Integrated Stormwater Management (iSWM) Subcommittee Meeting

Staff Planner: Casey Cannon

July 13, 2022

North Central Texas
Council of Governments
Environment & Development

Agenda

1. **Welcome and Introductions**

PRESENTATION/ACTION ITEMS

2. **Approval of March 30, 2022, Meeting Summary.** A vote on the meeting summary as presented.

INFORMATION ITEMS

3. **Task Order 6 (Work Scope) Updates.** Task Order project updates on the FY22 Work Program task deliverables.
4. **Discuss iSWM Outcome 17 (Water Quality) Process.** The proposed revisions to the iSWM Criteria Manual and Tiered Measurement Form regarding Outcome 17 (Water Quality) will be presented to the Subcommittee.
5. **Discuss iSWM FY23 Contract & Work Program.** NCTCOG will update the Subcommittee on FY23 Contract procurement process and solicit input on the FY23 Work Program tasks.
6. **Arlington iSWM Application.** The City of Arlington has submitted for iSWM certification and the review process is pending. NCTCOG will update the Subcommittee on the status of their application.
7. **Regional Public Works Program Update.** NCTCOG will provide an update on the FY22 Regional Public Works Program.
8. **Total Maximum Daily Load Program Update.** NCTCOG will provide an update on the FY22 Total Maximum Daily Load Program.

OTHER BUSINESS AND ROUNDTABLE DISCUSSION

9. **Upcoming Events and Conferences.**

10. **Future Agenda Items and Roundtable Discussion.**

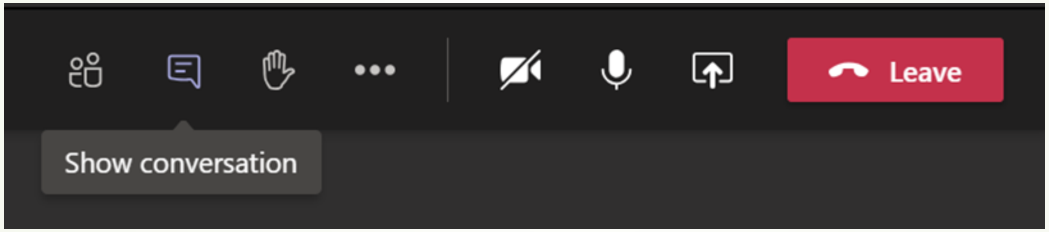
11. **Presentation on 3D Hydrodynamic Modeling for BMPS.** Dr. David Spelman from Bradley University will give a presentation on the general approach to modeling BMP devices with 3D Computational Fluid Dynamics, as well as the associated strengths and weaknesses.

12. **Schedule for the Next Meeting**. The next meeting is scheduled for October 5, 2022, online via Microsoft Teams.

Adjournment

WELCOME AND INTRODUCTIONS

- The meeting agenda, presentation and handouts are located on the iSWM Subcommittee webpage - https://www.nctcog.org/envir/committees/public-works-council/iswm-implementation-subcommittee
- Please use the chat function to add your name and organization for attendance



- Approval of March 30, 2022, Meeting Summary

Task Order 6 (Work Scope) Updates

FY22 Work Program Task Deliverables

- **Task 2 – Reorganize/Re-evaluate Site Development Controls**
  - BMP summary pages can be found online
- **Task 3 – BMP Design and Maintenance Training**
  - Virtual Training on permeable pavement held on December 9th, 2021
- **Task 4 – Technical Manual Updates**
  - Technical Manual Updates can be found online
- **Task 5 – Guidance on Forebay Design**
  - Memorandum on Forebay Design Guidance can be found online
- **Task 6 – Hydrologic Mimicry Research**
  - Memorandum with recommendations on Hydrologic Mimicry available online
- **Task 7 – Technical Assistance for Case Studies/Outcome 17**
  - Identifying and evaluating potential case studies/Outcome 17 Language Revisions
- **Task 8 – Economic Benefits of iSWM**
  - Brief educational documents are available online

Outcome 17 Updates

Background

- In 2014, the iSWM contractor was tasked with meeting with community members. NCTCOG learned that communities did not like the point system, and that the pass/fail grade was perceived as a barrier to communities becoming certified. The subcommittee determined that the point system would not be used moving forward. It was recommended that the water quality option 1 be revised or replaced.

17	Water Quality Protection				Require integrated site design practices; treat the water quality volume; and/or enact regional water quality programs	Section 1.3, Table 1.3; Section 3.2

Outcome 17 Updates

- NCTCOG staff and Halff Associates collaborated to develop initial recommended updates
- Volunteer members recommended putting a greater emphasis on treatment of the water quality volume than on the *integrated* site design practices
- Volunteers have provided comments, which have been taken into consideration by staff and Halff Associates
- Documents posted online.

17	Water Quality Protection				Require treatment of water quality protection volume and participation in regional offsite treatment, when available	Section 1.3, Table 1.3; Section 3.2	

Outcome 17 Updates

Removal of Options in Water Quality Protection

3.2 Water Quality Protection

3.2.1 Introduction

iSWM requires the use of *integrated* Site Design Practices as the primary means to protect the water quality of our streams, lakes, and rivers from the negative impacts of stormwater runoff from development. The *integrated* Site Design Practices shall be designed as part of the iSWM Plans. In addition to the *integrated* Site Design Practices, required water quality protection can be achieved by two additional options: (1) by treating the water quality protection volume and (2) assisting with off-site pollution prevention activities. These three approaches are described below.

Local Provisions:

3.2.2 Option 1: integrated Site Design Practices and Credits

The *integrated* Site Design Practices are methods of development that reduce the "environmental footprint" of a site. They feature conservation of natural features, reduced imperviousness, and the use of the natural drainage system. In this option, points are awarded for the use of different Site Design Practices. A minimum number of points are needed to meet the iSWM requirements for Water Quality. Additional points can be gained to qualify for development incentives.

List of *integrated* Site Design Practices and Techniques

Twenty *integrated* Site Design Practices are grouped into four categories listed below. Not all practices are applicable to every site.

- **Conservation of Natural Features and Resources**
  1. Preserve Undisturbed Natural Areas
  2. Preserve Riparian Buffers
  3. Avoid Floodplains
  4. Avoid Steep Slopes
  5. Minimize Siting on Porous or Erodible Soils
- **Lower Impact Site Design Techniques**
  6. Fit Design to the Terrain
  7. Locate Development in Less Sensitive Areas
  8. Reduce Limits of Clearing and Grading
  9. Utilize Open Space Development

3.2.3 Option 2: Treat the Water Quality Protection Volume

Treat the Water Quality Protection Volume by reducing total suspended solids from the development site for runoff resulting from rainfall of 1.5 inches (85th percentile storm). Stormwater runoff equal to the Water Quality Protection Volume generated from sites must be treated using a variety of on-site structural and nonstructural techniques with the goal of removing a target percentage of the average annual total suspended solids.

A system has been developed by which the Water Quality Protection Volume can be reduced, thus requiring less structural control. This is accomplished through the use of certain reduction methods, where affected areas are deducted from the site area, thereby reducing the amount of runoff to be treated. For more information on the Water Quality Volume Reduction Methods see *Section 1.3 of the Water Quality Technical Manual*.

3.2.4 Option 3: Assist with Off-Site Pollution Prevention Programs and Activities

Some communities have implemented pollution prevention programs/activities in certain areas to remove pollutants from the runoff after it has been discharged from the site. This may be especially true in intensely urbanized areas facing site redevelopment where many of the BMP criteria would be difficult to apply. These programs will be identified in the local jurisdiction's approved TPDES stormwater permit and/or in a municipality's approved watershed plan. In lieu of on-site treatment, the developer can request to simply assist with the implementation of these off-site pollution prevention programs/activities.

Developers should contact the municipality to determine if there are any plans to address runoff pollutants within the region of proposed development. If no plans exist, consider proposing regional alternatives that would address pollution prevention.

Outcome 17 Updates

Removal of Point System in Water Quality Protection

3.2 Water Quality Protection

3.2.1 Introduction

iSWM requires the use of *integrated* Site Design Practices as the primary means to protect the water quality of our streams, lakes, and rivers from the negative impacts of stormwater runoff from development. In addition to integrated Site Design Practices, iSWM requires treating the water quality protection volume (Option 1). Assisting with off-site pollution prevention activities (Option 2) is dependent on the availability of a regional program and is encouraged, but not the primary intent. These three approaches are described below.

[Local Provisions:]

3.2.2 *integrated Site Design Practices* ~~*and Credits*~~

The *integrated* Site Design Practices are methods of development that reduce the "environmental footprint" of a site. They feature conservation of natural features, reduced imperviousness, and the use of the natural drainage system. ~~In this option, points are awarded for the use of different Site Design Practices. A minimum number of points are needed to meet the iSWM requirements for Water Quality. Additional points can be gained to qualify for development incentives.~~

List of *integrated* Site Design Practices and Techniques

Twenty *integrated* Site Design Practices are grouped into four categories listed below. Not all practices are applicable to every site.

- **Conservation of Natural Features and Resources**
  1. Preserve Undisturbed Natural Areas
  2. Preserve Riparian Buffers
  3. Avoid Floodplains
  4. Avoid Steep Slopes
  5. Minimize Siting on Porous or Erodible Soils
- **Lower Impact Site Design Techniques**
  6. Fit Design to the Terrain
  7. Locate Development in Less Sensitive Areas
  8. Reduce Limits of Clearing and Grading
  9. Utilize Open Space Development

~~**Point System**~~

~~All sites that meet iSWM applicability must provide on-site enhanced water quality protection. Under the *integrated* Site Design Practice option, sites that accumulate a minimum number of points by incorporating *integrated* Site Design Practices are considered to have provided enhanced water quality protection.~~

~~The point system is made up of three components:~~

1. ~~The initial percentage of the site that has been previously disturbed sets the minimum requirement. This is shown in the left-hand column of Table 3.4.~~
2. ~~A minimum required total of Water Quality Protection (WQP) points is needed to meet the basic water quality criteria. This minimum is shown in the center column of Table 3.4.~~
3. ~~Optional additional points can be accumulated through additional use of Site Design Practices to be eligible for developer incentives. Each developer incentive attained requires ten (10) additional Site Design Practice points above the minimum required points as shown in the right-hand column of Table 3.4.~~

~~As shown in Table 3.4, the initial percentage of site disturbance sets the minimum required points necessary to meet Water Quality Protection criteria. If a developer wishes to go beyond this minimum then the number of additional points required to attain specific development incentives is also given.~~

~~Table 3.4 *integrated* Site Design Point Requirements~~

~~Percentage of Site (by Area) with Natural Features Prior to Proposed Development~~	~~Minimum Required Points for Water Quality Protection (WQP)~~	~~Additional Points Above WQP for Development Incentives~~
~~> 50%~~	~~50~~	~~10 points each~~
~~20 - 50%~~	~~30~~	~~10 points each~~
~~< 20%~~	~~20~~	~~10 points each~~

~~The minimum number of points required to achieve WQP, as shown in the center column of Table 3.4, depends on the proportion of undisturbed natural features that exist on the site before it is developed. It is assumed that disturbing a site that has little previously disturbed area will cause more relative environmental impact than a site that has already incurred significant site disturbance. Therefore, disturbing a "pristine" site carries a higher restoration/preservation requirement.~~

~~For the purpose of this evaluation, undisturbed natural features are areas with one or more of the following characteristics:~~

- ~~Unfilled floodplain~~
- ~~Stand of trees, forests~~
- ~~Established vegetation~~
- ~~Steep sloped terrain~~
- ~~Creeks, gullies, and other natural stormwater features~~
- ~~Wetland areas and ponds~~

~~The number of points credited for the use of *integrated* Site Design Practices is shown in Table 3.5. To determine the qualifying points for a site, the developer must reference Table 3.5 and follow the guidance for each practice in the *Planning Technical Manual*.~~

Outcome 17 Updates

Proposed Revisions: *integrated* Site Design Practices

2.0 *integrated* Development Process

This Chapter discusses the five-step development process. Local governments will integrate these processes into their current process by the addition of local provisions.

2.1 Planning

2.1.1 *integrated Site Design Practices*

The *integrated* Site Design Practices are methods of development that reduce the "environmental footprint" of a site that conserves natural features, reduces imperviousness, and uses of the natural drainage features as much as practicable .

List of *integrated* Site Design Practices and Techniques

Twenty *integrated* Site Design Practices are grouped into four categories listed below. Not all practices are applicable to every site. It is recommended to implement at least 50% of the practices that are applicable to each site.

- **Conservation of Natural Features and Resources**
  1. Preserve Undisturbed Natural Areas
  2. Preserve Riparian Buffers
  3. Avoid Floodplains
  4. Avoid Steep Slopes
  5. Minimize Siting on Porous or Erodible Soils
- **Lower Impact Site Design Techniques**
  6. Fit Design to the Terrain
  7. Locate Development in Less Sensitive Areas
  8. Reduce Limits of Clearing and Grading
  9. Utilize Open Space Development
  10. Consider Creative Designs
- **Reduction of Impervious Cover**
  11. Reduce Roadway Lengths and Widths
  12. Reduce Building Footprints
  13. Reduce the Parking Footprint
  14. Reduce Setbacks and Frontages
  15. Use Fewer or Alternative Cul-de-Sacs
  16. Create Parking Lot Stormwater "Islands"
- **Utilization of Natural Features for Stormwater Management**
  17. Use Buffers and Undisturbed Areas
  18. Use Natural Drainageways Instead of Storm Sewers
  19. Use Vegetated Swale Instead of Curb and Gutter
  20. Drain Rooftop Runoff to Pervious Areas

Outcome 17 Updates

Proposed Revisions: Water Quality Protection

3.2 Water Quality Protection

3.2.1 Introduction

iSWM requires the use of the water quality protection volume to capture the 85th percentile of the 24-hour storm as the primary means to protect the water quality of our streams, lakes, and rivers from the negative impacts of stormwater runoff from development. While the treatment of the water quality protection volume is required by iSWM, it is also recommended to minimize the need for treatment by utilizing the *integrated* Site Design Practices, as described in Section 2.1.1. In addition to the water quality protection volume, iSWM encourages involvement in off-site pollution prevention activities, but it is not the primary intent of iSWM.

[Local Provisions:]

3.2.2 Treat the Water Quality Protection Volume

Treat the Water Quality Protection Volume by reducing total suspended solids from the development site for runoff resulting from the 85th percentile of the 24-hour storm (1.5 inches). Stormwater runoff equal to the Water Quality Protection Volume generated from sites must be treated using a variety of on-site structural and non-structural techniques with the goal of removing a target percentage of the average annual total suspended solids.

The Water Quality Protection Volume can be reduced through practices . given in *Section 1.3 of the Water Quality Technical Manual.*

Water Quality Protection Volume

The Water Quality Protection Volume (WQ_v) is the runoff from the first 1.5 inches of rainfall. Thus, a stormwater management system designed for the WQ_v will treat the runoff from all storm events of 1.5 inches or less, as well as a portion of the runoff for all larger storm events. For methods to determine the WQ_v, see *Section 1.2 of the Water Quality Technical Manual.*

[Local Provisions:]

3.2.3 Assist with Off-Site Pollution Prevention Programs and Activities

Some communities have implemented pollution prevention programs/activities in certain areas to remove pollutants from the runoff after it has been discharged from the site. This may be especially true in intensely urbanized areas facing site redevelopment where many of the BMP criteria would be difficult to apply. These programs could include a regional Watershed Protection Plan, or may be identified in the local jurisdiction's approved TPDES stormwater permit and/or in a municipality's approved watershed plan. When on-site treatment options are very limited, the developer may request an alternative of assisting with the implementation of these off-site pollution prevention programs/activities.

Developers should contact the municipality to determine if there are any plans to address runoff pollutants within the region of proposed development. If no plans exist, consider proposing regional alternatives that would address pollution prevention.

[Local Provisions:]

Outcome 17 Updates

Proposed Revisions: Table 1.3

Table 1.3 Summary of Options for Design Focus Areas

Design Focus Area	Reference Section	Required Downstream Assessment	Design Options
Water Quality Protection	3.2	no	**Option 1:** Use *integrated* Site Design Practices for conserving natural features, reducing impervious cover, and using the natural drainage systems
			Option 2: Treat the Water Quality Protection Volume (WQ_v) by reducing total suspended solids from the development site for runoff resulting from rainfalls of up to 1.5 inches (85^{th} percentile storm)
			Option 3: Assist in implementing off-site community stormwater pollution prevention programs/activities as designated in an approved stormwater master plan or TPDES Stormwater permit

Outcome 17 Updates

Proposed Revisions: Table 1.3

Table 1.3 Summary of Options for Design Focus Areas

Design Focus Area	Reference Section	Required Downstream Assessment	Design Options
Water Quality Protection	3.2	no	**Required:** Treat the Water Quality Protection Volume (WQ_V) by reducing total suspended solids from the development site for runoff resulting from rainfalls of up to 1.5 inches (85th percentile storm)
			AND Assist in implementing off-site community stormwater pollution prevention programs/activities such as a nearby Watershed Protection Plan, or as designated in an approved stormwater master plan or TPDES Stormwater permit
			Recommended: Use *integrated* Site Design Practices for conserving natural features, reducing impervious cover, and using the natural drainage systems

iSWM PROGRAM UPDATES

FY23 Contract & Work Program

- The FY23 contract is undergoing review as part of the procurement process. There will be a need for volunteers to help score RFSQ responses in the fall.
- There is also a need to determine Work Program tasks for FY23. Staff is requesting members recommend potential tasks for the Work Program

Arlington iSWM Application Review

- The Review of Arlington's iSWM Application is pending.
- The Review board has completed the initial review but is requesting clarification on one item before finishing certification.

PUBLIC WORKS PROGRAM UPDATE

- Public Works Council (PWC), August 18th, 9:30am in-person at NCTCOG Offices (Regional Forum Room)

- Annual Public Works Roundup, September 13th, 2022, in-person at the Grapevine Convention Center
  - Registration will open in early July
  - More information, including sponsorship opportunities, can be found online.

For more information on the Public Works program please contact Erin Blackman at eblackman@nctcog.org or (817) 608-2360.

PUBLIC WORKS PROGRAM UPDATE

- Upcoming trainings and events:

  - Basic Wastewater Operations Training, August 2 – 4, in-person at NCTCOG Offices

  - Water Distribution Training, September 6 – 8, in-person at NCTCOG Offices

  - Public Works Training Calendar

For more information on the Public Works program please contact Erin Blackman at eblackman@nctcog.org or (817) 608-2360.

TMDL PROGRAM UPDATE

- New Resources Under Development:
  - "***Don't Feed the Birds***" and "***No Muss, No Flush – Be Wise When You Flush***" educational explainer videos (expected to be finalized after upcoming joint subcommittee meeting)

- Upcoming Meetings and Events:
  - **Joint TMDL Stormwater and Wastewater Technical Subcommittee Meeting:**
    July 26, 2022 at 9:30 AM via Microsoft Teams
  - **Upper Trinity River Basin Coordinating Committee:**
    August 16, 2022 at 9:30 AM via Microsoft Teams
  - **TMDL Monitoring Coordination Forum Technical Subcommittee Meeting:**
    September 29, 2022 at 9:30 AM via Microsoft Teams

For more information on the TMDL program please contact Hannah Allen at hallen@nctcog.org or (817) 695-9215.

TMDL PROGRAM UPDATE

- TMDL Implementation Plan Items:
  - ***Dry Branch Creek TMDL Technical Support Document*** under development by the Texas Institute for Applied Environmental Research. TIAER presented at the June 15th TMDL Coordination Committee Meeting (slides available online)
  - ***TCEQ's Public Comment Period for North Fork Cottonwood Creek(NFCC) Addendum and State Water Quality Management Plan (WQMP)*** closed in early June and will be going to EPA for approval. Following approval, NCTCOG will receive the Addendum for NFCC and incorporate into the Implementation Plan.

For more information on the TMDL program please contact Hannah Allen at hallen@nctcog.org or (817) 695-9215.

UPCOMING EVENTS, CONFERENCES, AND OPPORTUNITIES

- Texas Floodplain Management Association 2022 Technical Summit
  - August 23-26, 2022 in Lost Pines, Texas
  - Registration available online.
- iSWM "Interim" Conditions of Development Survey
  - Please respond to the survey online .

ROUNDTABLE DISCUSSION

UPCOMING NCTCOG MEETINGS

Next iSWM Meeting: October 5, **2022** at 1:30 p.m.

- Regional Stormwater Management Coordinating Council, **August 17, 2022**
- Public Works Council Meeting, **August 18, 2022**
- Joint TMDL Stormwater & Wastewater Technical Subcommittee Meeting, **July 26, 2022**
- Upper Trinity River Basin Coordinating Committee, **August 16, 2022**
- TMDL Monitoring Coordination Forum Technical Subcommittee Meeting, **September 29**, **2022**

Meeting Information at:

https://www.nctcog.org/envir/committees

UPCOMING iSWM Agenda Topics

Next iSWM Meeting: October 5, 2022 at 1:30 p.m.

- Discussion of the proposed new iSWM contract. NCTCOG will need volunteers for scoring committee – please contact Casey Cannon at ccannon@nctcog.org or (817) 608-2323.

CFD Applications in Stormwater Treatment

Dr. David Spelman
Assistant Professor
dspelman@fsmail.bradley.edu

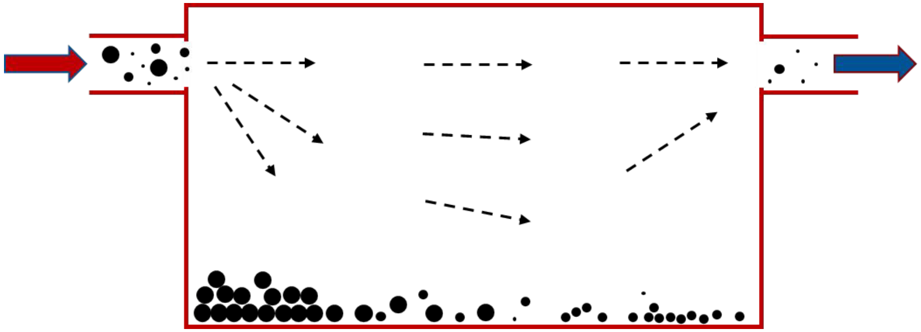
Background

1. Stormwater transports particulate matter (PM) which acts as a vehicle for anthropogenic pollutants such as nutrients, metals, and pathogens

2. Removal of PM is a primary focus of stormwater control and regulation

3. Primarily separated via gravitational sedimentation in devices ranging from small footprint, underground concrete tanks to large wet detention ponds

4. PM transport and fate processes can be modeled using computational fluid dynamics (CFD)



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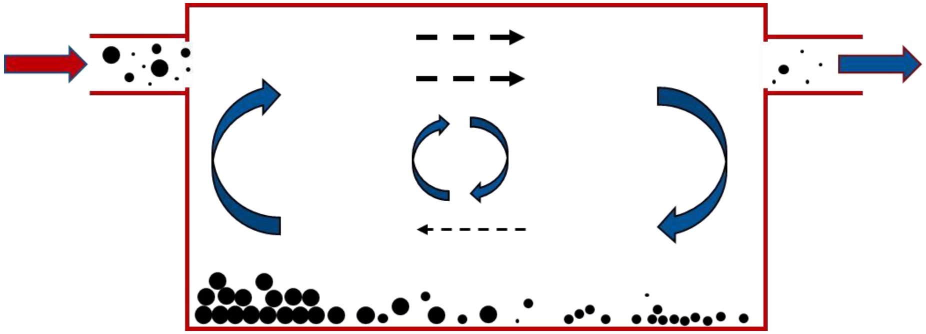
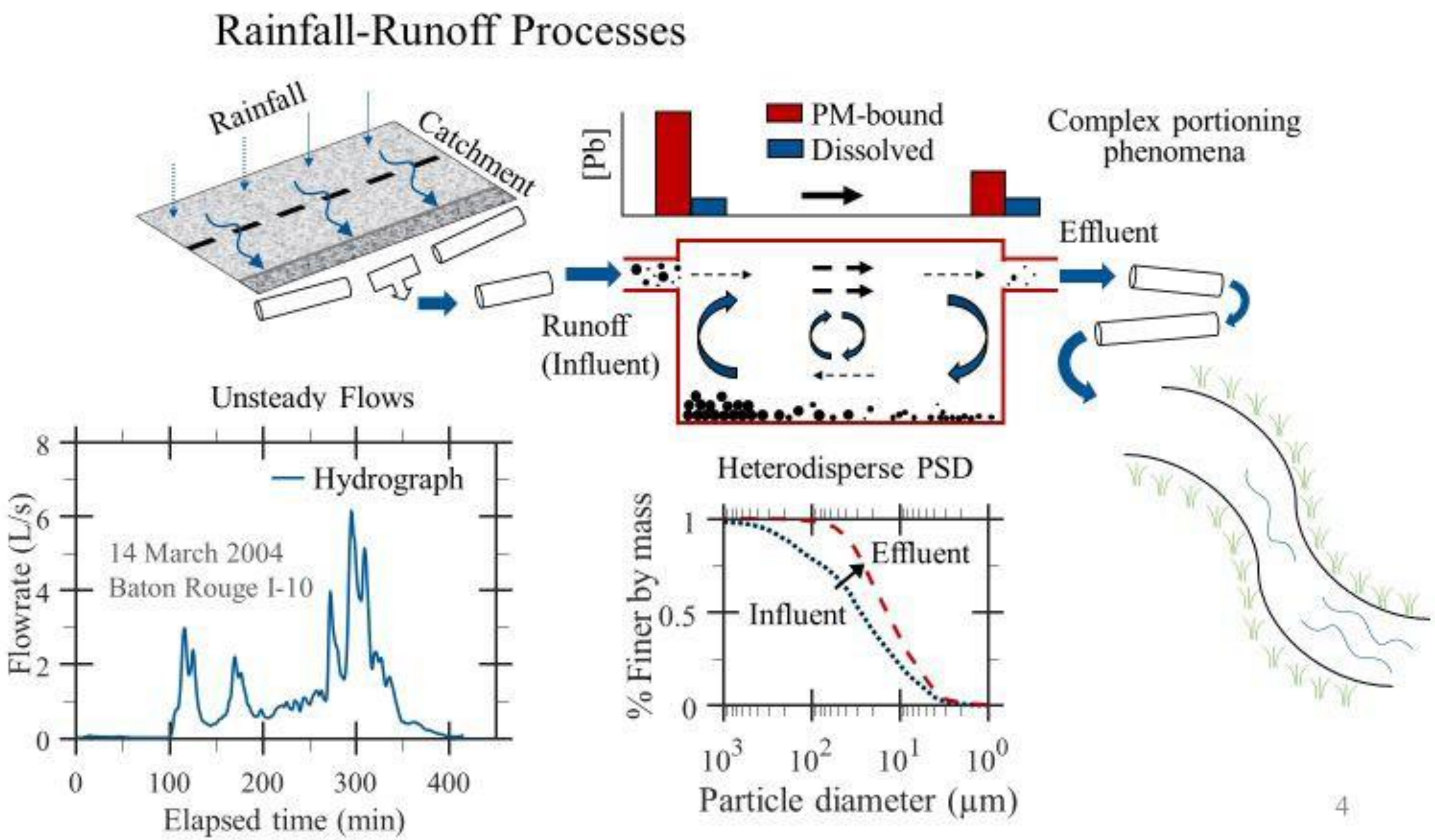




Rainfall-Runoff Processes
Rainfall
Catchment
[Pb]
PM-bound
Dissolved
Complex portioning phenomena
Effluent
Runoff (Influent)
Unsteady Flows
Hydrograph
14 March 2004
Baton Rouge I-10
Flowrate (L/s)
Elapsed time (min)
Heterodisperse PSD
% Finer by mass
Effluent
Influent
Particle diameter (μm)
4

Unique Challenges for Stormwater

Monitoring Challenges

- Full scale monitoring of stormwater treatment systems in notoriously difficult
- Difficult and expensive to measure flow velocities in the field
- Limited opportunity for benchmarking CFD models due to lack of available data

Unique Challenges for Stormwater

Time scale

- Flows are highly unsteady
- Small time steps needed for unsteady simulation
- Long simulation durations needed
  - Event-based simulation O(hours-days)
  - Continuous simulation O(months-years)
- Steady simulation inappropriate but unsteady simulation impractical

Unique Challenges for Stormwater

Spatial scale

- Capturing important flow characteristics necessitate fine grids
- Systems can be very large - basins
- For basins, z dimension is orders of magnitude smaller than x,y

Unique Challenges for Stormwater

Stormwater systems act as temporary storage

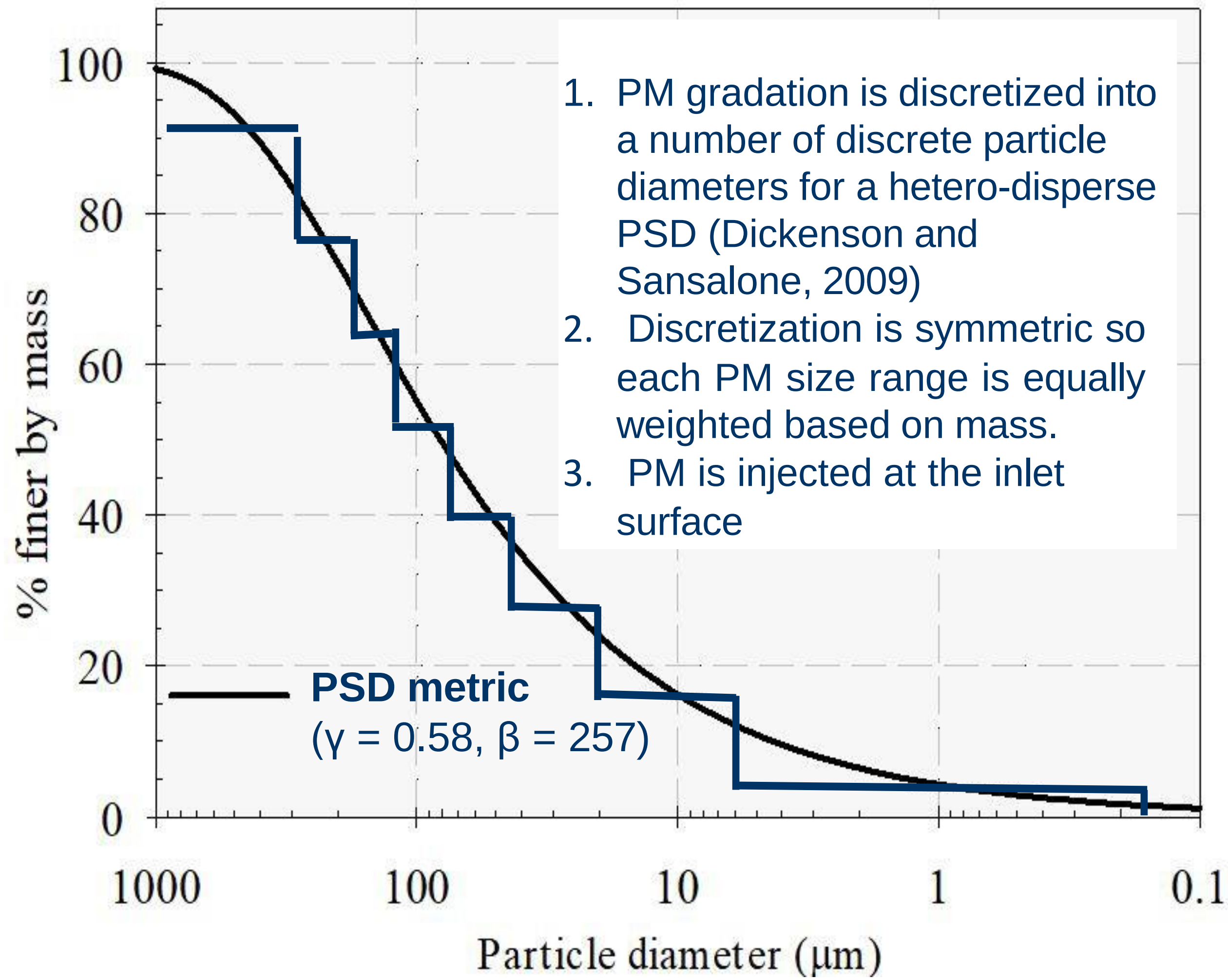
- By design, the volume of water held within varies drastically in time
- Capturing this in CFD can be difficult
  - Volume of Fluid (VOF) modeling
  - Shallow Water Equation simplification

Unique Challenges for Stormwater

Complex Contaminant Transport

- Heterodisperse particle size distribution (PSD)
- Complex partitioning of metals, nutrients, and pathogens
- Ill-understood biochemical mechanisms
  - Empirical equations exist but site-specific calibration often necessary

PSD Discretization



1. PM gradation is discretized into a number of discrete particle diameters for a hetero-disperse PSD (Dickenson and Sansalone, 2009)
2. Discretization is symmetric so each PM size range is equally weighted based on mass.
3. PM is injected at the inlet surface

BRADLEY University

Multiphase Turbulence Flow

Navier–Stokes (N-S) equations

$$\nabla \cdot \mathbf{u} = 0,$$

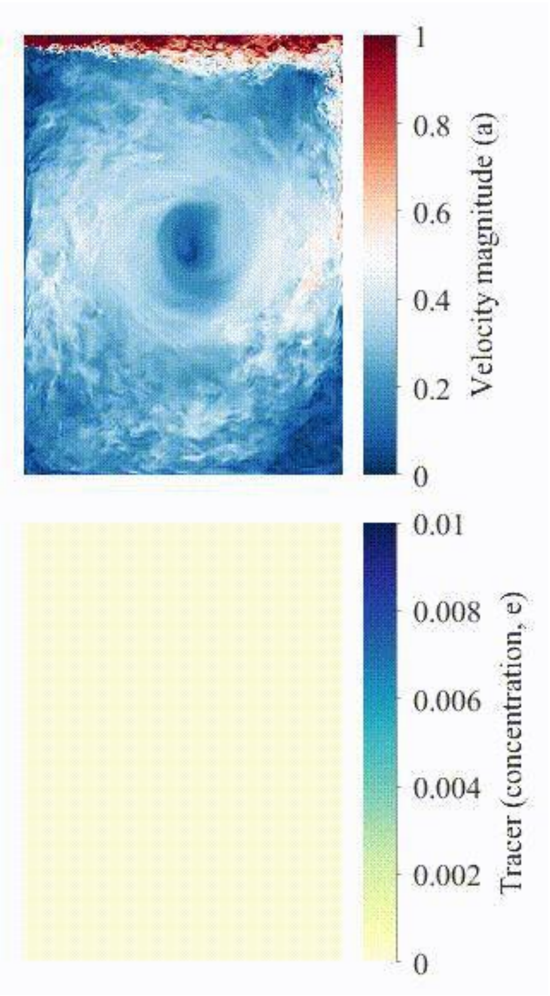
$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u} \otimes \mathbf{u}) = -\nabla P + \nabla \cdot [(\mu + \mu_t) \nabla \mathbf{u}],$$

Species transport equation

$$\frac{\partial Y}{\partial t} + \nabla \cdot (\mathbf{u} Y) = \nabla \cdot [(D + D_t) \nabla Y] + \mathbf{s}.$$

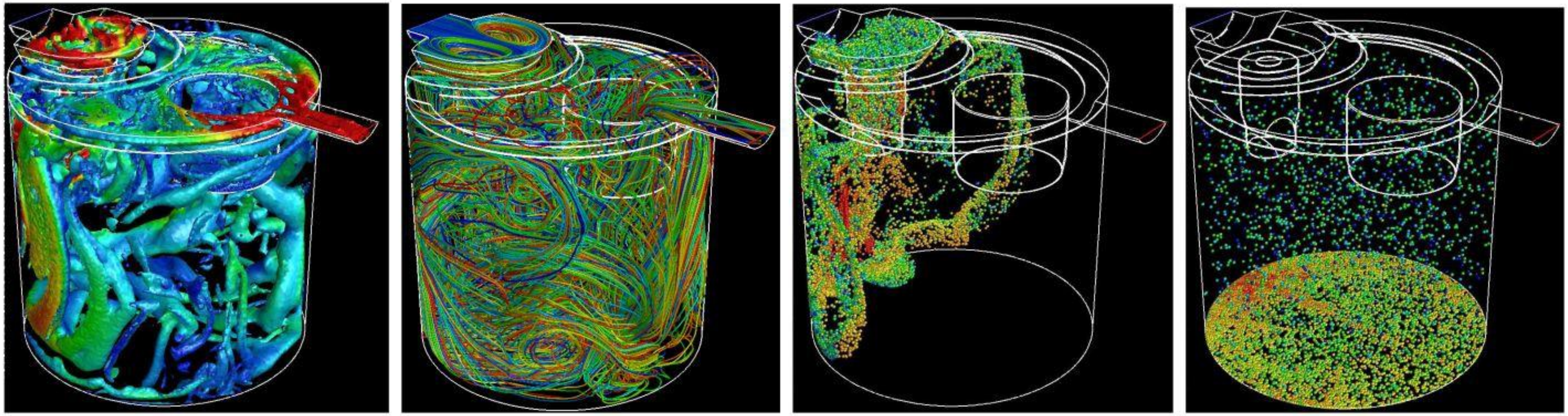
PM transport equation with equilibrium Euler

$$\frac{\partial C}{\partial t} + \nabla \cdot [(\mathbf{u} + w_s \hat{\mathbf{g}}) C] = \nabla \cdot [(D + D_t) \nabla C].$$



Li, H., Balachandar, S., Sansalone, J., (2021)

Lagrangian Particle Tracking (LPT)



$$\nabla \cdot \mathbf{u} = 0,$$

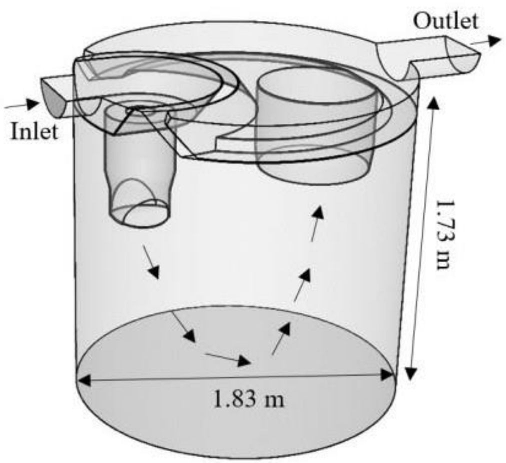
$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u} \otimes \mathbf{u}) = -\nabla P + \nabla \cdot [(\mu + \mu_t) \nabla \mathbf{u}],$$

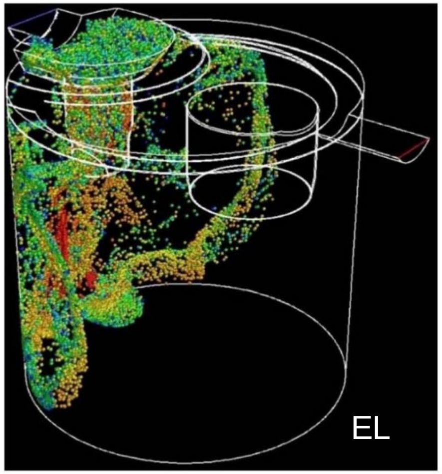
$$\frac{d\mathbf{x}_p}{dt} = \mathbf{u}_p$$

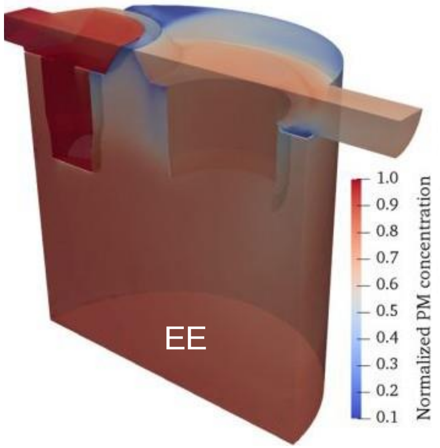
$$m \frac{d\mathbf{u}_p}{dt} = \mathbf{f}_g + \mathbf{f}_b + \mathbf{f}_d(\mathbf{u}_p, \overline{\mathbf{u}})$$

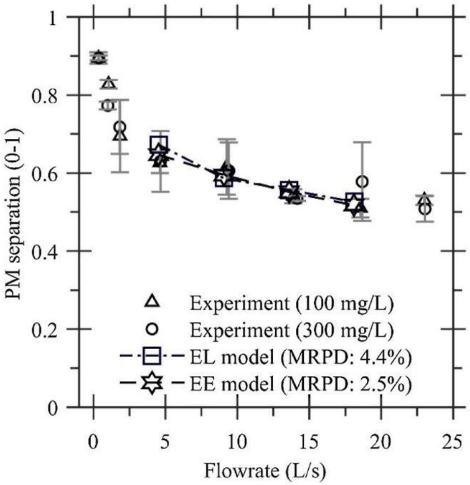
- Intuitive and easy to understand
- Do not assume unique particle velocity
- No limit in particle Stokes number
- Difficult to select number of number particle beforehand

Hydrodynamic Separators
Steady CFD Simulation









$$\nabla \cdot \mathbf{u} = 0,$$

$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u} \otimes \mathbf{u}) = -\nabla P + \nabla \cdot [(\mu + \mu_t) \nabla \mathbf{u}],$$

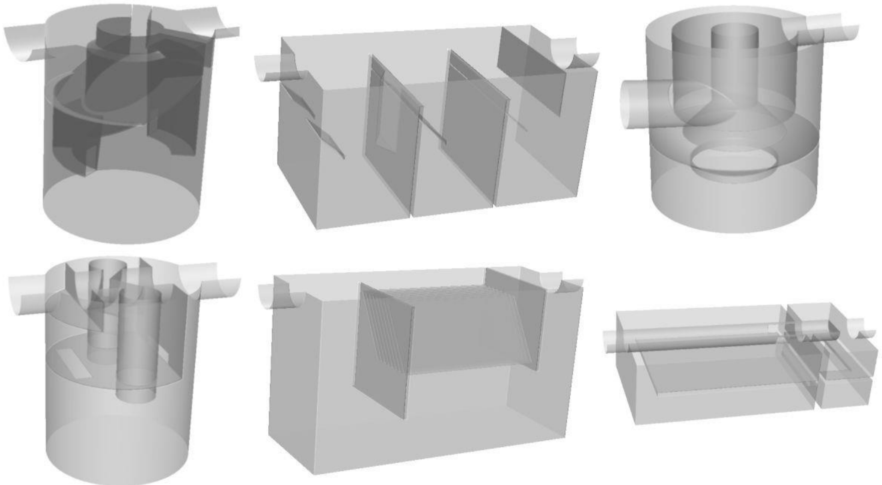
$$\frac{\partial C}{\partial t} + \nabla \cdot [(\mathbf{u} + w_s \hat{\mathbf{g}}) C] = \nabla \cdot [(D + D_t) \nabla C].$$

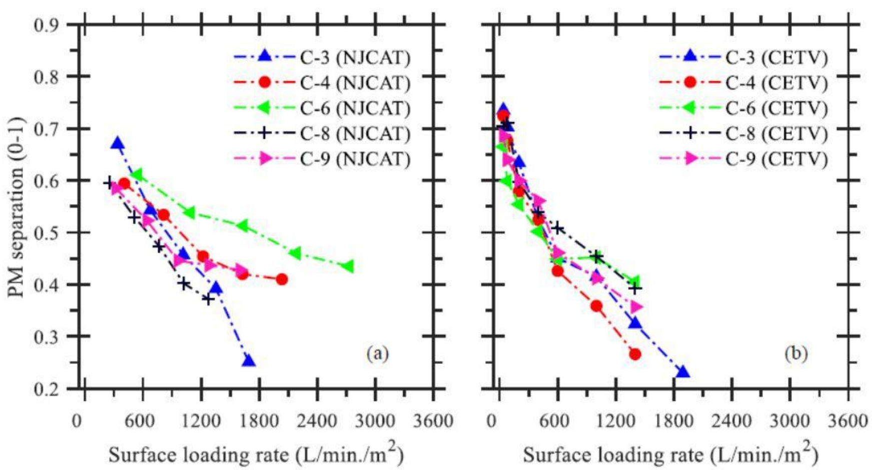
$$\frac{d\mathbf{x}_p}{dt} = \mathbf{u}_p$$

$$m \frac{d\mathbf{u}_p}{dt} = \mathbf{f}_g + \mathbf{f}_b + \mathbf{f}_d (\mathbf{u}_p, \bar{\mathbf{u}})$$

- Both LPT and Euler method predict HS PM separation

Application to NJCAT and CETV



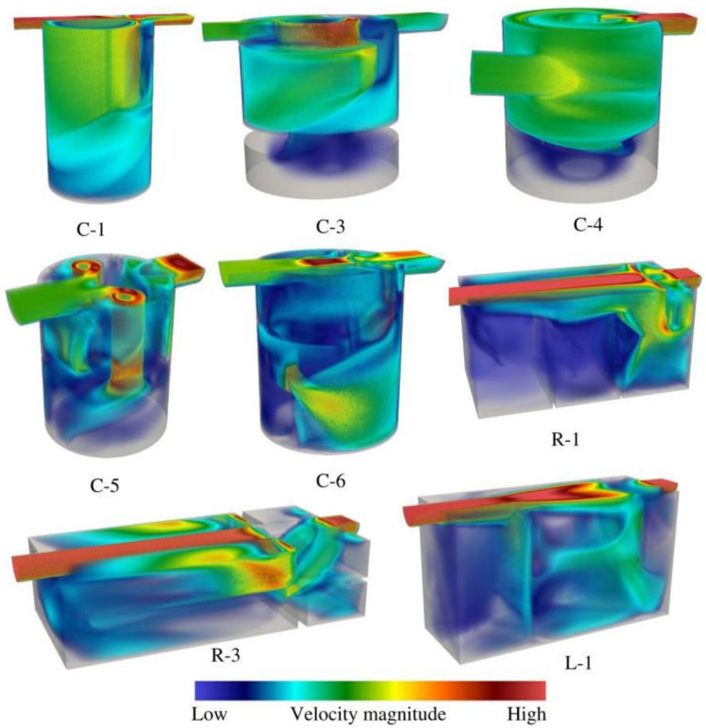


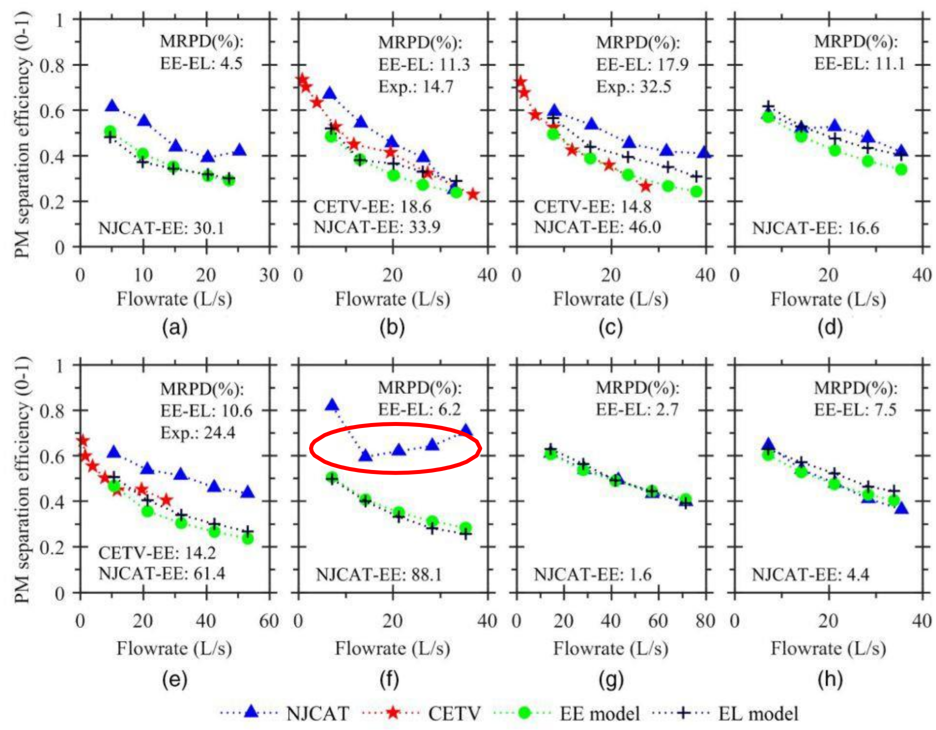
Existing physical-based HS certification programs such as New Jersey Corporation for Advanced Technology (NJCAT) and Canadian environmental technology verification (CETV):

- Expensive
  - Field testing costs: ~250k-700k, 2-5 years
  - Laboratory testing cost: ~150k, 1-2 years
- Variability in the results for the same system
- Inconsistent ranking of PM separation for same group of HS systems
- Failed certification is unaffordable to smaller manufacturers
- Challenge to inform system design and optimization

Note NJCAT and CETV share similar laboratory HS testing protocol

CFD Can Assist Regulatory Certification

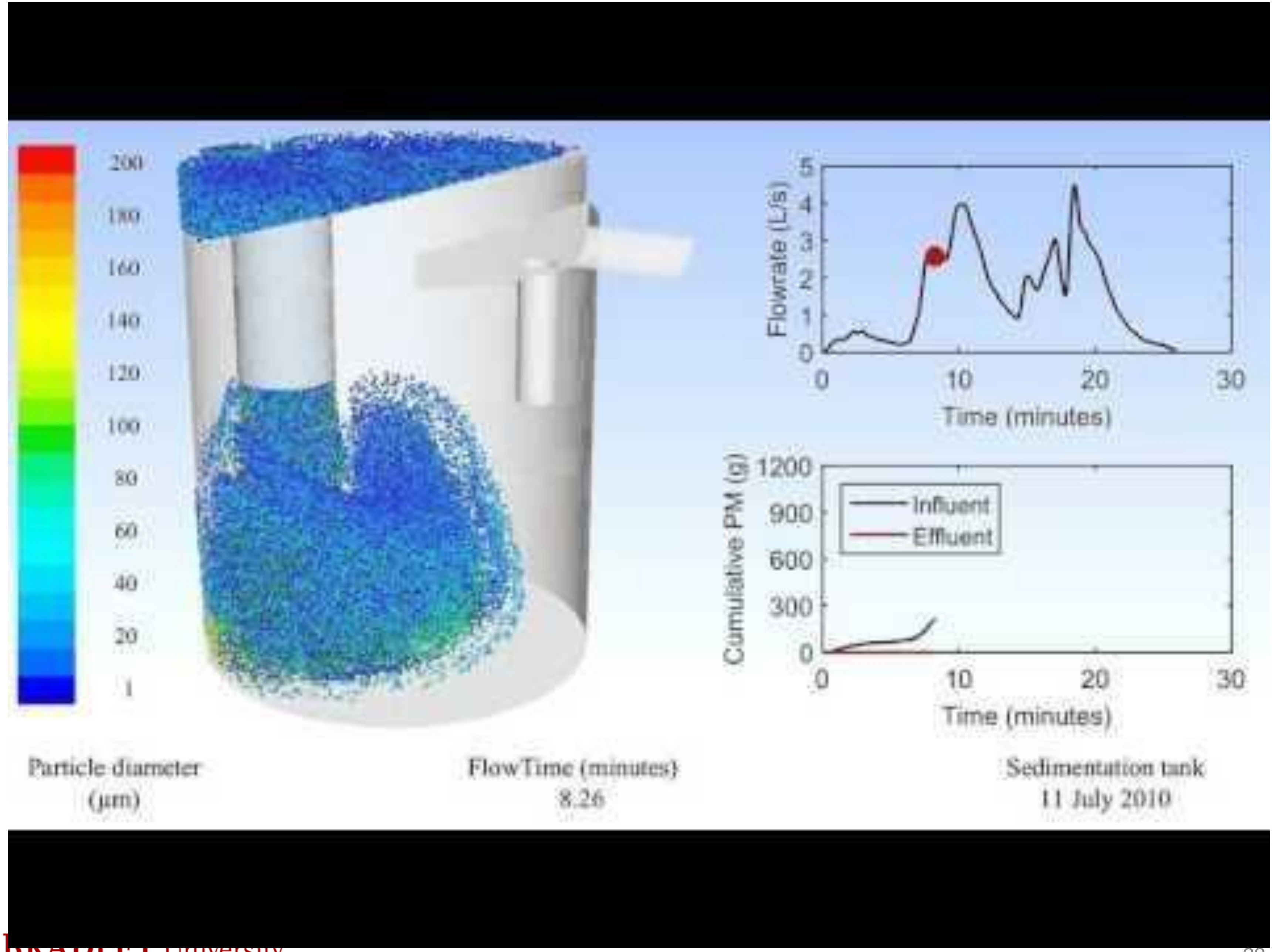




- CFD simulations show better agreement with PM separation reported by CETV protocol
- CFD simulations suggest some PM separation claims can be in error
- Overall cost of CFD is one order magnitude more economical and faster than the physical-based certification
- CFD provides the potential of a rigorous, consistent, and revisable certification complementary tool along with required physical testing

Hydrodynamic Separators
Unsteady CFD Simulation

- Unsteady simulation has been validated against measured particulate matter (PM) separation data for individual storm events
  - Garofalo and Sansalone (2011)
  - Spelman and Sansalone (2017)
- Computationally expensive
- Results are specific to the storm event and site
- Long-term performance infeasible to simulate
- Relatively difficult CFD setup process


200
180
160
140
120
100
80
60
40
20
1
Particle diameter (μm)
FlowTime (minutes) 8.26
Sedimentation tank 11 July 2010
Flowrate (L/s)
Time (minutes)
Cumulative PM (g)
Influent
Effluent
Time (minutes)

Stepwise Steady Concept

Need some way to get around the time scale difficulties

One idea: find a way to simulate unsteady transport behavior using steady CFD simulation

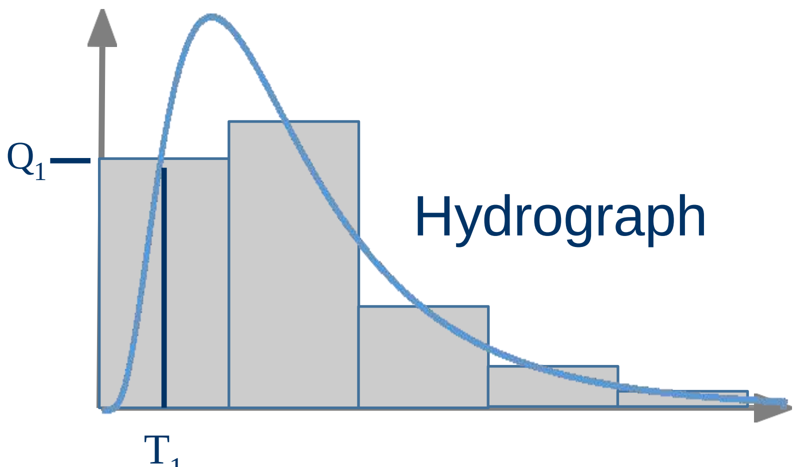
Discretize a hydrograph into a series of steady flows

Run a set of steady CFD models to characterize system behavior across the range of expected flow conditions

Stepwise Steady Concept

Assume that steady flow transport behavior can predict the unsteady reality

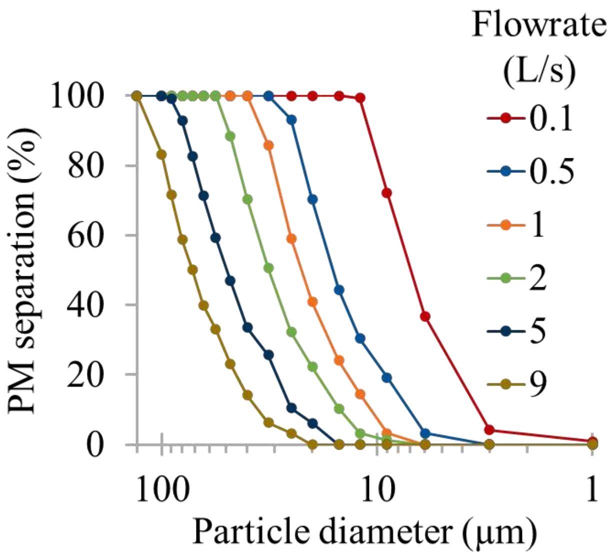
PM transport behaves nonlinearly with flowrate

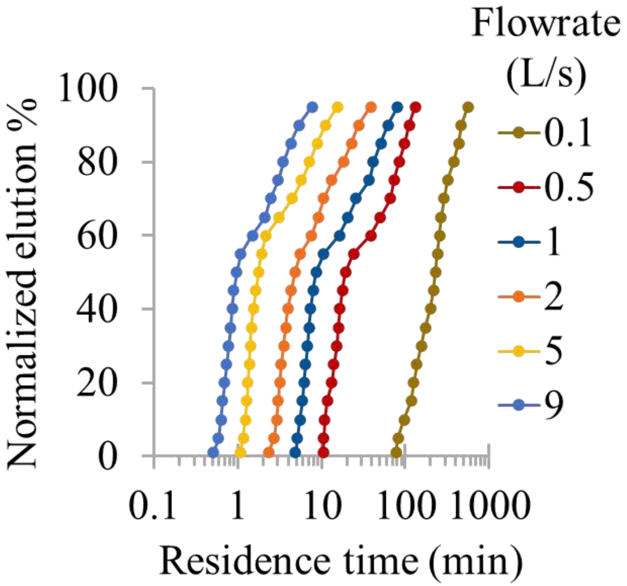


What is the representative flowrate for PM injected at time T_1 that reproduces unsteady transport?

Spelman and Sansalone (2017)

1. Developed a robust and computationally viable method for use in long-term, continuous PM transport modeling
2. Multiple stepwise steady method iterations and developments since 2011
3. The most recent can reasonably reproduce unsteady PM transport behavior in systems of all sizes





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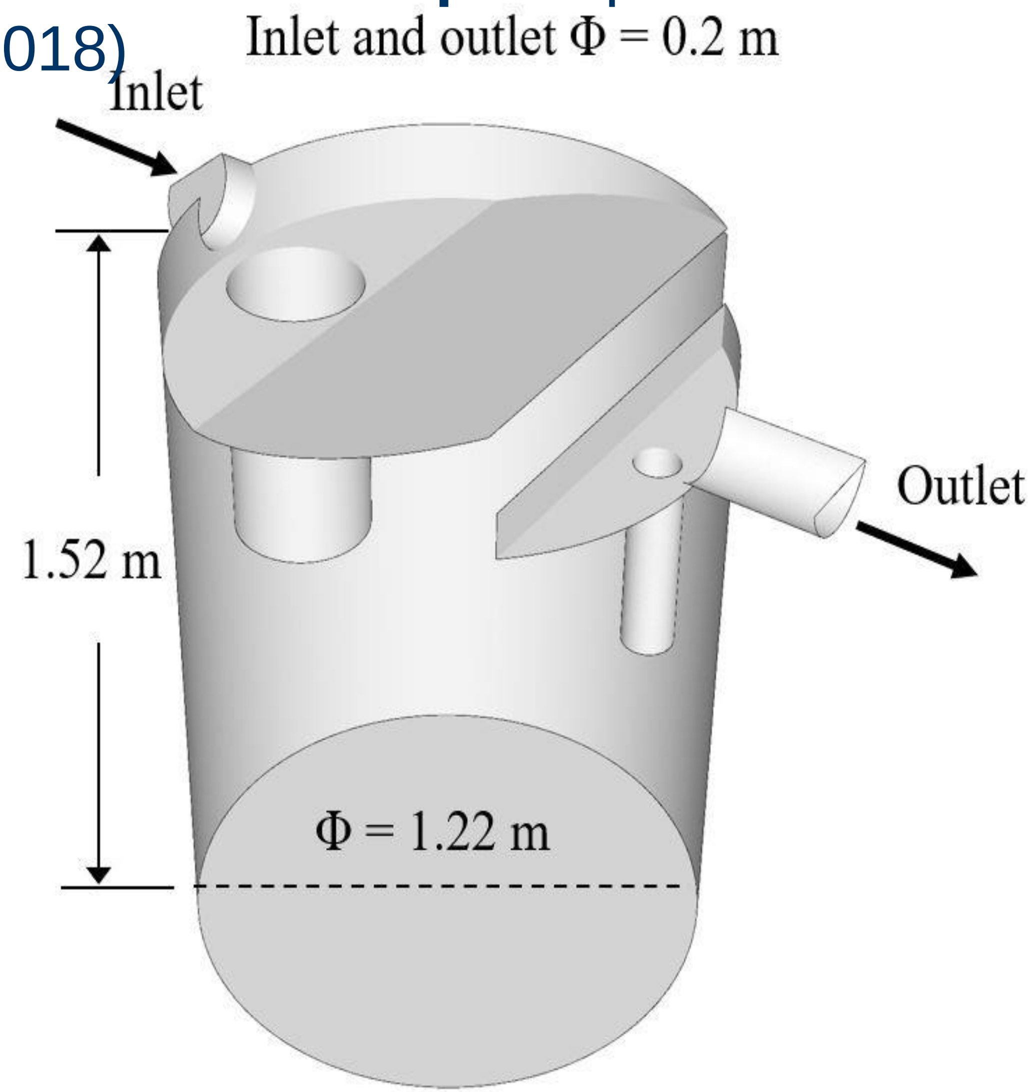
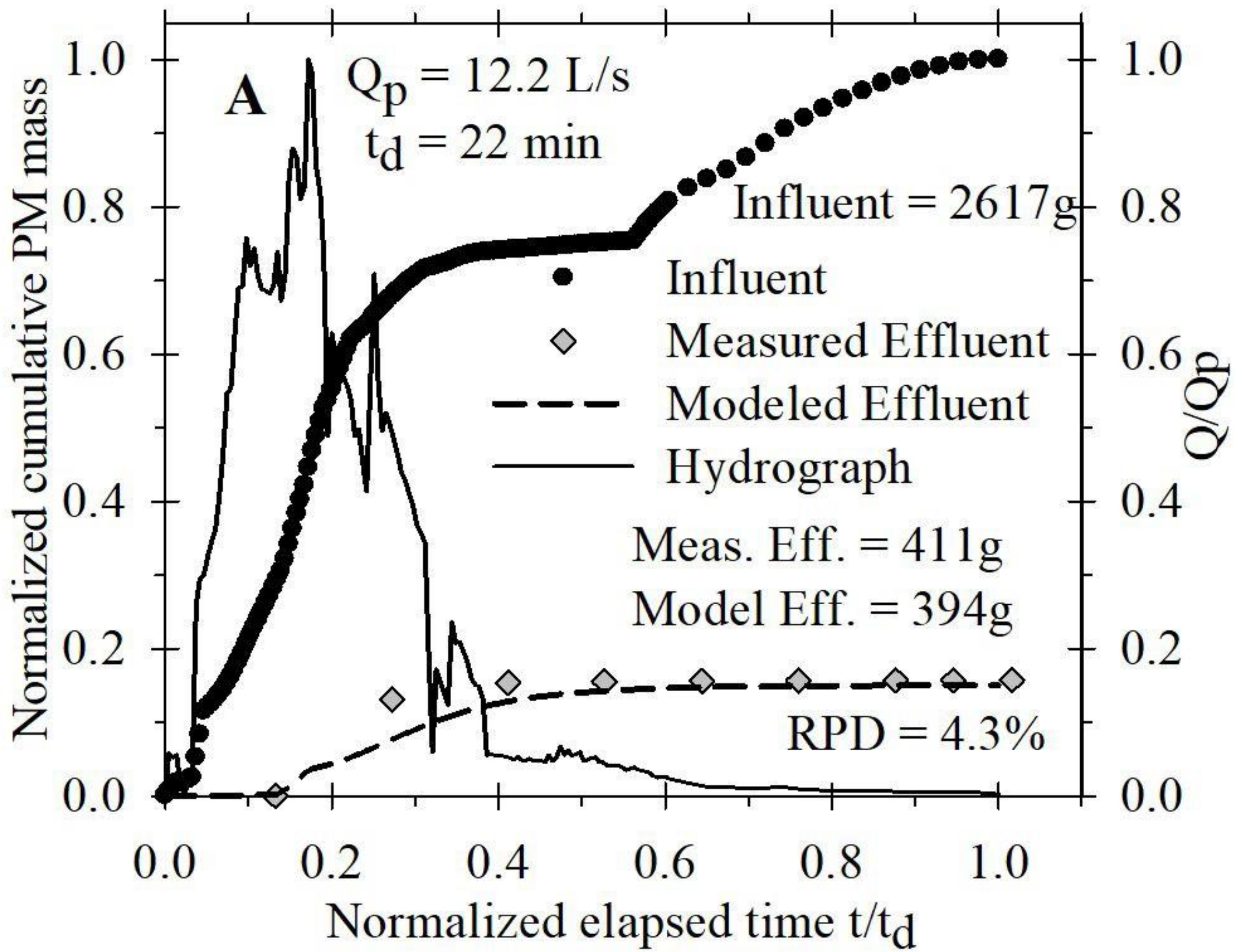
Validation Example: Spelman and Sansalone (2018)

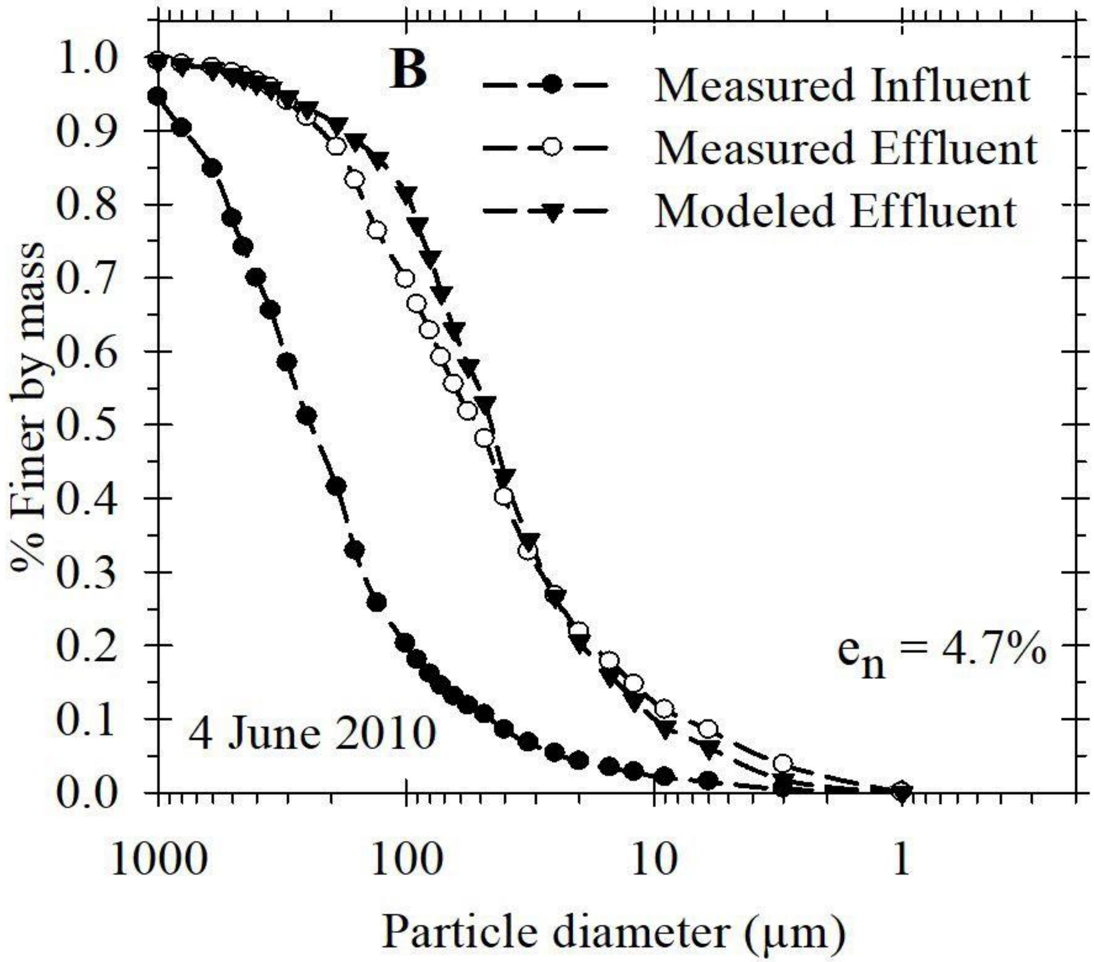


1. Baffled Hydrodynamic Separator (BHS)
2. Turnover volume of 1.7 m^3
3. 4 storm events modeled
4. Measured PM separation data available for all events (Cho and Sansalone, 2013)

Modeled vs Measured Results: BHS (1 of 2)



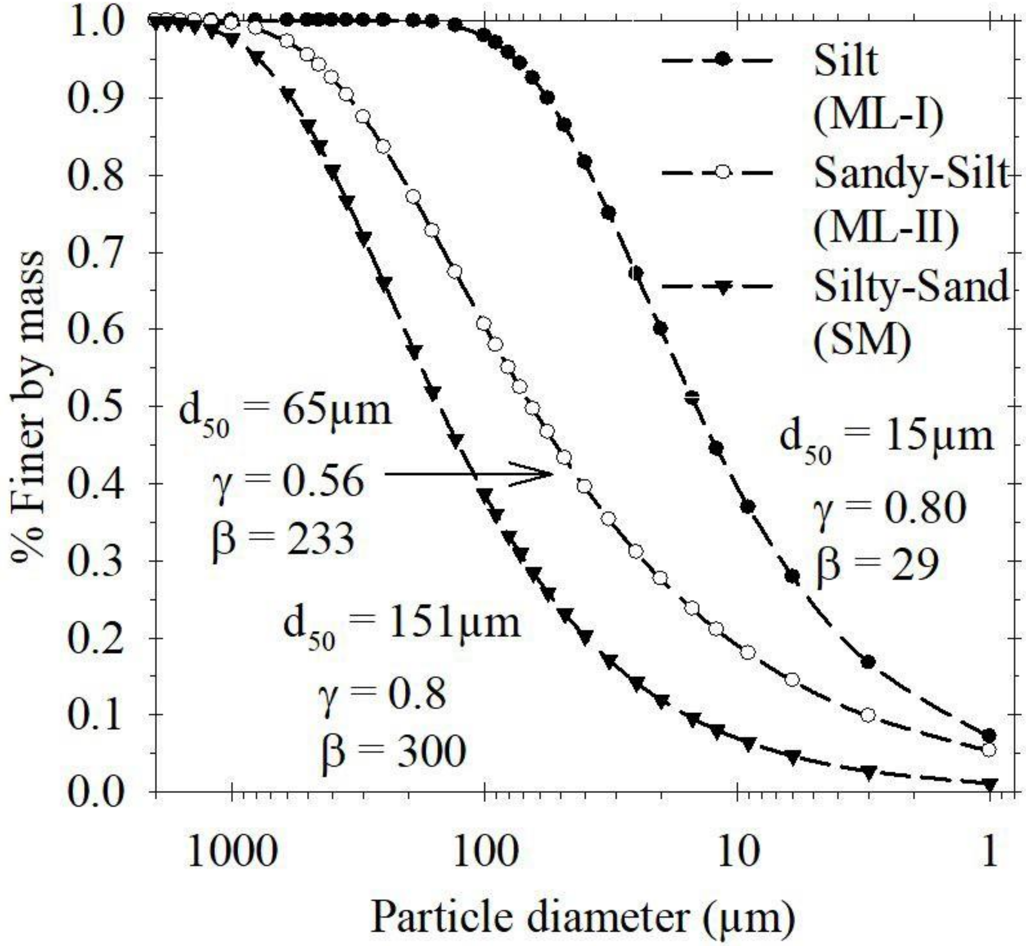
Modeled vs Measured Results: BHS (2 of 2)



Validated 4 different storm events

Can now extend model to hypothetical situations

Assumed Heterodisperse Influent PSDs for Design Storm Analysis



1. PSDs modeled with gamma distributions using the shape (γ) and scale (β) parameters

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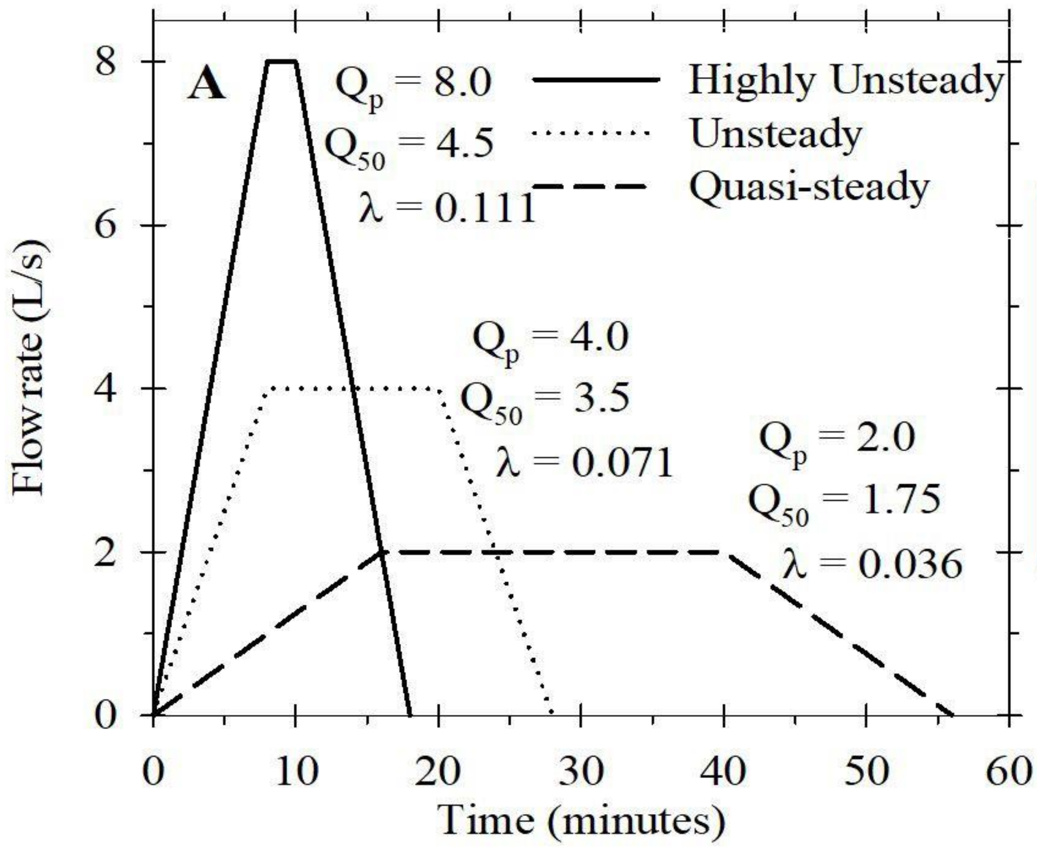
Design Storms: BHS



1. Volume = 4.8 m3
2. Turnover fraction = 2.8
3. Constant assumed suspended sediment concentration (SSC) of 200 mg/L

Q_{50} = Median flowrate
Q_p = Peak flowrate
λ = Hydrograph unsteadiness

BHS separation fraction based on 4800 g of influent PM											
Separation fraction		ρ_{sg}	Highly Unsteady λ=0.111 Q_{50}=4.5 L/s			Unsteady λ=0.071 Q_{50}=3.5 L/s			Quasi-Steady λ=0.036 Q_{50}=1.75 L/s		
			10°C	20°C	30°C	10°C	20°C	30°C	10°C	20°C	30°C
Particle size distribution (PSD) class	Silt (ML-I)	1.2	0.25	0.26	0.27	0.27	0.28	0.30	0.29	0.32	0.35
		1.8	0.34	0.37	0.39	0.40	0.44	0.48	0.49	0.54	0.58
		2.4	0.41	0.44	0.48	0.49	0.53	0.57	0.58	0.63	0.66
	Sandy-Silt (ML-II)	1.2	0.55	0.57	0.58	0.59	0.61	0.62	0.62	0.65	0.67
		1.8	0.65	0.67	0.69	0.70	0.73	0.75	0.76	0.78	0.80
		2.4	0.70	0.73	0.75	0.76	0.78	0.80	0.80	0.82	0.84
	Silty-Sand (SM)	1.2	0.71	0.73	0.75	0.75	0.77	0.78	0.79	0.81	0.83
		1.8	0.81	0.82	0.84	0.84	0.86	0.88	0.89	0.90	0.92
		2.4	0.85	0.86	0.88	0.89	0.90	0.91	0.92	0.93	0.94

CFD Application to Basins

Aim to improve understanding of basin hydrodynamics and contaminant transport processes

Improve basin design and predictive capability

Models of wet basin design response with residence time metrics for presumptive guidance

- Spelman and Sansalone (2021)

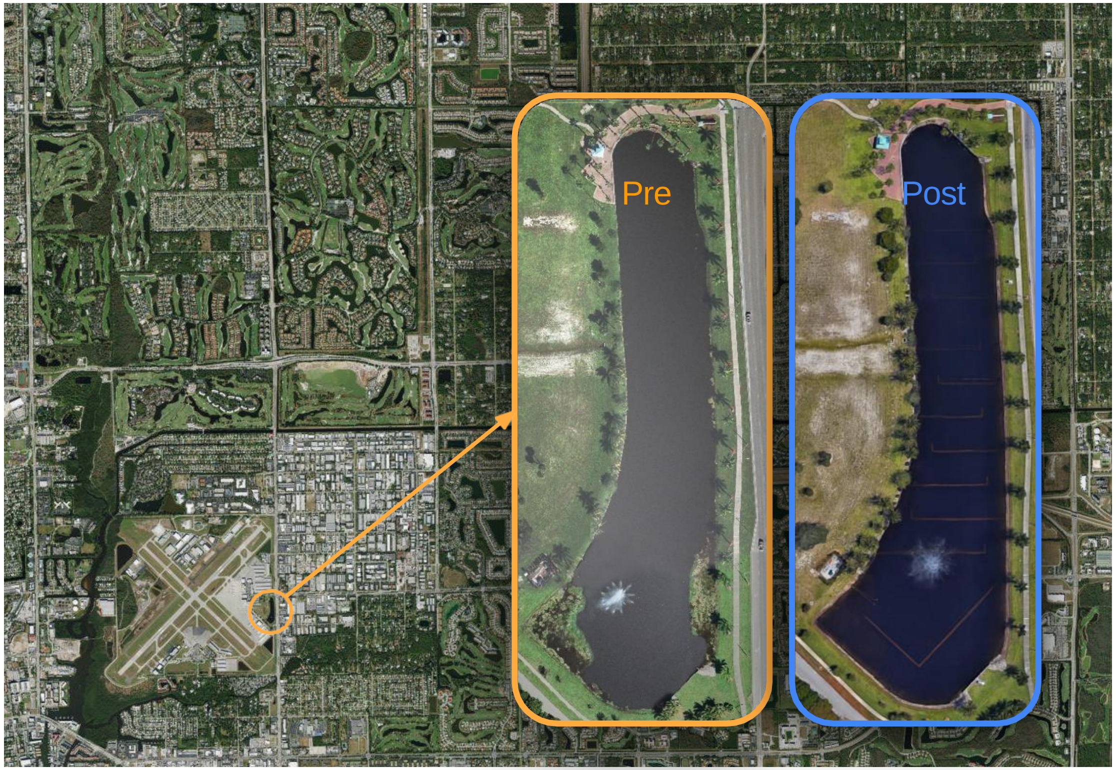
CFD application: impaired basin restoration and retrofit

Background:

- Common stormwater management system in US
- Increasingly application as type of green water infrastructure
- System impairment due to design and lack of maintenance

Challenges/motivation:

- Coupling with urban hydrology
- Constrained land availability
- Opportunity cost of land



Naples airport (APF) basin retrofit, source: google

Study Introduction

1. Basins designed based on mean wet-season hydraulic residence time (HRT)
2. One common guideline (rule of thumb) in Florida is the use of a 14-day HRT basin design
3. Residence time is an accepted surrogate for basin performance

$$HRT = \frac{Volume}{Flowrate}$$

4. Difference between HRT and constituent residence time due to short-circuiting and mixing
5. Residence time also varies since basins subject to unsteady flows
6. If only HRT is considered in design, what variability in load reduction is expected?

Study Introduction

1. What factors influence basin behavior?
2. Are basin shape or inlet configuration important?
3. What effect would internal basin retrofit (baffling) have on PM separation and residence
4. The fundamental challenge is a lack of robust predictive capability in comparing load reduction of design alternatives
5. Basins represent costly infrastructure mainly due to their size and land requirement
6. Basin design based on factors other than volume (HRT) alone may provide more cost-effective solutions

Methodology

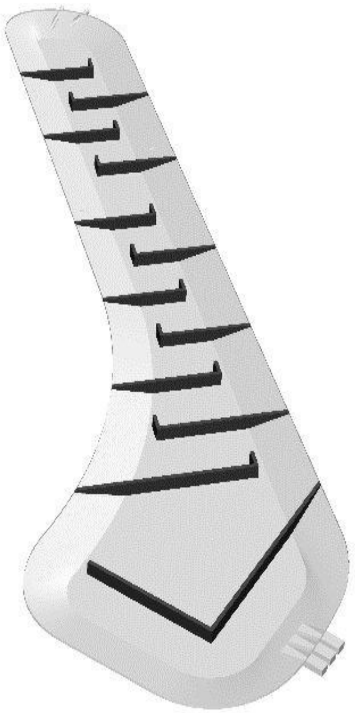
1. Use CFD and stepwise steady (IS^3) to simulate long-term basin performance
2. Simulate a representative wet season
    A. Based on historical rainfall record
    B. Route rainfall to runoff using SWMM
3. Model 7 basins to quantify the effect of:
    A. Basin volume
    B. Basin internal hydrodynamics:
        i. Internal retrofit (baffles)
        ii. Inlet configuration

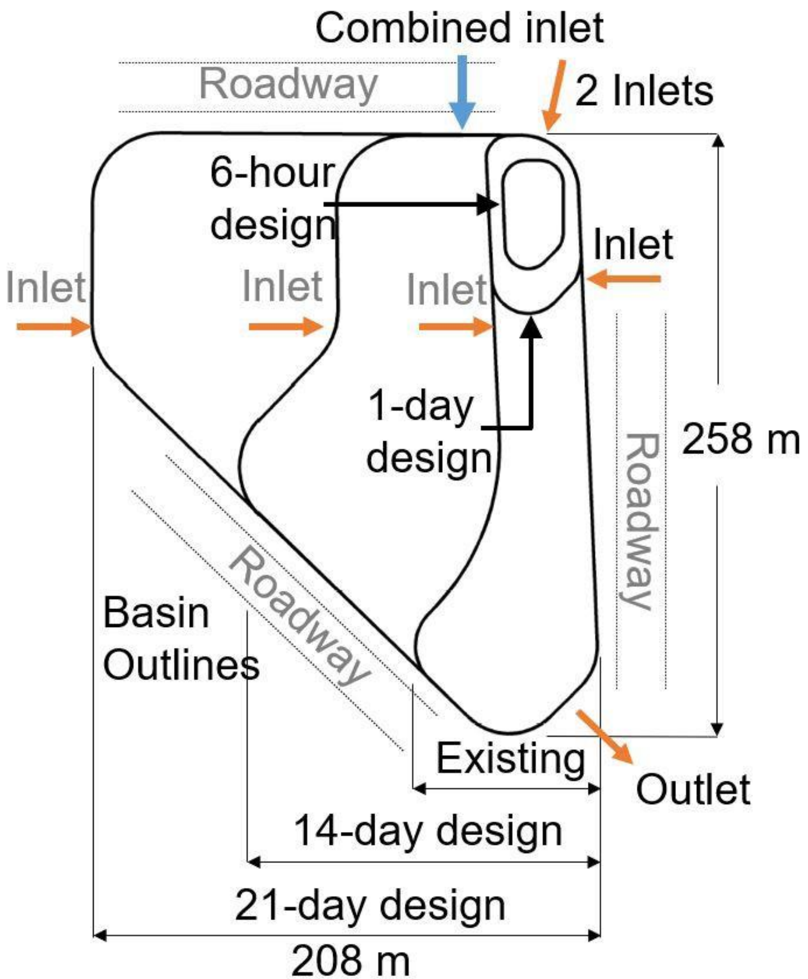
Modeled Basin Designs

Basin Attributes

1. 4:1 side slopes
2. 3 m depth
3. 15.2 m baffle spacing
4. 12.2 m baffle-basin edge gap
5. 12 porous gabion baffles

Existing w/ retrofit





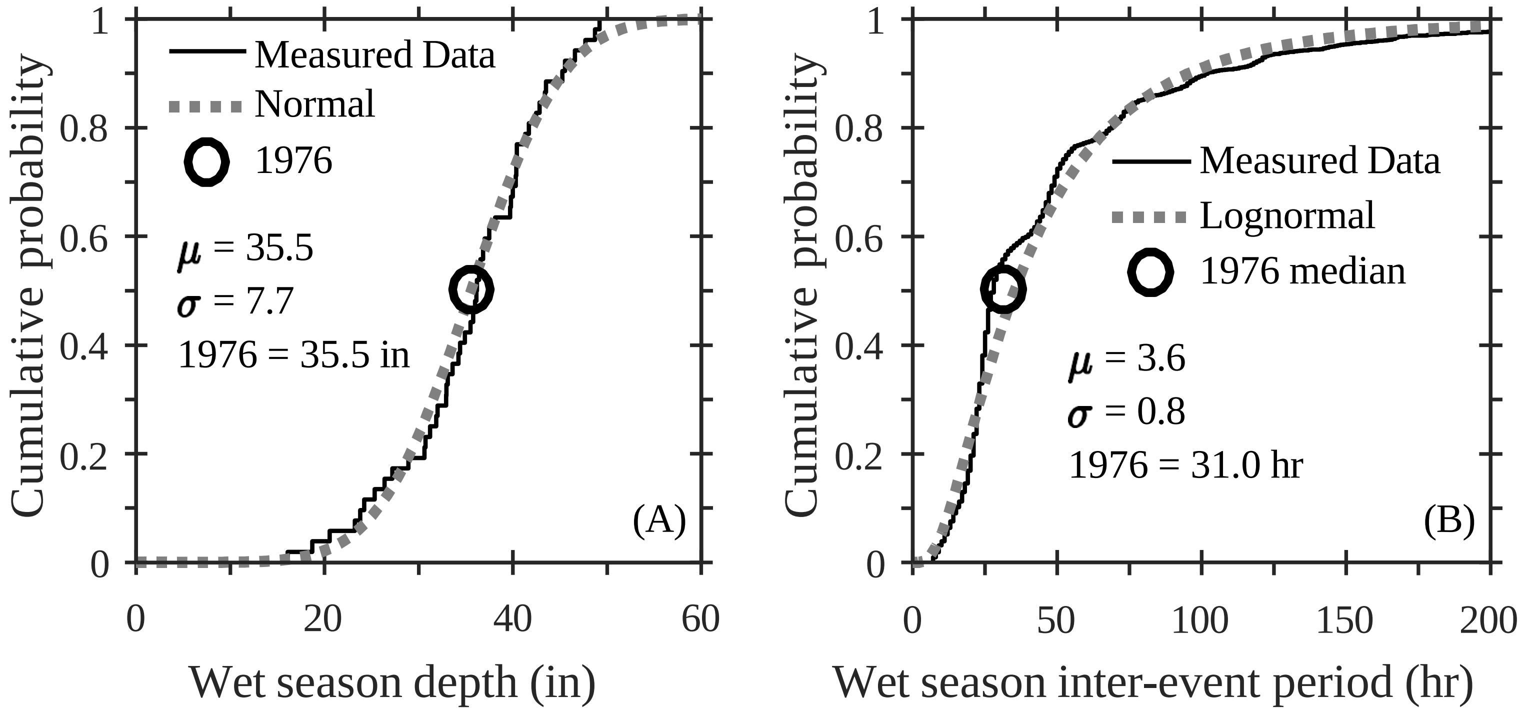
Summary of Basin Properties and Cost

Basin Information	6-hour design	1-day design	Existing w/o retrofit	Existing w/ retrofit	14-day design combined inlet	14-day design multiple inlets	21-day design
Basin volume (m^3)	1260	4800	24900	24200	71500	71500	106900
Basin surface area (m^2)	820	2200	10600	10600	26500	26500	38800
Number of inlets	4	4	4	4	1	4	4
~ Basin construction cost (M$)	0.208	0.235	0.386	0.711	0.75	0.75	1.085
~ Land cost present value (M$)	0.15	0.40	1.93	1.93	4.82	4.82	7.05
~ Basin total cost (M$)	0.357	0.635	2.316	2.641	5.57	5.57	8.135

1. The cost of land represents the majority of basin cost when sized larger than 1-day HRT

2. Retrofit (baffling) doubles construction cost, but has little impact on total basin cost

Historic Rainfall Distributions and Selection of the 1976 Representative Wet Season

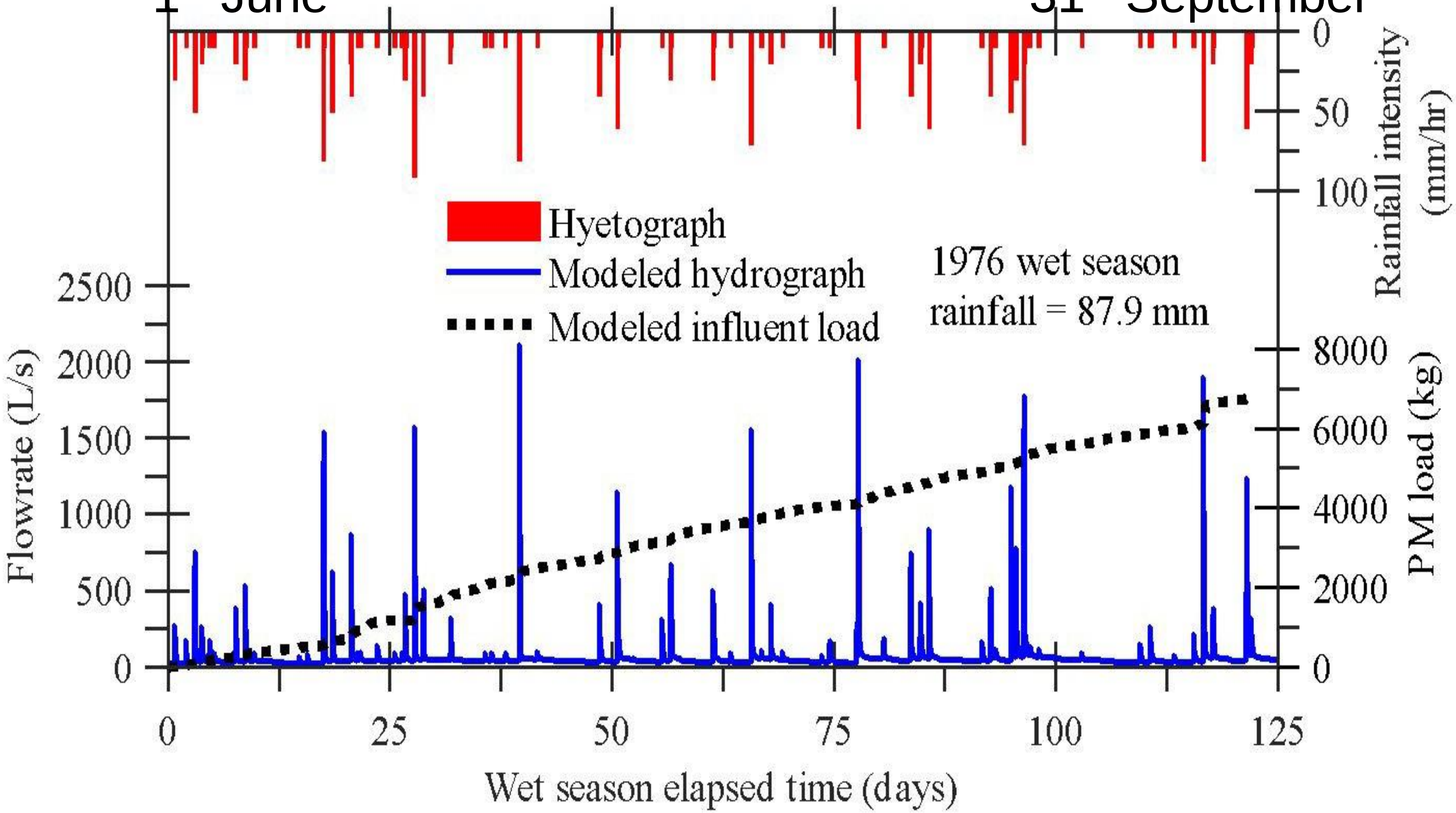


1. 1976 represents near-median rainfall behavior for Naples, FL

2. Wet season depth was normally distributed
3. Inter-event period fit a lognormal distribution

Modeled (SWMM) Wet Season Hyetograph, Hydrograph, and PM load

1st June   31st September

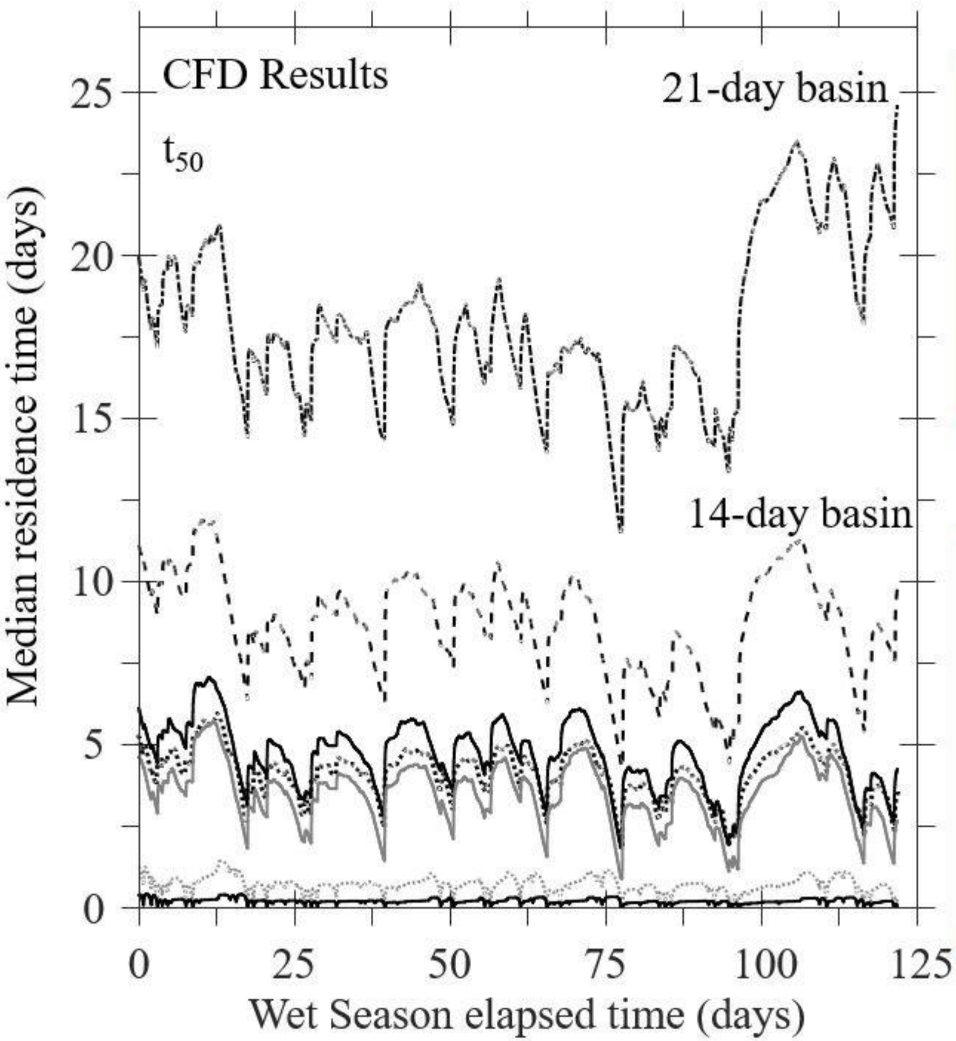


Summary of Computational Expense

CPU utilized 16 core Intel Xeon E5-2698 v3 DPM = Discrete Phase Model	6-hour design	1-day design	Existing w/o retrofit	Existing w/ retrofit	14-day design combined inlet	14-day design multiple inlets	21-day design
Total CPU-days	216	307	254	196	276	240	538
CPU expenditure - academia	$26	$37	$31	$24	$33	$29	$65
CPU expenditure - industry	$669	$950	$787	$607	$853	$745	$1,667
CPU - DPM fraction	0.12	0.09	0.12	0.12	0.09	0.16	0.07
Number of mesh elements ($x10^6$)	8.2	8.4	9.6	11.1	11.1	10.3	18.8
Memory Requirement (GB)	56	56	56	56	56	56	72

1. Around 10% of computational effort comes from particle tracking, with 90% dedicated to fluid flow calculations

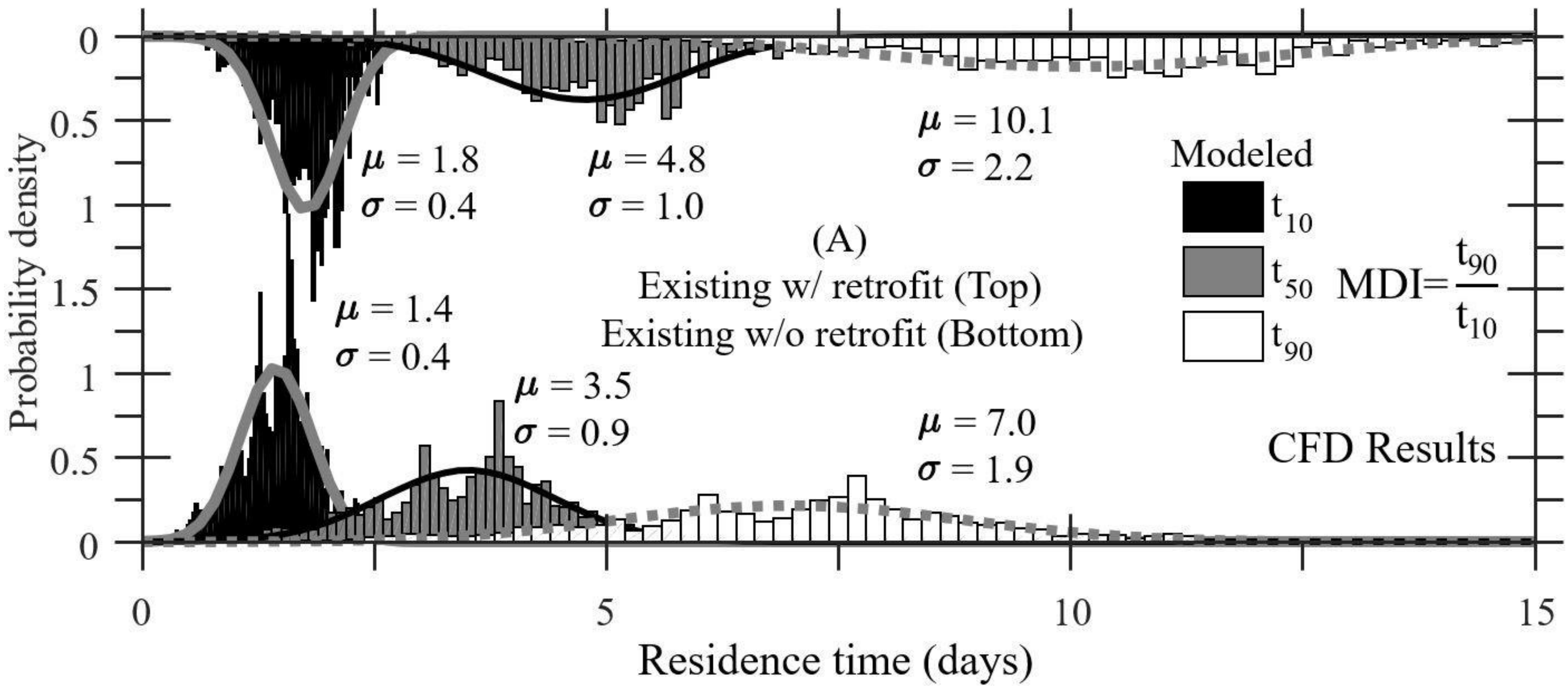
Median Residence Time Throughout Wet Season



- 21-day design
- 14-day design
- Existing w/ retrofit
- 14-day combined inlet
- Existing w/o retrofit
- 1-day design
- 6-hour design

1. Residence time (RT) varies in response to flowrate (storm events)
2. Longer RT near end of wet season for the 21-day design due to influence of low dry season flows

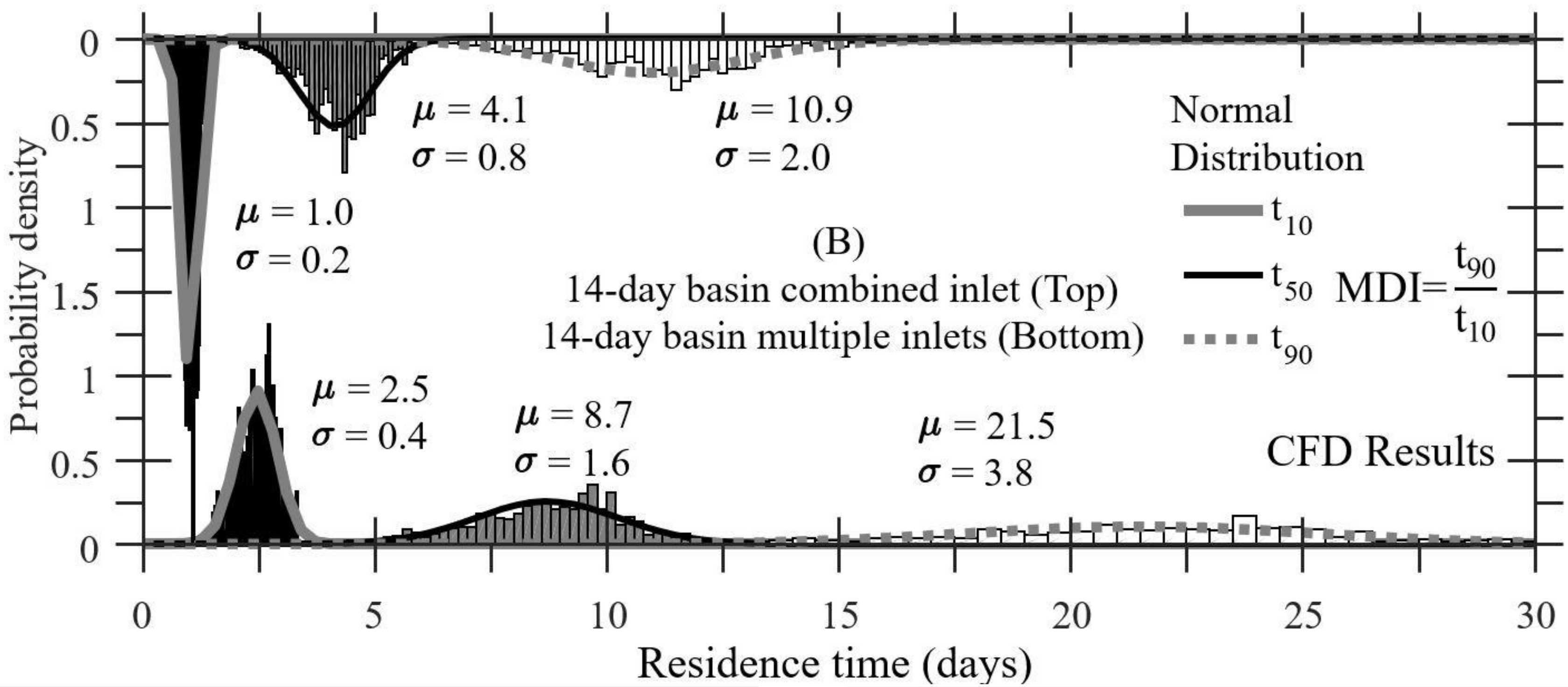
Frequency Distribution of Wet Season Residence Time Existing Basin



1. HRT = 4.8 - 5.0 days
2. Diverse spectrum of constituent residence time throughout wet season

3. Retrofit shifted the entire RTD toward longer residence time, little effect on shape

Frequency Distribution of Wet Season Residence Time 14-Day Basin



1. HRT = 14 days
2. Diverse spectrum of constituent residence time throughout wet season

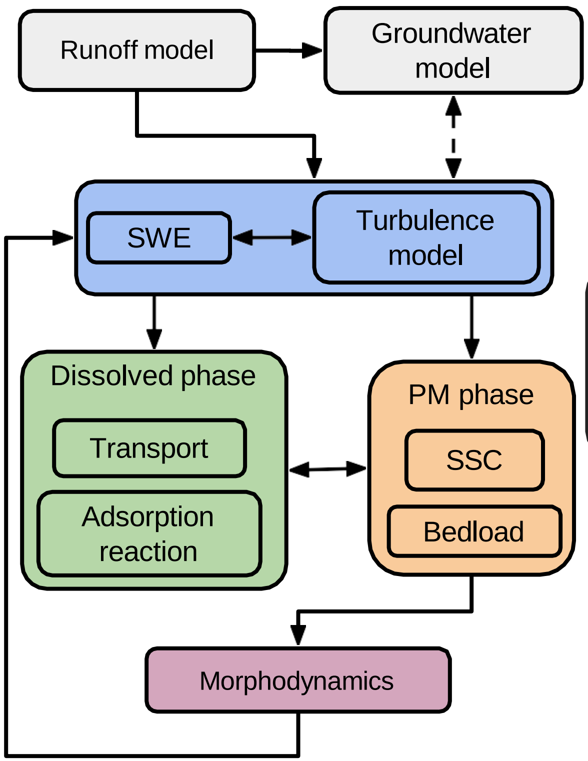
3. Combined inlet configuration shifted the entire RTD toward longer residence time (less spread)

Basin Modeling Alternative

A different way of modeling long-term basin treatment dynamics at reasonable computational expense:

The Shallow Water Equation

Modeling Framework for Basin Infrastructure



basinFoam architecture
(Li & Sansalone 2020, 2021)

$$\frac{\partial h}{\partial t} + \nabla \cdot (h\mathbf{u}) = 0$$

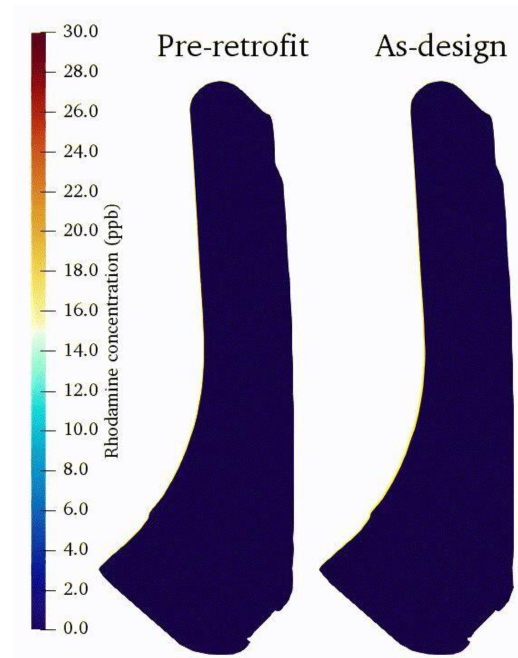
$$\frac{\partial h\mathbf{u}}{\partial t} + \nabla \cdot (h\mathbf{u}\mathbf{u}) = -\left|\mathbf{g}\right| h \nabla (h + h_0) + \nabla \cdot \left[h (\nu + \nu_t) \nabla \mathbf{u}\right] - \frac{\tau_b}{\rho} + \frac{\tau_w}{\rho} + \mathbf{s}$$

$$\frac{\partial h Y_i}{\partial t} + \nabla \cdot (h\mathbf{u} Y_i) = \nabla \cdot \left[h (D + D_t) \nabla Y_i\right] - \omega_i$$

$$\omega_i = k_{fi} \prod_k [Z]_k^{v_{ki}^{*}} - k_{ri} \prod_k [Z]_k^{v_{ki}^{**}}$$

$$\frac{\partial h C_j}{\partial t} + \nabla \cdot (h\mathbf{u} C_j) = \nabla \cdot \left[h (D + D_t) \nabla C_j\right] - D_j + E_j + \theta_j$$

$$(1 - \phi) \frac{\partial h_0}{\partial t} + \nabla \cdot \mathbf{q}_b = \sum_j (D_j - E_j)$$



Flow routing is directly considered in SWE

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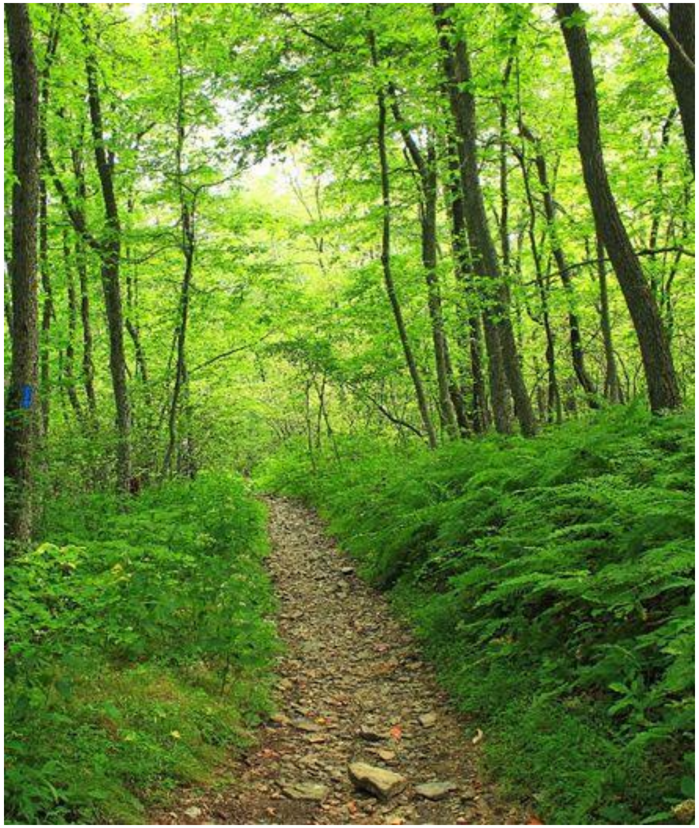
Concluding Remarks

1. Be critical of CFD results, assume they are wrong until proven otherwise
2. CFD should be used as a tool to develop, and in tandem with, robust and representative monitoring (current monitoring is neither robust or representative)
3. Follow the work of Dr. Haochen Li, amazing recent advancements!



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