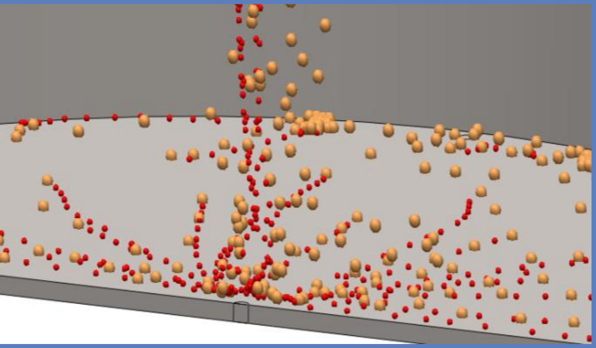
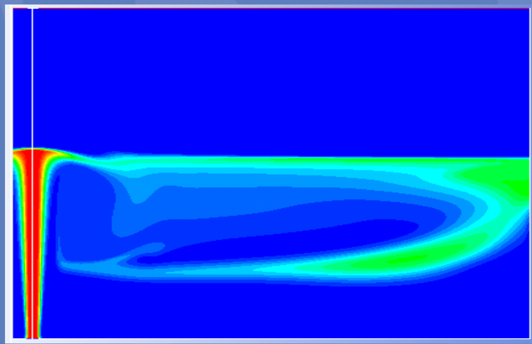
SAND2014-20007C

Particle Resuspension in Water Distribution Storage Tanks





Clifford K. Ho, Joshua Christian, Eric Ching, Jason Slavin, Jesus Ortega
Sandia National Laboratories

Regan Murray and Lew Rossman
U. S. Environmental Protection Agency

Office of Research and Development
Homeland Security Research Program

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Overview

- Background and Objectives
- Modeling Studies
- Experimental Validation Study
- Conclusions

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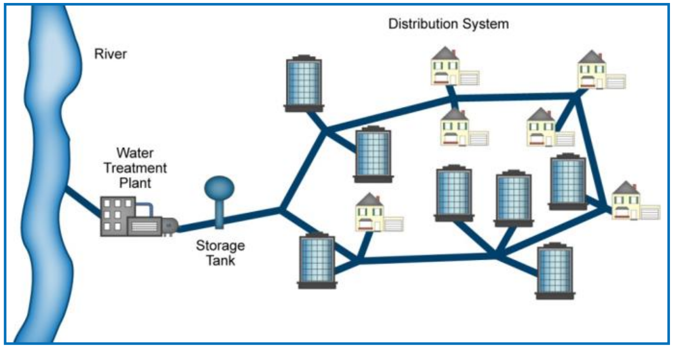
Background

- Contamination of storage tanks has been known to result in waterborne disease outbreaks
- Contaminants can attach to sediments and persist in water storage tanks
- Sediments can be resuspended and transported back into the water distribution network
- The potential risk to consumers is not well characterized



Sediment Survey and Analysis

- Study collected sediment samples from drinking water storage tanks at 25 U. S. locations
- Sediments were characterized by %clay, %sand, %silt, pH, total exchange capacity, total organic carbon, and %organic matter
- Contaminant adherence tests were conducted for four contaminants – biologicals adhered more readily than chemicals

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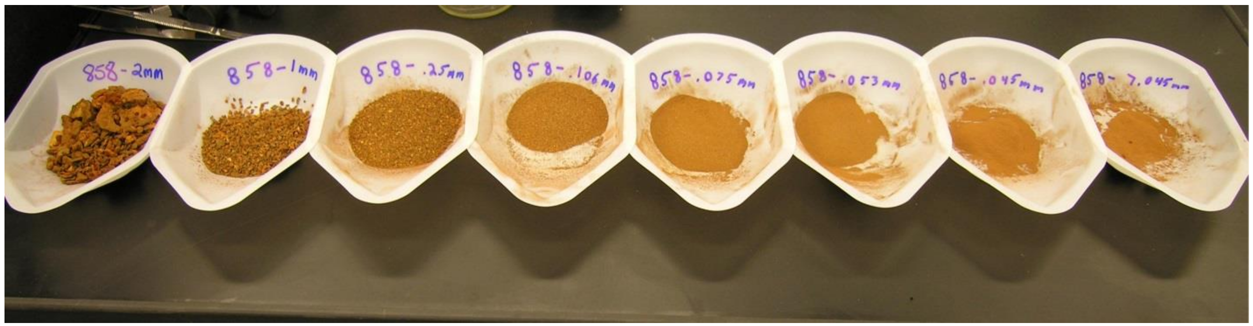
Sediment Particle Size



Bin Number	1	2	3	4	5	6	7	8
Particle Diameter (mm)	>2	1-2	.25-1	.106-.25	.075-.106	.053-.075	.045-.053	<.045
Mass Fraction	.5279	.1372	.1657	.856	.277	.255	.171	.132
Number Fraction	3.83e-5	3.99e-5	3.36e-4	.0122	.0579	.1504	.2686	.5106

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Objective and Approach

- To determine the conditions under which tank sediments might be resuspended, creating potential exposure risks for water consumers
  - Perform simulations to understand where and when particles move during filling and draining cycles in a water distribution storage tank
  - Determine impact of particle size, inlet diameter, flow rate, inlet location, and raised inlet on potential for particle resuspension
  - Perform experiment to verify models and characterize particle resuspension during filling and draining of a small-scale tank

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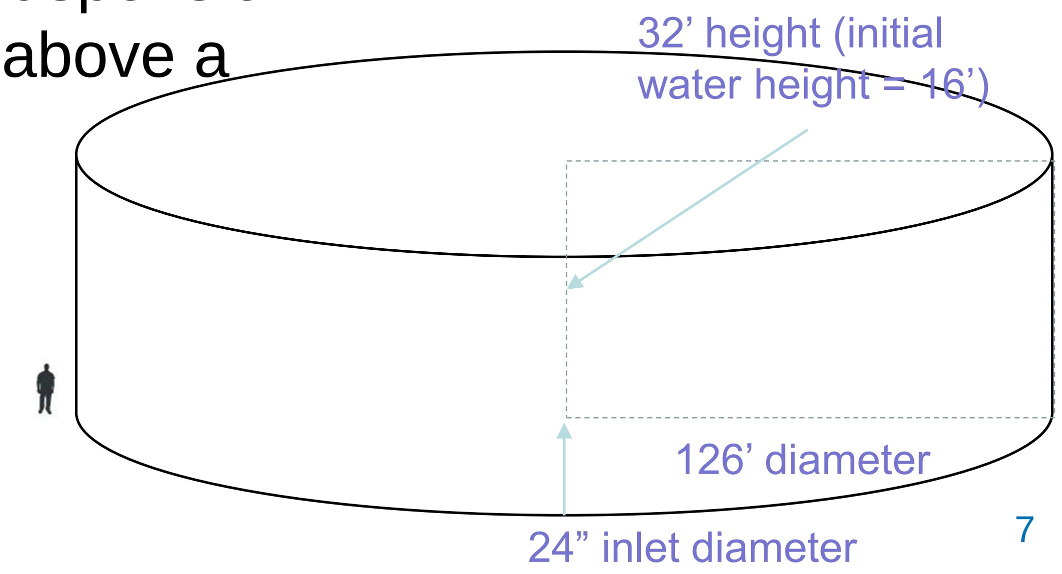
Modeling Methodology

- FLUENT CFD Software
- Accounts for liquid/air interface
- Uses turbulence model for flow
- Allows for particle resuspension when shear stress is above a threshold



“Operational” Simulation Study

- Goal: to understand where and when particles move during filling and draining cycles in a water distribution storage tank
- Assumptions:
  - Low and high inlet flow rates
  - Three particle sizes: 1, 0.1, and 0.01mm
  - 2,000 particles of each size distributed uniformly along bottom of tank
  - Start with tank half full, then filling cycle followed by draining cycle
  - 2D axisymmetric domain

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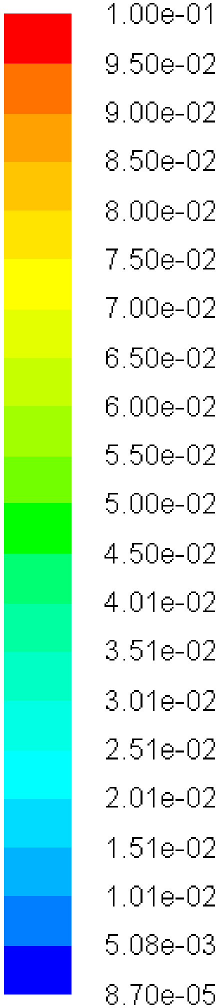
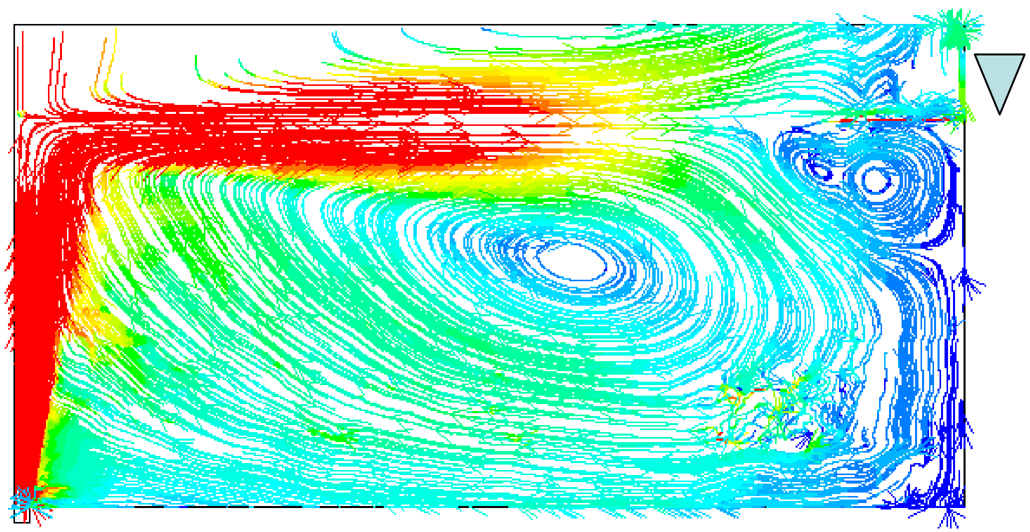
Flow pathlines during filling





t = 5400 s

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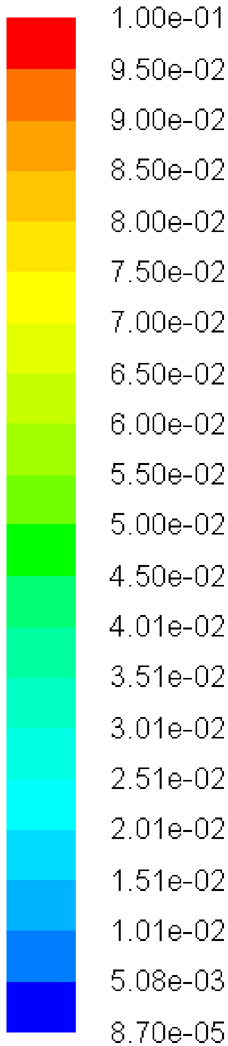
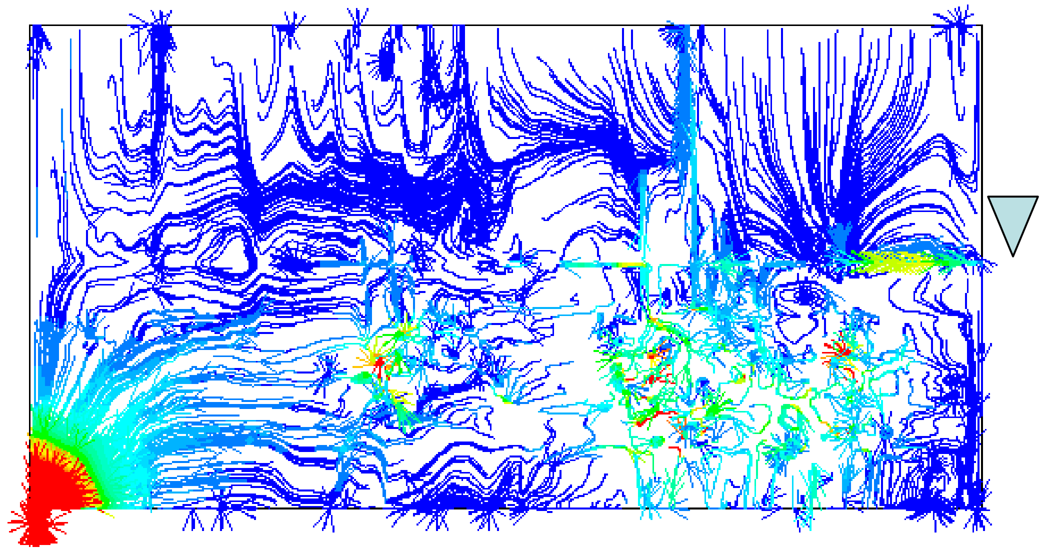
Flow pathlines during draining





t = 10,800 s

Particle Movement Animation

- High flow rate (10,000 gpm)

Simulated particle movement during filling and draining of a water-distribution storage tank (axi-symmetric)

Blue mesh = water

Red particles = 1 mm diameter

Green particles = 0.1 mm diameter

Blue particles = 0.01 mm diameter

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Results of Operational Study

- Particle resuspension from tank bottom generally occurred immediately following start of either filling or draining event
- During filling, particles typically carried further away from the inlet/outlet, making them less susceptible to removal
- Smaller particles were more susceptible to resuspension and entrainment
- Greater shear stress during draining led to more particle resuspension than during filling
- Recirculation zones of particles near the inlet/outlet were observed

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"Parametric" Simulation Study

- Goal: To determine the impact of particle size, inlet diameter, flow rate, inlet location, and raised inlet on potential for particle resuspension
- Assumptions:
  - 3D half-symmetry domain
  - 3 particle sizes
  - 2,000 particles of each size distributed uniformly along bottom of tank
  - 2 flow rates (high and low)
  - 2 inlet/outlet locations (near side wall or center)
  - 2 inlet/outlet diameters (24" or 36")
  - Start with tank half full and fill or drain until shear stresses are steady

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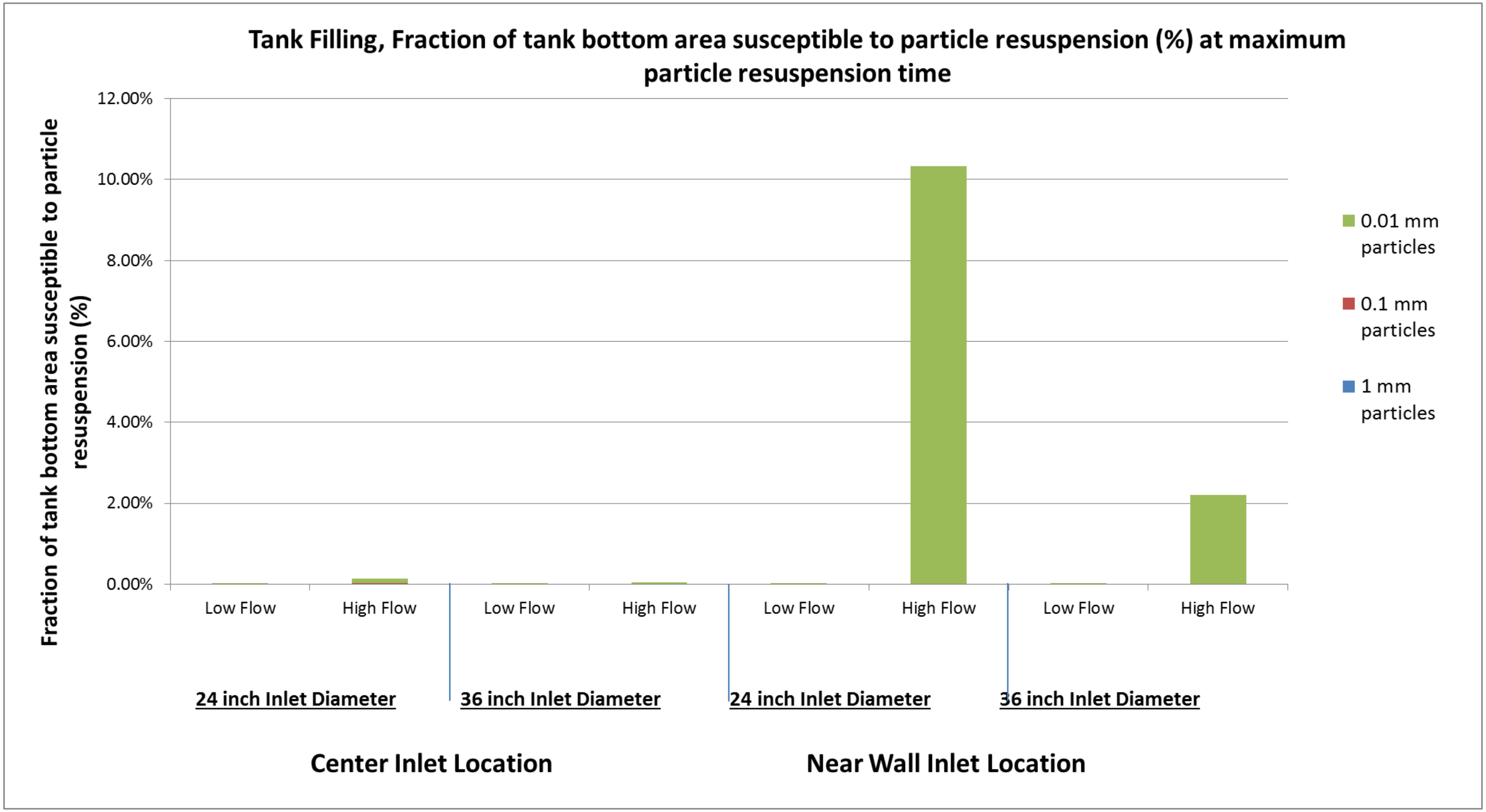
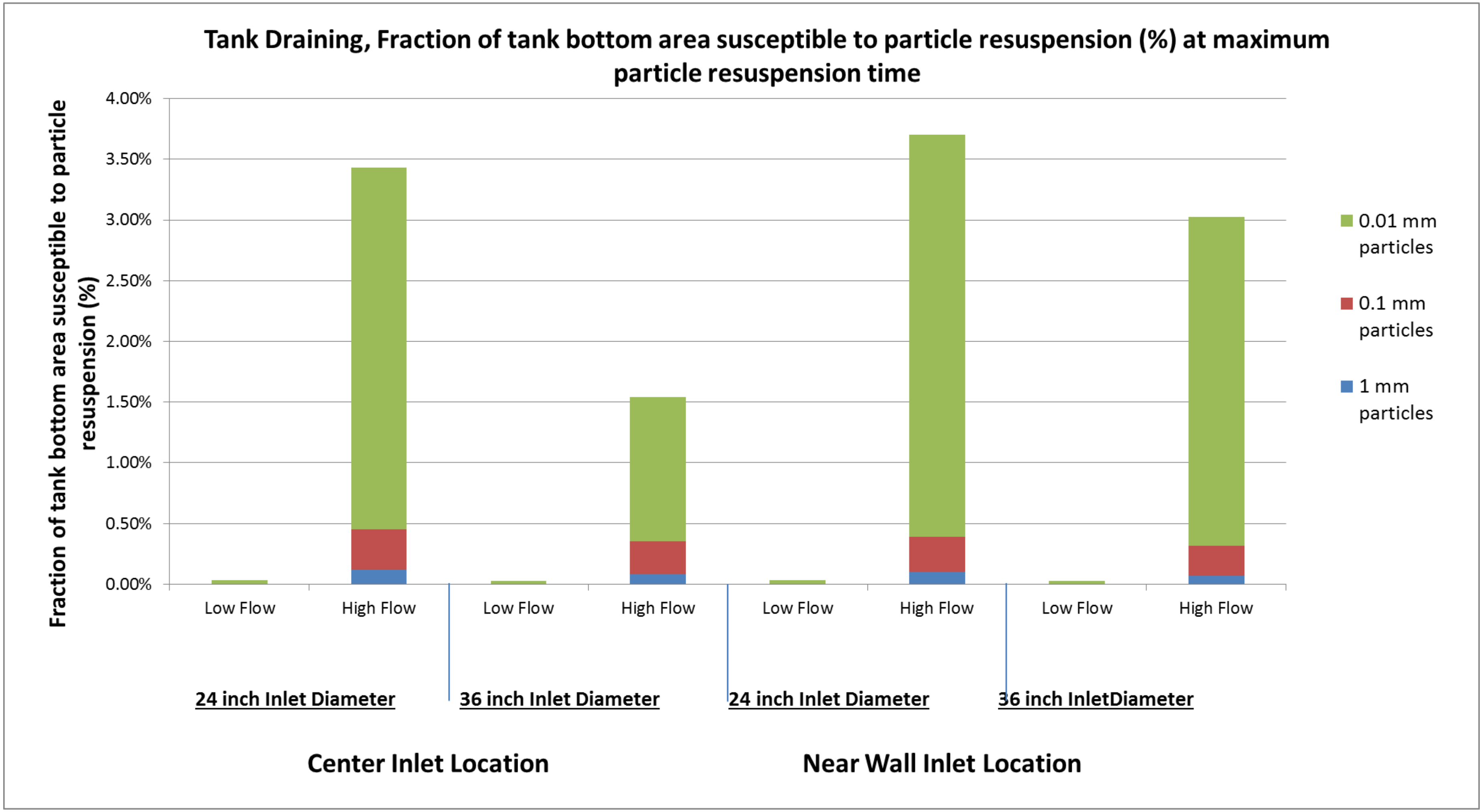
Results for Filling



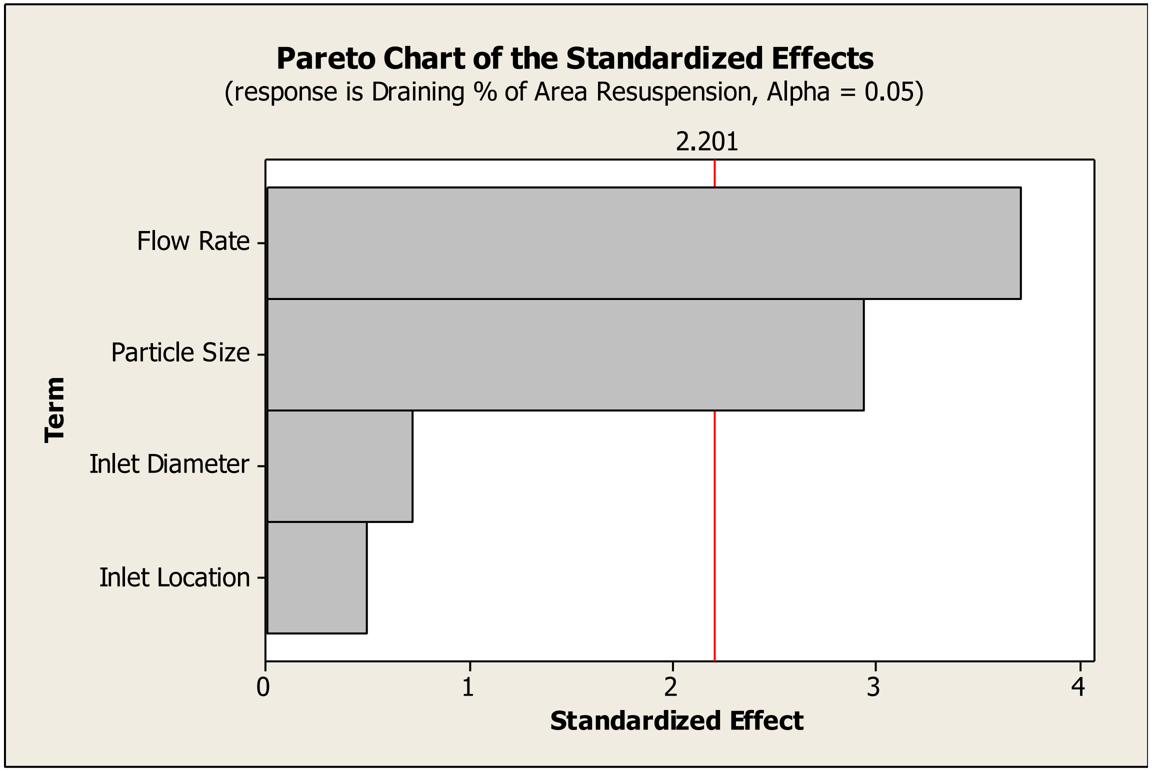
- Low flow = 0.215 m^3/s
- High flow = 0.631 m^3/s

Results for Draining

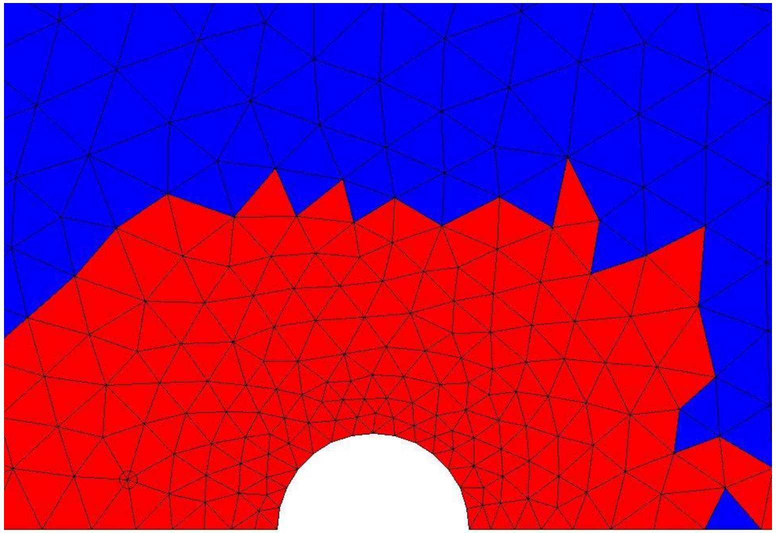


- Low flow = 0.215 m^3/s
- High flow = 0.631 m^3/s

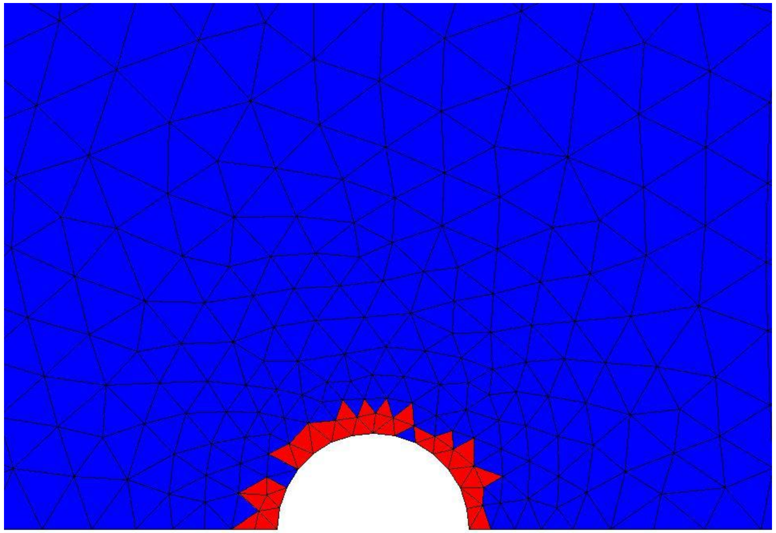
Importance of Factors on Resuspension



Draining: Location of Resuspended Particles for High vs. Low Flow Rates



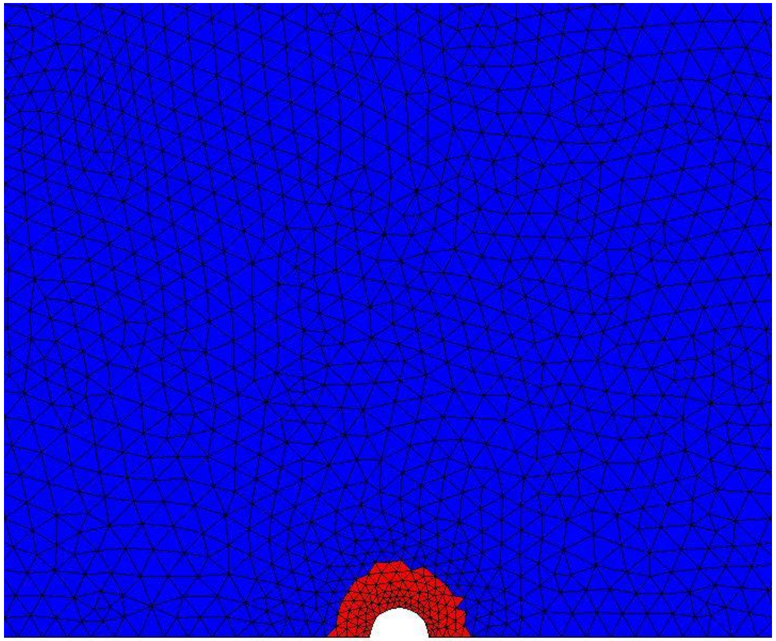
High flow rate



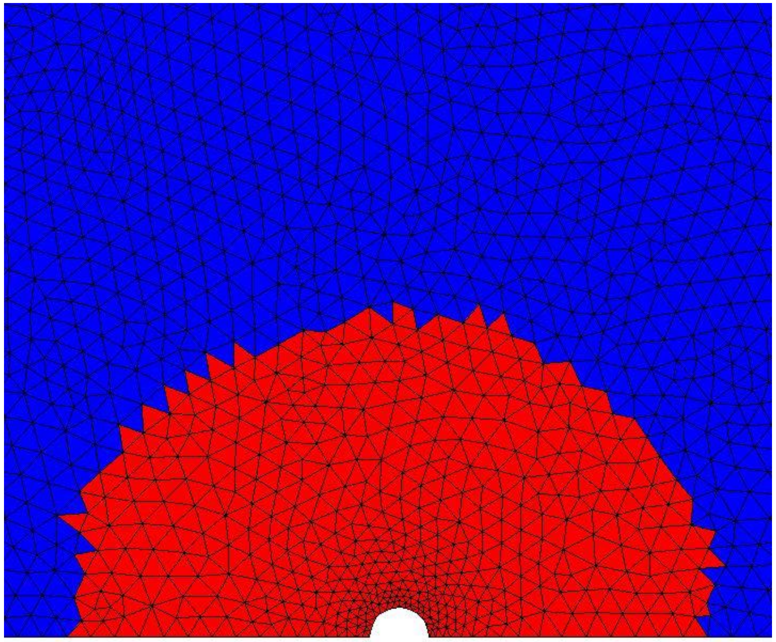
Low flow rate

24-in center inlet, 0.1 mm particle size

Draining: Location of Resuspended Particles for Large vs. Small Particles



1 mm size particles

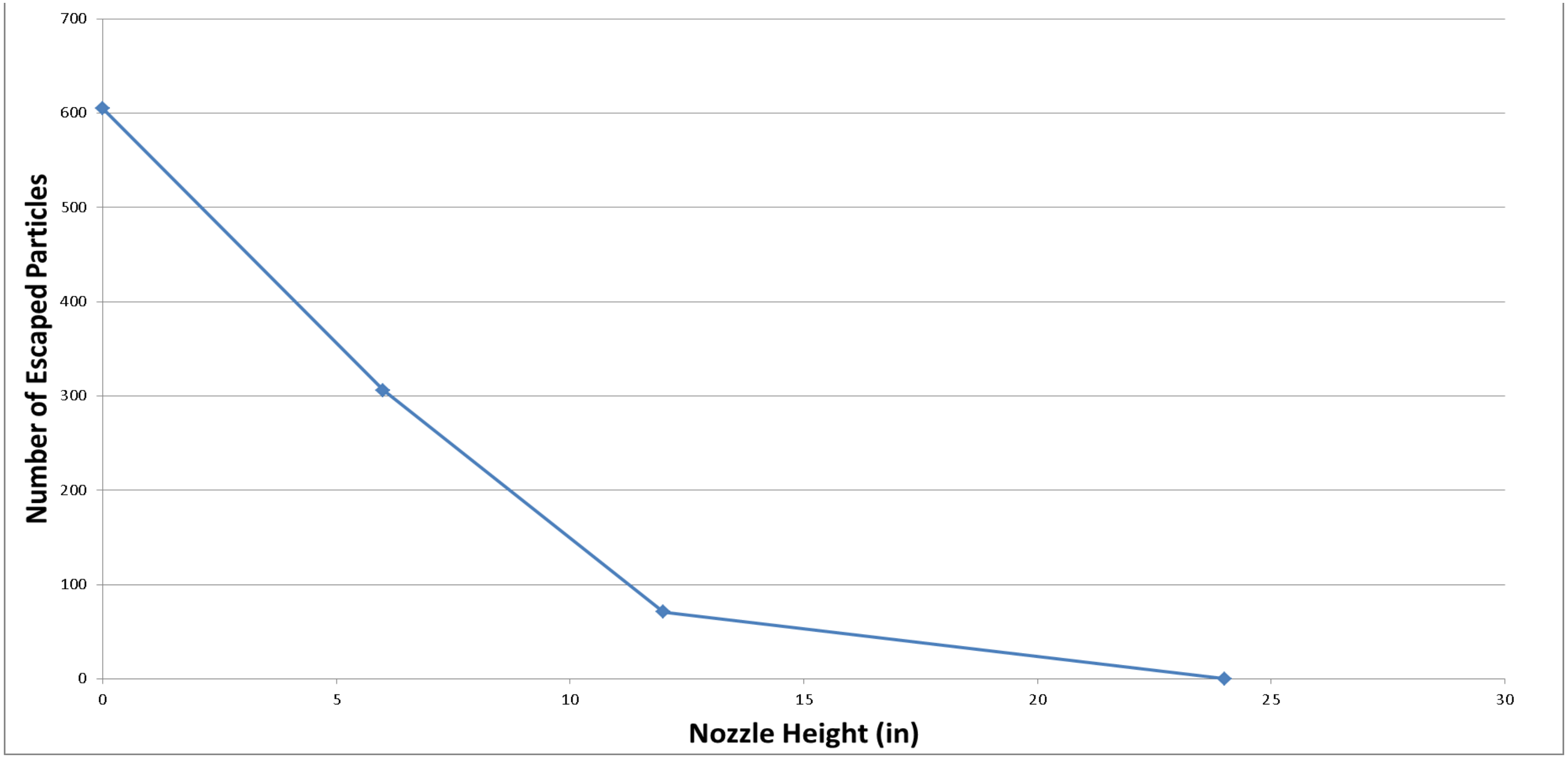


0.01 mm size particles

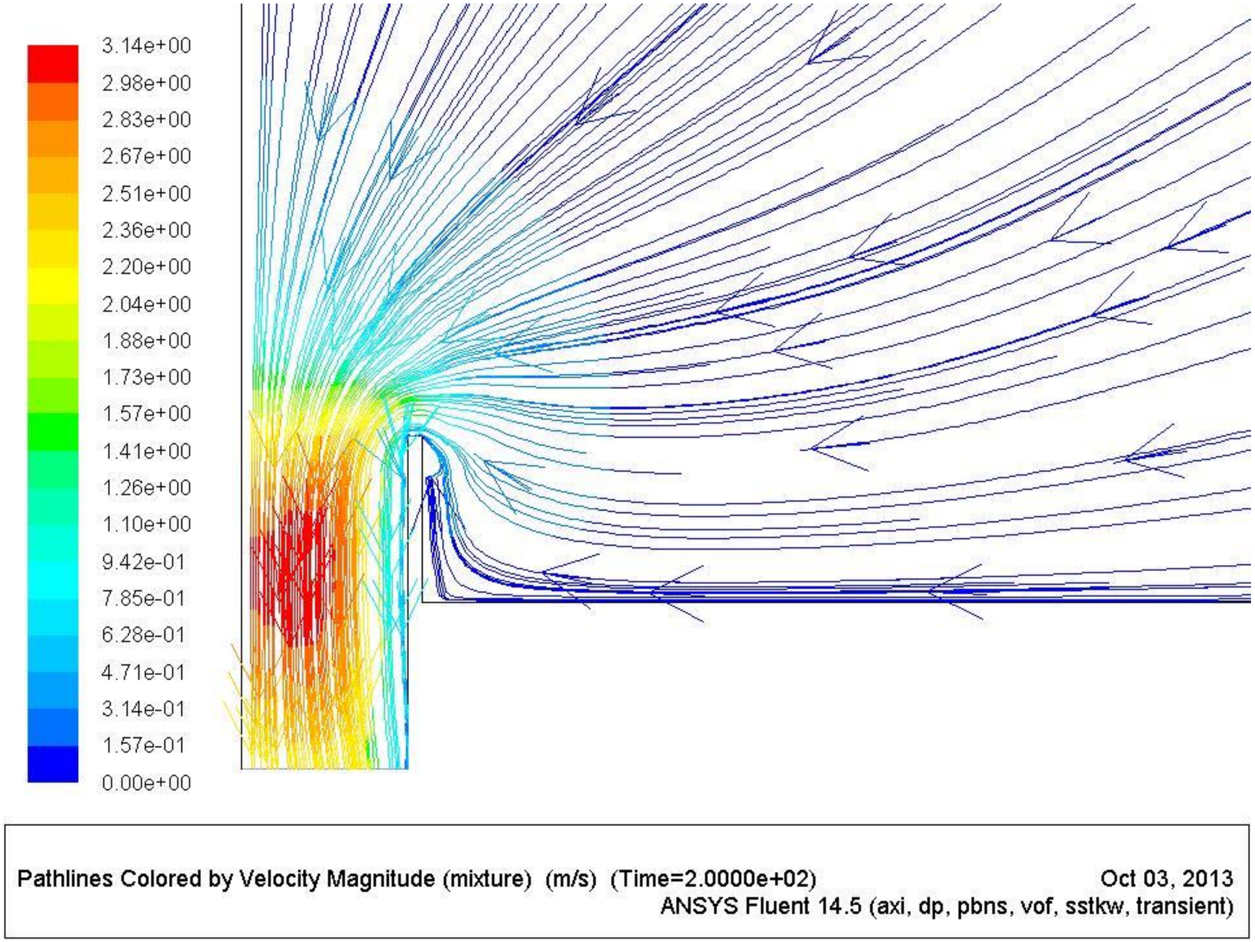
24-in center inlet, high flow rate

Raised Inlet to Reduce Removal

Raised Inlet Analysis



Raised Inlet Analysis – Draining



Results of Parametric Study

- Particle size, flow rate, and inlet location were important factors
  - Smaller particles were more susceptible to resuspension, although the difference was less during draining than filling
  - Higher flow rates yielded more resuspension
  - Near-wall inlet yielded more resuspension
  - More particles resuspended during draining than filling
- Raising the inlet into tank significantly reduces number of resuspended and removed particles

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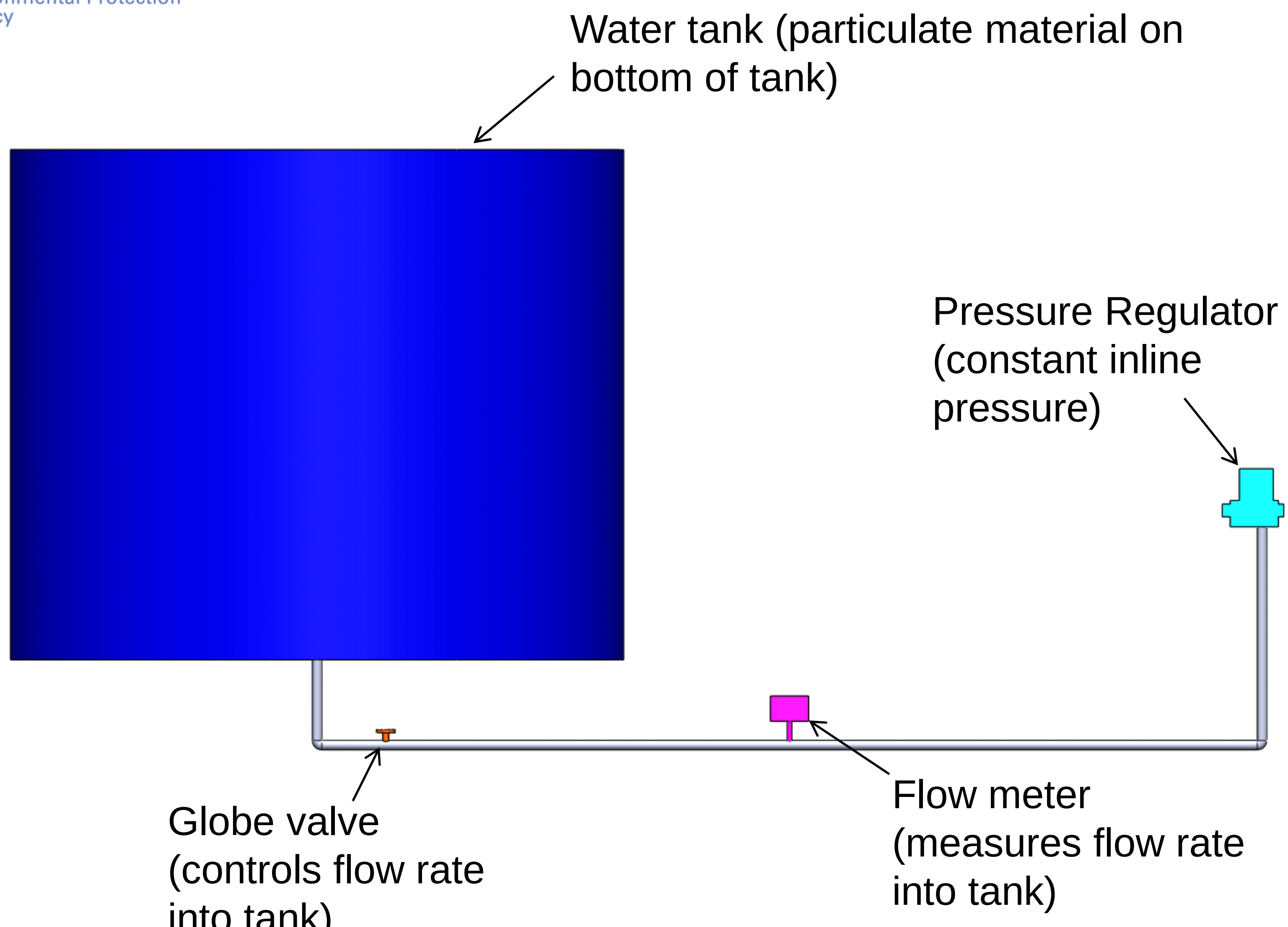
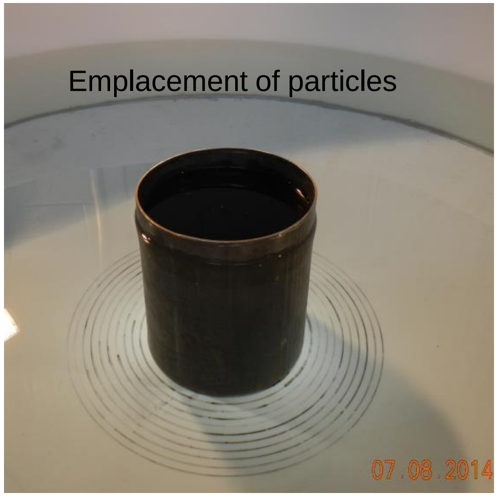
Experiments

- Goal: To perform small-scale tests to verify models and to observe particle resuspension during filling and draining
- Materials
  - –Plastic tank (48 inch diameter)
  - –Silica sand and glass beads
- Procedure
  - –Measure velocities in tank with center inlet location
  - –Observe particle behavior (suspension and relocation)
  - –Record extent of particle resuspension
  - –Measure particle loss while draining
  - –Vary flow rates and particle sizes

Experimental Setup





Emplacement of particles

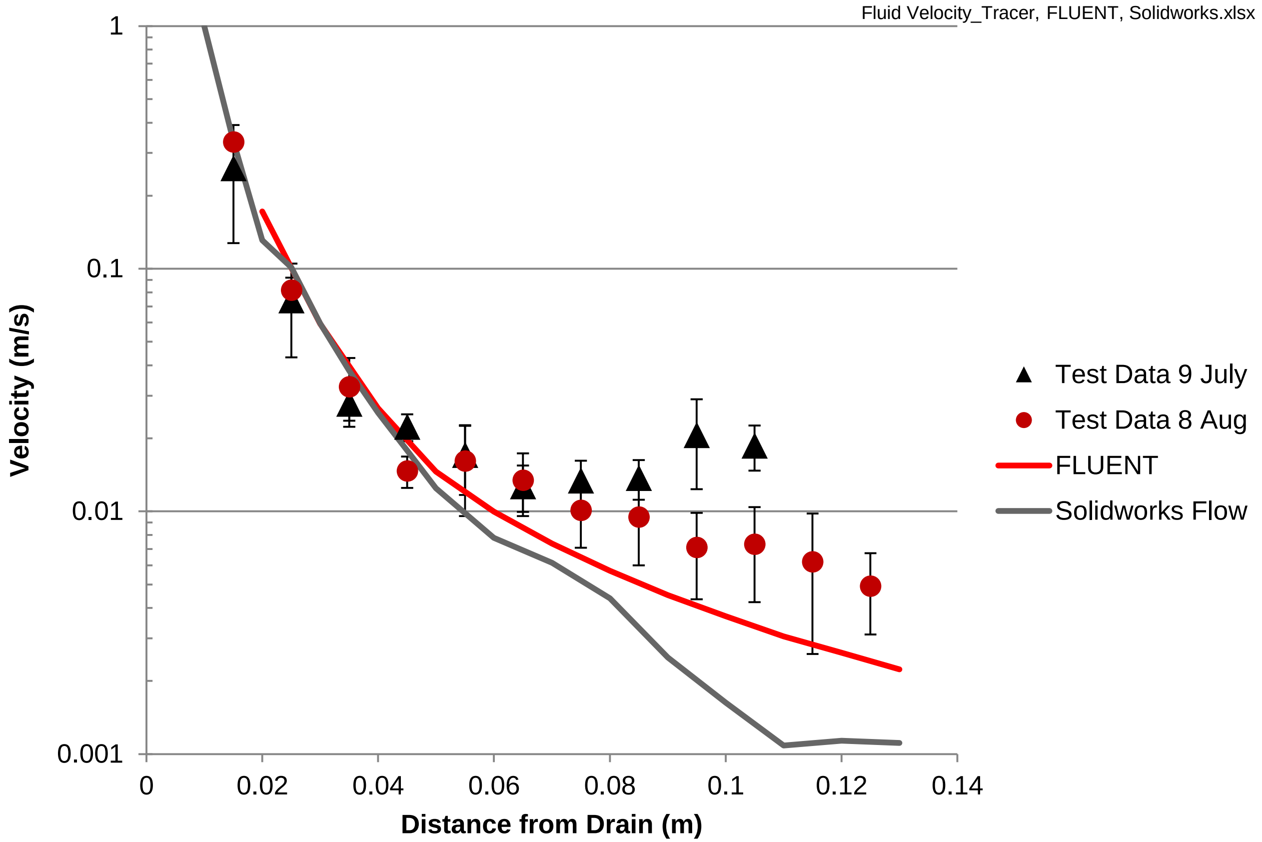
Valves to divert flow from filling to draining

Flow that was drained was diverted through sieves for collection and weighing

Dye Tests to Measure Velocities

Velocity Comparison
(Model vs. Experiment)

Fluid velocity as a function of distance from drain center



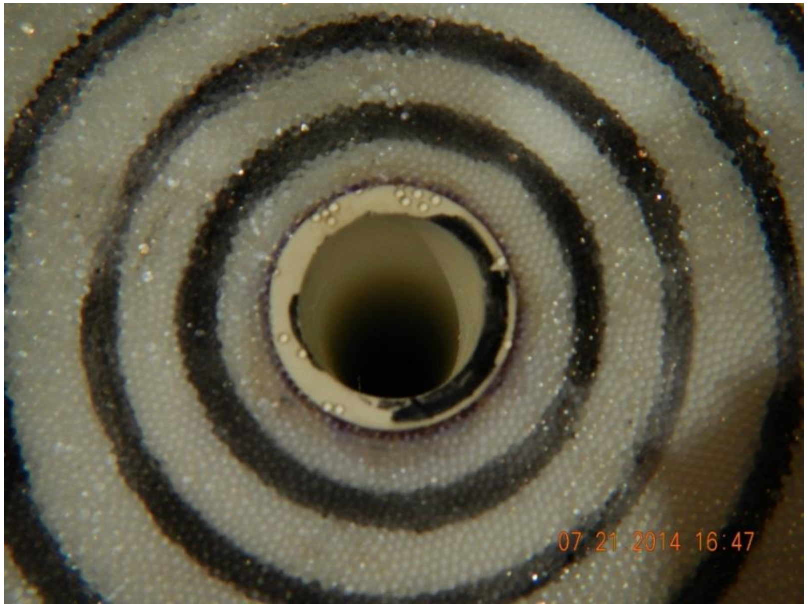
Draining – 0.853-1.68mm Silica Sand

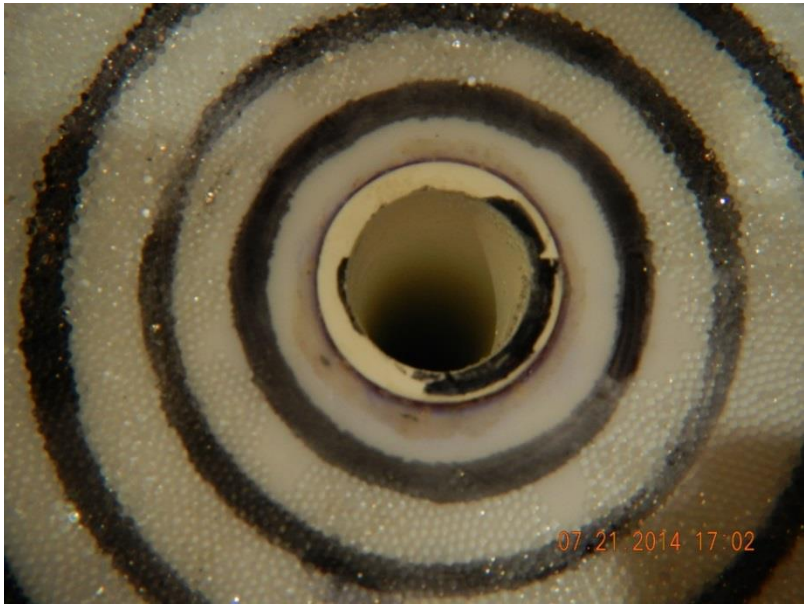
- Before Draining
- After Draining

Silica Sand Test – Draining

Draining – 1mm Glass Beads

- Before Draining
- After Draining





Results of Experimental Study

- Testing was performed to build confidence in the models
  - Measured & simulated velocities along tank bottom matched well up to ~5 cm from drain, including region where particles were resuspended
  - Model predictions generally matched experimental data for glass beads, and generally over predicted for silica sand
- Both modeling and experiments showed that a raised inlet reduced particle resuspension and removal during filling & draining
  - Minimum height to completely mitigate particle movement near the inlet/outlet was found to be about 3 - 8% of the head of water
    - In the tests, an extension of 1 cm (0.39”) mitigated particle movement with a maximum head of water of 30 cm (12”)
    - In the models, an extension of ~0.38 m (1.3 ft) mitigated particle movement with a head of water of 4.9 m (16 ft)

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Conclusions

- Particle size, flow rate, and inlet location important factors for resuspension
  - Small particles, high flow rates, and near-wall inlet resulted in more resuspension
- More particles resuspended during draining than filling because of greater shear stress
- Resuspension generally occurred immediately following start of either filling or draining event
- Entrainment of particles during filling typically carried particles further away from the inlet/outlet, making them less susceptible to removal
- Recirculation zones observed near the inlet/outlet