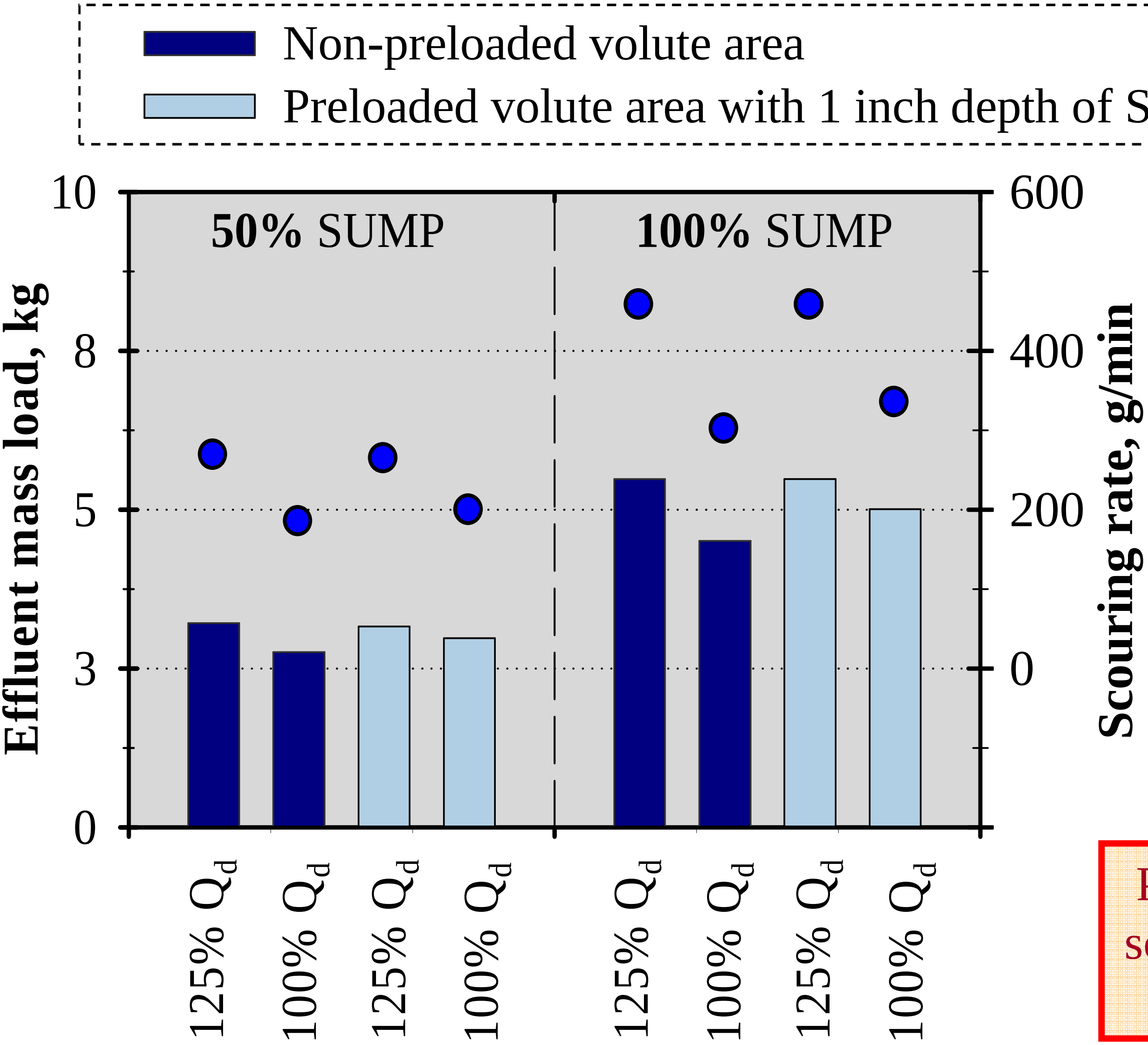
20 August 2004 storm: Hydrodynamic separator mass load reduction as a function of particle fraction



Particle fraction	**Δ (mass)**
Sediment	79.0 %
Settleable	21.0 %
Suspended	14.0 %
Total SSS	**60.0** %

- Mass balance error = - 3.5 %
- Q_{AVE} = **306** 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

Results of sediment scouring test in screened HS (7 ft diameter)



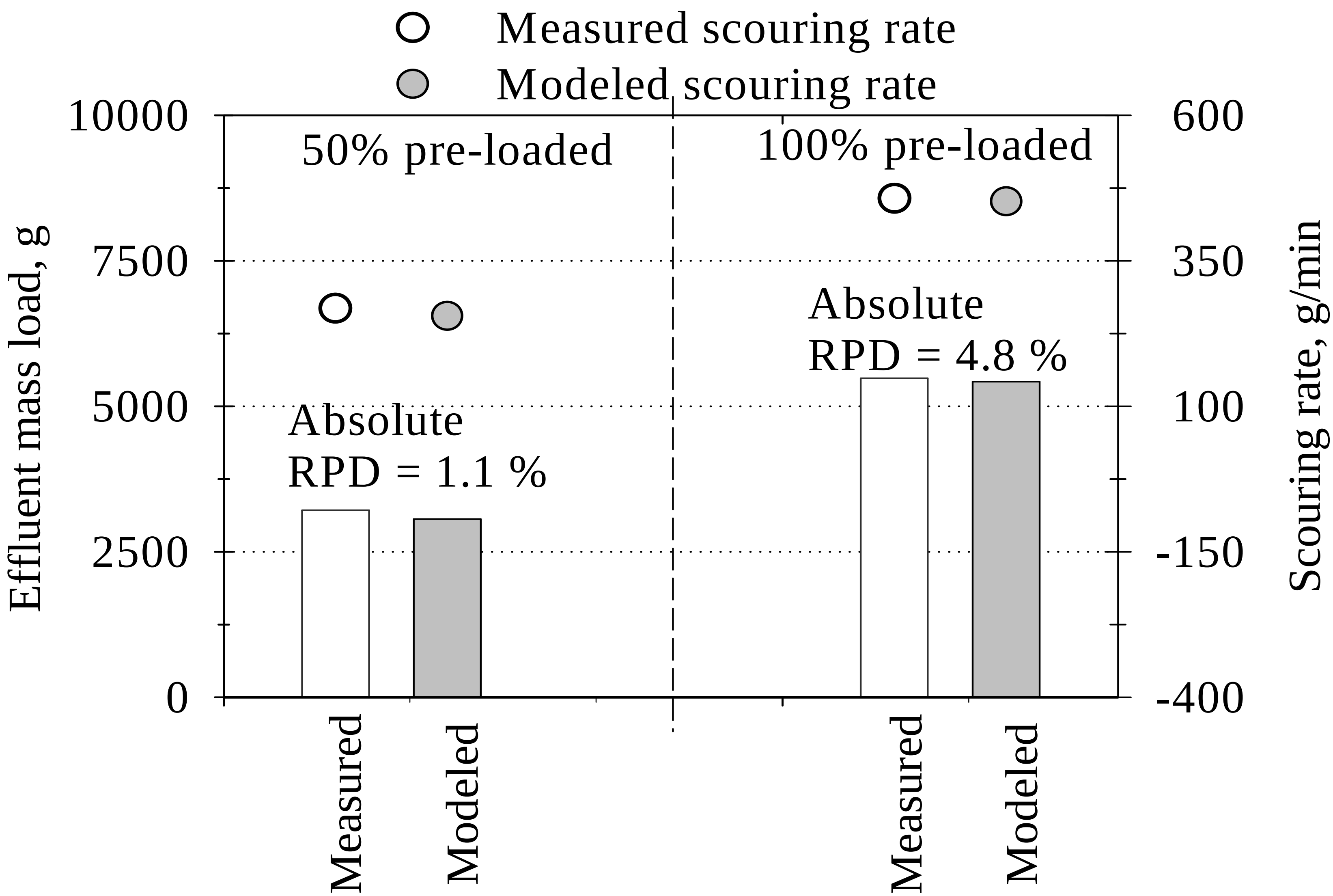
Total influent volume = 27,400 L

HS unit volume = 2,814 L

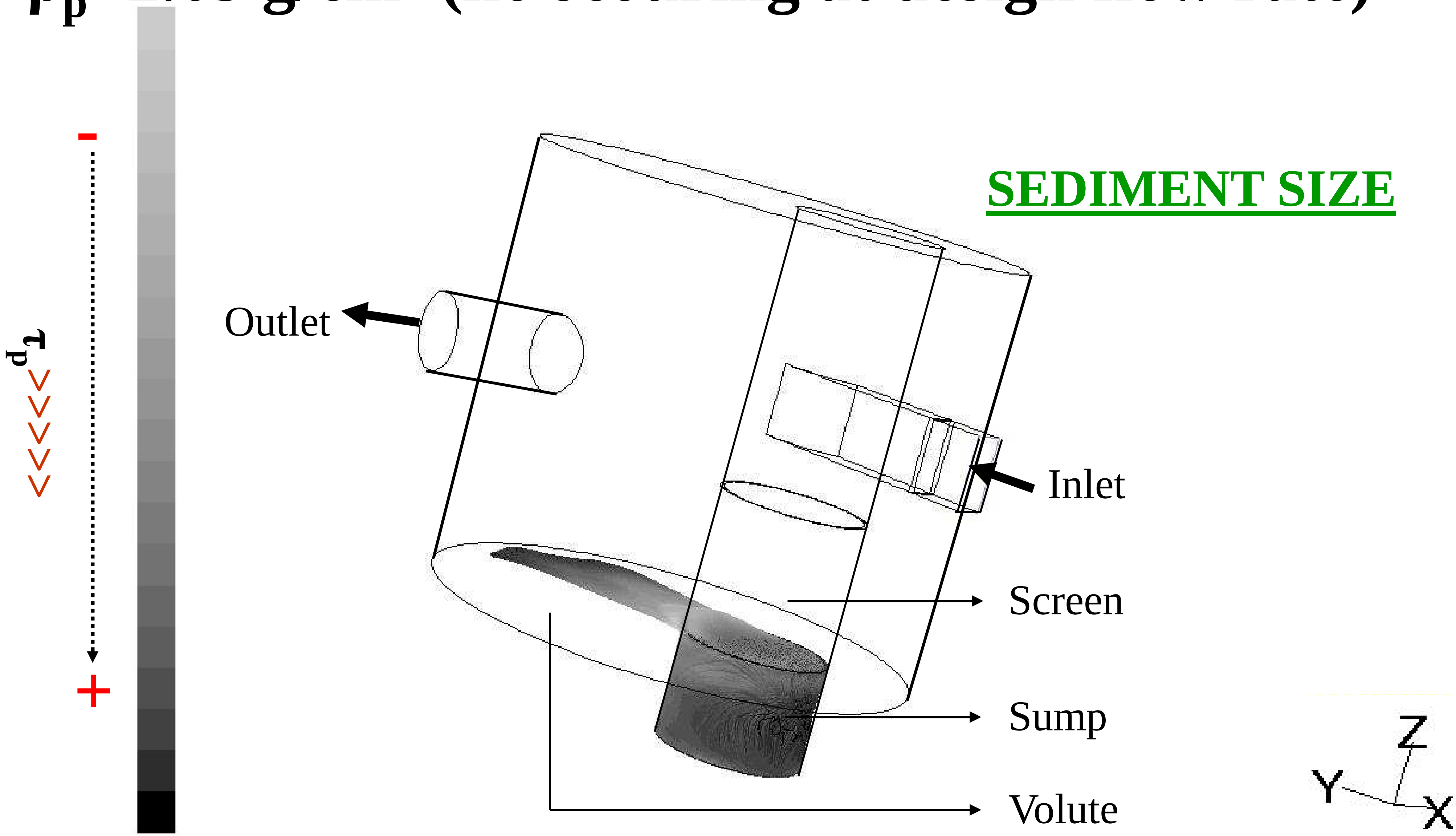
- **Sediment preloading condition in the sump** had the most dominant impact on the degree of scour
- **Flow rate** also make a significant difference on sediment scouring.

Proper management and clean-out schedules are critical for successful performance of the unit!!

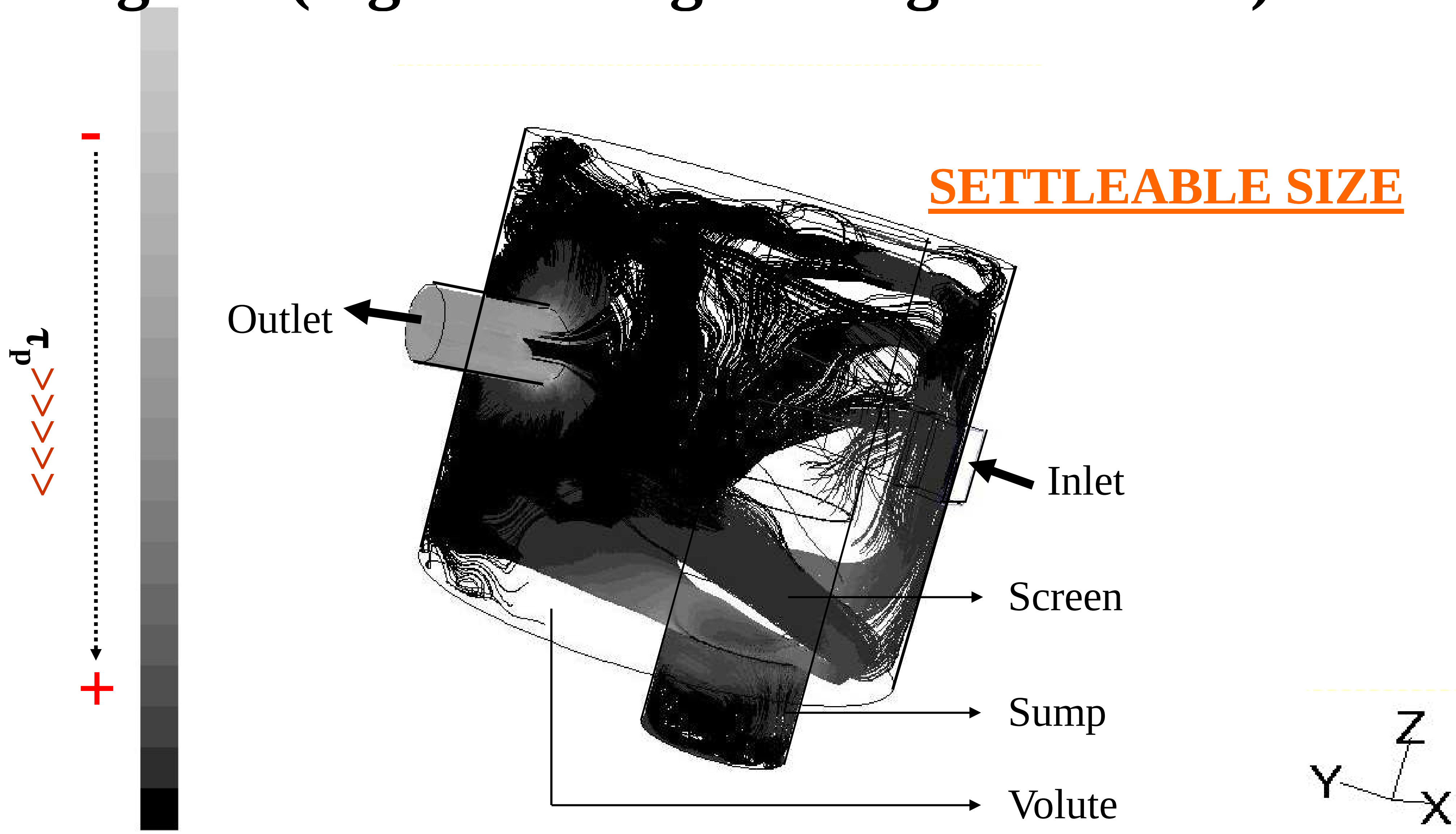
Scour – Modeled vs. Measured (Design flow rate @ 590 gpm)



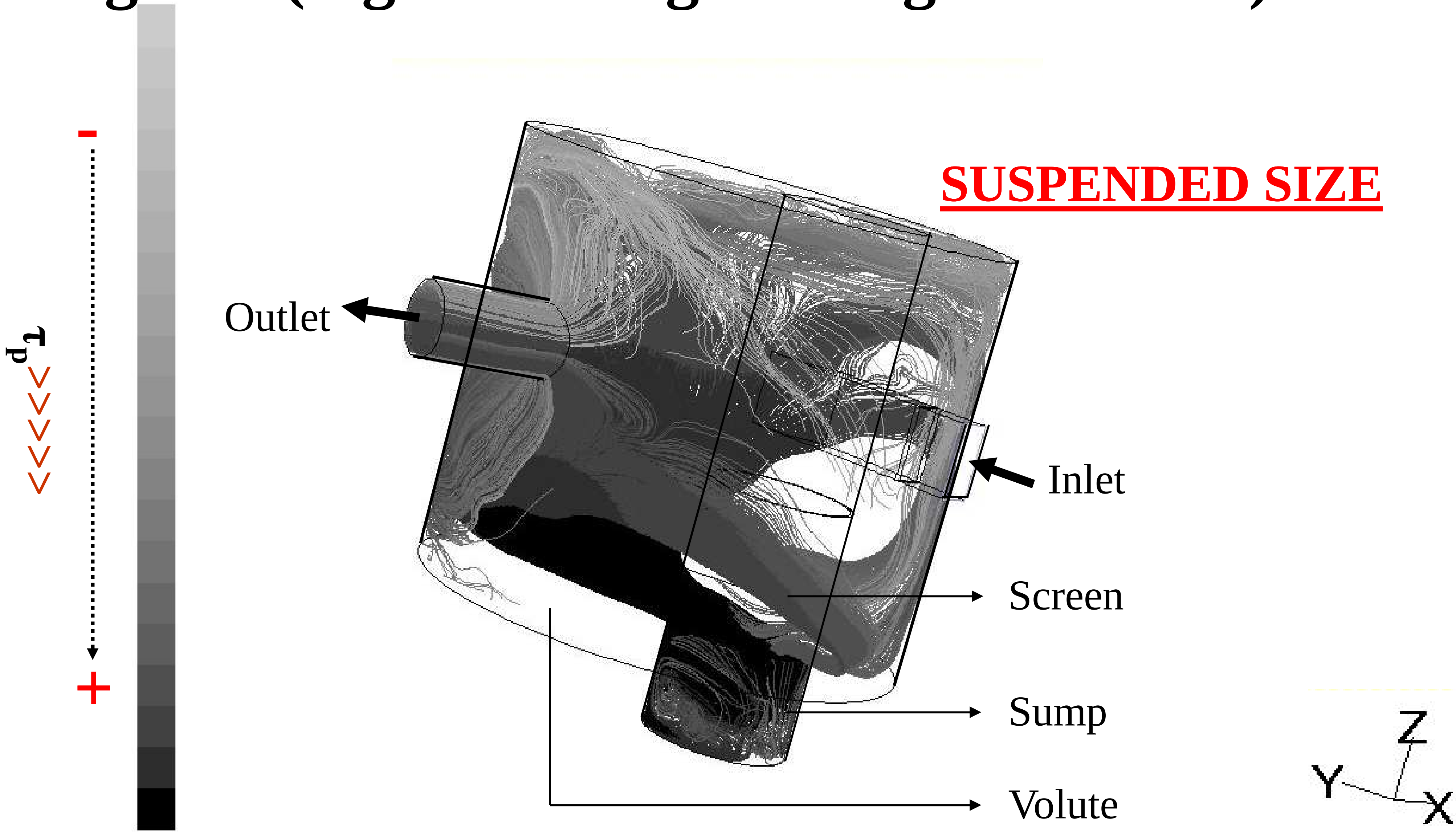
Scoured particle trajectories, d_p=400 μm, ρ_p=2.63 g/cm^3 (no scouring at design flow rate)



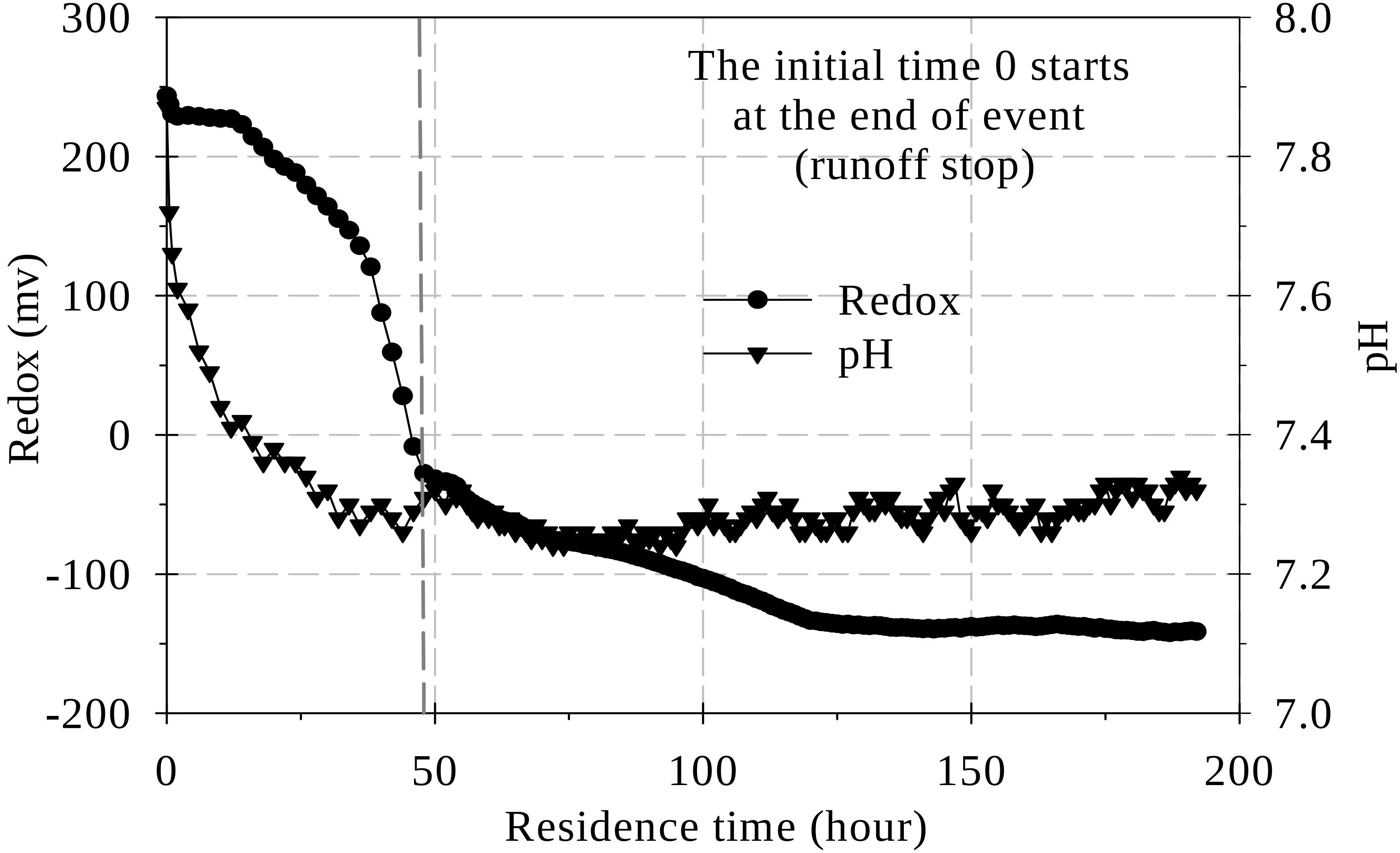
Scoured particle trajectories, d_p=40 µm, ρ_p=2.63 g/cm^3 (high scouring at design flow rate)



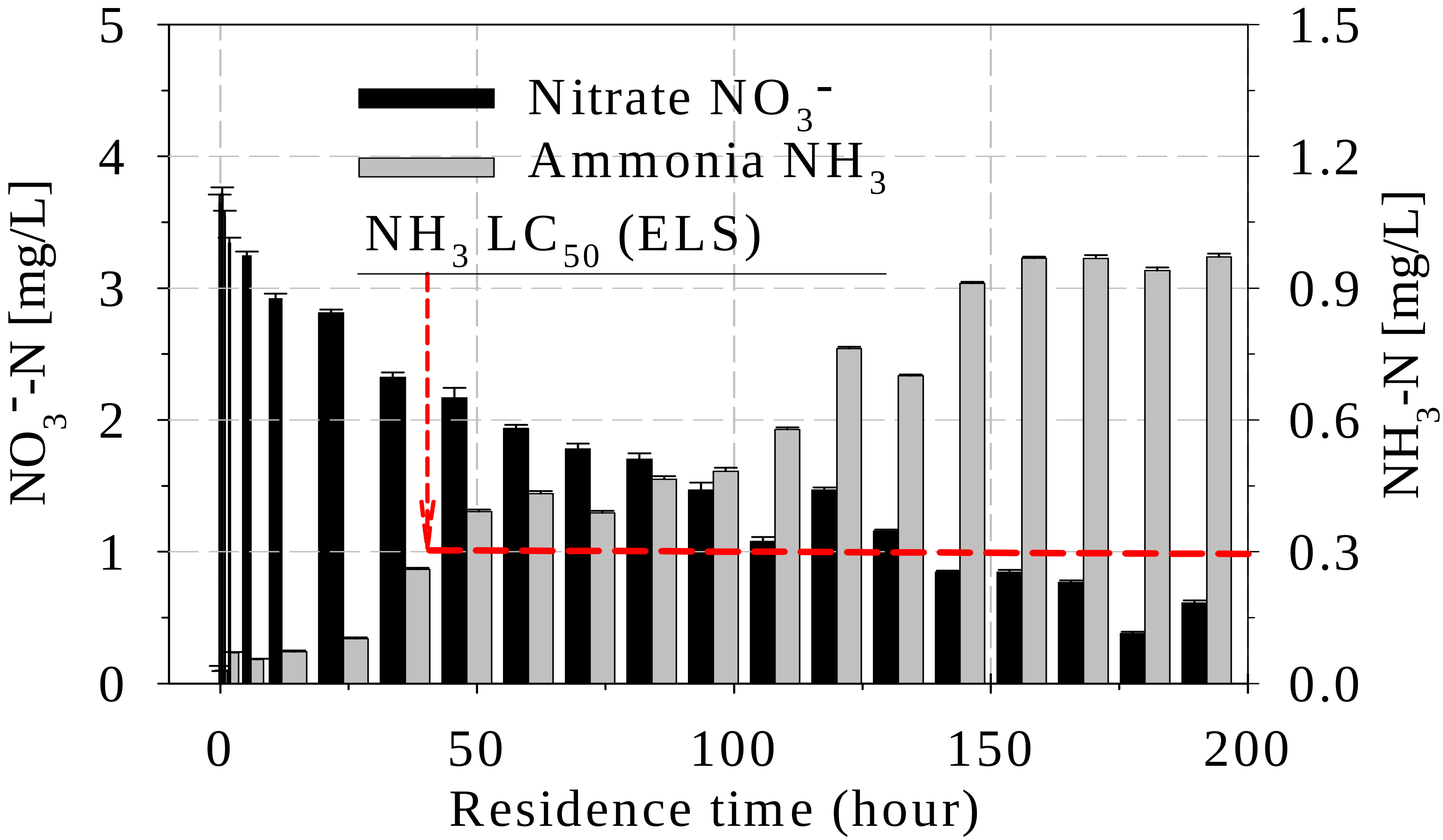
Scoured particle trajectories, d_p=10 μm, ρ_p=2.63 g/cm^3 (high scouring at design flow rate)



Redox potential and pH



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.