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Open-Source Real-Time Control for Flooding and Water Quality

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Why Bigger Storms Demand Smarter SCMs
Swale
Stormwater Wetland
Bioretention Cell
What size storm are most of these systems sized for?
Wet Pond
Permeable Pavement

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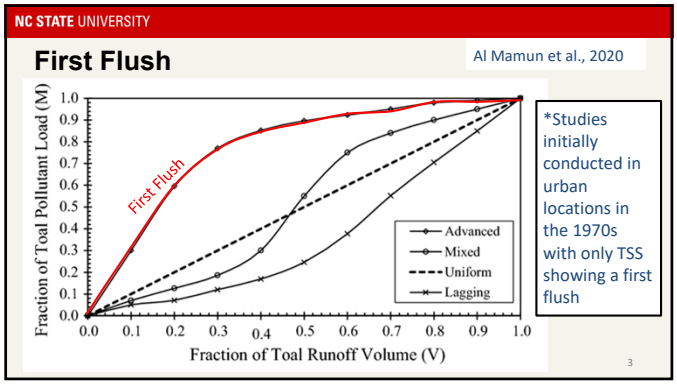
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First Flush
Al Mamun et al., 2020
Fraction of Toal Pollutant Load (M)
Fraction of Toal Runoff Volume (V)
First Flush
Advanced
Mixed
Uniform
Lagging
*Studies initially conducted in urban locations in the 1970s with only TSS showing a first flush

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Do SCMs provide WQ treatment for all storm sizes?
Considered to provide water quality treatment
Design storm (*usually 1 to 1.5 in*) → stormwater fills and exits the cell as it should, residing long enough to provide treatment

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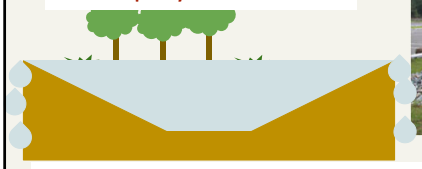
Do SCMs provide WQ treatment for all storm sizes?

Not considered to provide water quality treatment



Overtopping → stormwater volume exceeds the design volume, water exits the system other than through the outlet

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In other systems, large storms can lead to:

Water short-circuiting over berms

Overall, large storms are not considered to be treated by most SCMs!

High flows that greatly reduce the detention time of a pollutant

Overflow via emergency spillways & other overflow structures

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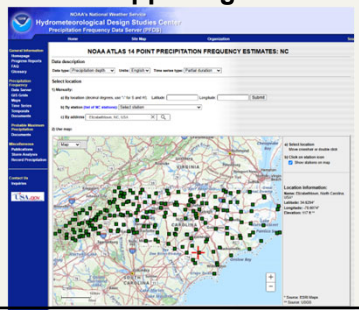
How often is this happening in NC?



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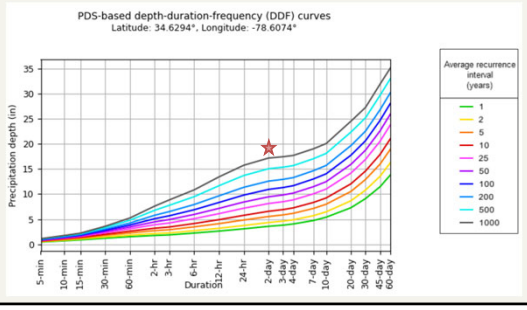
Elizabethton - Hurricane Matthew 2016



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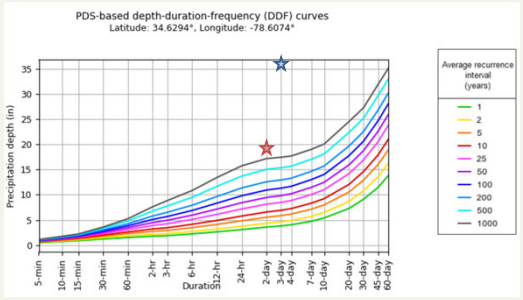
Elizabethton - Hurricane Florence 2018



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Another Example…

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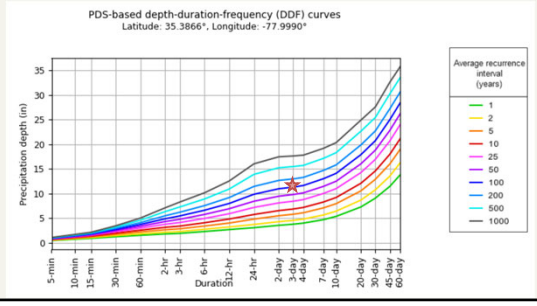
Goldsboro - Hurricane Floyd 1999



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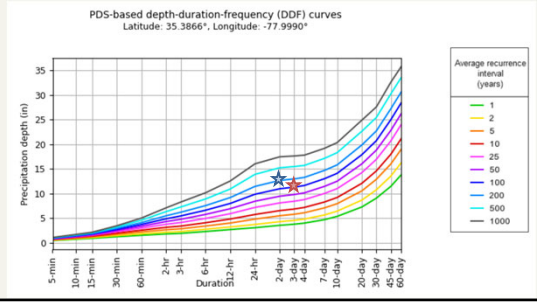
Goldsboro - Hurricane Matthew 2016



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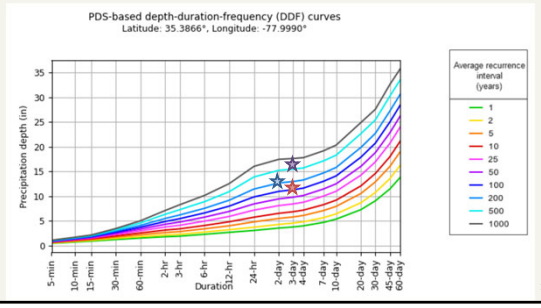
Goldsboro - Hurricane Florence 2018



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What are the Chances??

- That Elizabethton would experience two ~1000+ ARI storms in 2 years?

~ 0.00001%

- That Goldsboro would experience 3 big storms (100-year, 200-year, 500-year) in 20 years?

~ 0.07%

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How much pollutant loading do large storms contribute annually? Do we need to start designing SCMs to better treat these storms?

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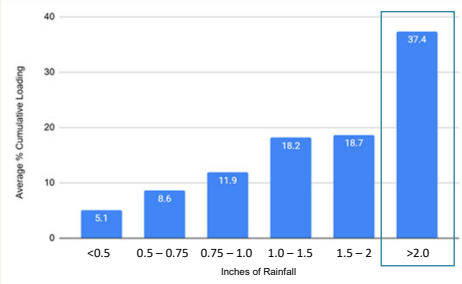
Average Cumulative Loading Percent

Looking at cumulative loads across 22 monitored sites in the Mid-Atlantic, storms > 2 in contributed 37.4% of the cumulative loading!



Van Pelt, 2025

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Urbanization and Larger Storms

- Rapid urbanization is increasing impervious surfaces
- More runoff → flash flooding → ecosystem degradation
- Larger storms make this issue worse

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Our SCMs need to be more robust (and probably bigger)… But what about all the SCMs that already exist?

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Wet Ponds are at a Particularly Big Risk

- Traditional stormwater design assumes stationarity
- Many ponds are undersized as they were not designed for current development levels or larger storms

October 10th, 2024 *August 8th, 2024*

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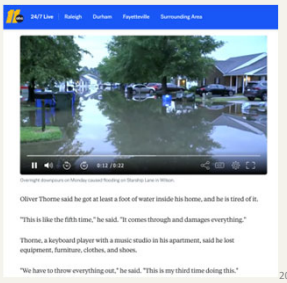
Wet Ponds are at a Particularly Big Risk

- Static outlet designs can't adapt to real-time conditions
- Often underutilized during storms
- Leads to flooding, streambank erosion, and untreated runoff



Oliver Thorne said he got at least a foot of water inside his home, and he is tired of it.

"This is like the fifth time," he said. "It comes through and damages everything."

Thorne, a keyboard player with a music studio in his apartment, said he lost equipment, furniture, clothes, and shoes.

"We have to throw everything out," he said. "This is my third time doing this."

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Wet Ponds are at a Particularly Big Risk

- Manual maintenance is labor-intensive and reactive
- Many SCMs require physical visits to adjust valves or clear blockages
- Limited municipal staff and tight budgets restrict site attention
- Costs add up with routine site visits that could be automated

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Ways to Control and Monitor SCMs

Passive Control:	• Traditional SCMs operate without external input
Real-Time Control (RTC):	• Outlet structures are adjusted based on real-time conditions like rainfall, pond depth, or forecasts
Internet of Things (IoT):	• A network of connected sensors and devices for monitoring and control

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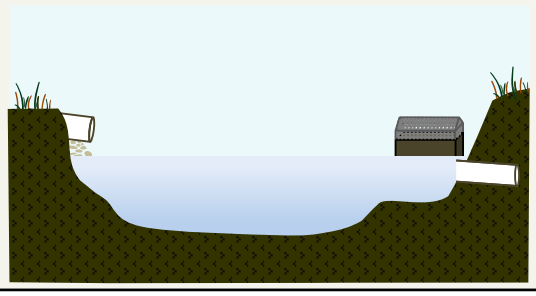
Turning a Passive Control Pond…



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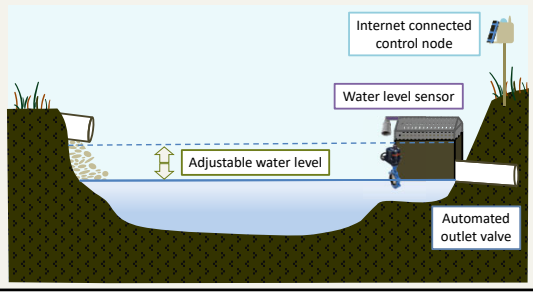
…Into a Real-Time Control Pond!



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Past Research

- Up to 66% reduction in phosphorus loads, 67% reduction in downstream erosion, and flattened hydrographs
  - "Open storm: a complete framework for sensing and control of urban watersheds," Bartos, et al. 2018
  - "Smarter Stormwater Systems," Kerkez, et al. 2016
  - "Emerging investigators series: building a theory for smart stormwater systems," Mullapudi, et al. 2017

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Turns Retroactive Maintenance into Proactive

- Can trigger automated alerts when sensors detect abnormal conditions
- One staff member can remotely monitor multiple SCMs across a municipality
- Helps optimize site visits

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Study Sites

- 4 ponds in the Contentnea Creek watershed in Wilson, NC

Site 1: Downstream Country Club

Site 2: Upstream Country Club

Site 3: Starship Neighborhood

Site 4: Parkside Neighborhood

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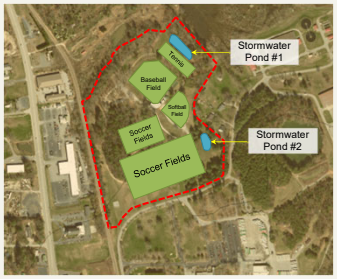
Study Sites

- 4 ponds in the Contentnea Creek watershed in Wilson, NC
- 2 ponds in the Lower Mud Creek watershed in Hendersonville, NC



Sites 5 and 6: Berkeley Mills Park Sports Complex

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Retrofit Monitoring

- Monitored a year of water quality events before the retrofit
- Measuring peak flows, flow rates, and water quality
  - Automated samplers
  - Water level data loggers
  - TSS, TP, Ortho-P, TKN, NH4, NO2-3

ISCO Automated Sampler in Job Box

Water Quality Samples

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But what good is RTC if it's not easily adopted and understood?

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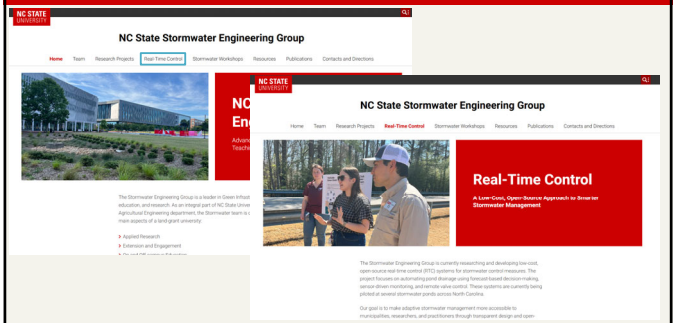

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Open-Source Tools and Commercial Systems: Tradeoffs

Open-Source	Commercial
Pros: • Low-cost components • Fully customizable and modular • Community-supported development • Local data ownership **Cons:** • Requires some technical knowledge to build • No 24/7 outside tech support • More hands-on maintenance and setup	**Pros:** • Turnkey, vendor-supported solutions • Established track record in some municipalities • Includes technical support, warranty, and updates **Cons:** • High upfront and recurring costs • Limited customization • Vendor lock-in and reliance on proprietary systems

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What other SCMs can RTC be used for?

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Dry Detention Basin Retrofits

- ***Challenge:*** DDBs are among the most common SCMs in NC but are poor performers for water quality
- ***RTC Application:*** Retrofit DDBs with automated surface-release controls to lengthen HRT
- ***Result:*** 91% TSS, 79% TN, and 52% TP removal

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Case Study Sites

- Applied to install batch detention retrofits at DDBs in Garner and Clayton
- Pre- and post-retrofit monitoring for TSS, TN, TP, peak flow, and HRT
- Would start in 2027 if funded

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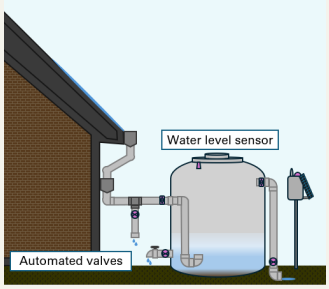
Smart Rainwater Harvesting

- ***Challenge:*** Balancing storage for future use vs. capacity for next storm
- ***RTC Application:*** Water level sensors and automated release based on weather forecasts
- ***Result:*** 8% peak flow reduction, 32% decrease in runoff volume, and 10% increase in water retention



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Case Study Site

- Tryon Palace in New Bern, North Carolina
- Installation Goals:
  - Reduce potable water use
  - Manage stormwater
  - Protect historic landscape
  - Supplement irrigation to 465m² of gardens

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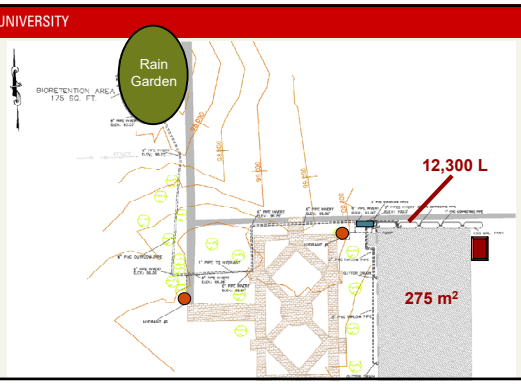

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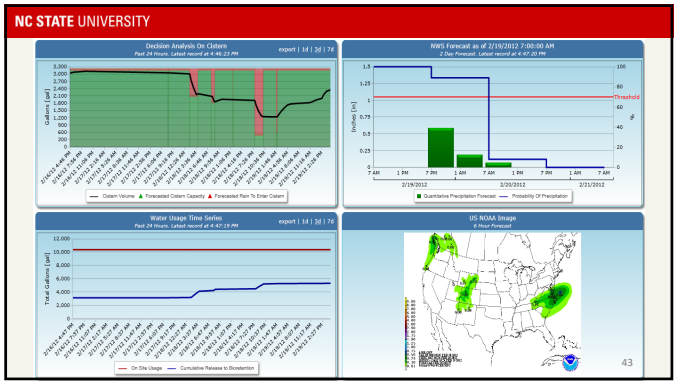
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Decision Analysis On Cistern
NWS Forecast as of 2/19/2012 7:00:00 AM
Water Usage Time Series
US NOAA Image
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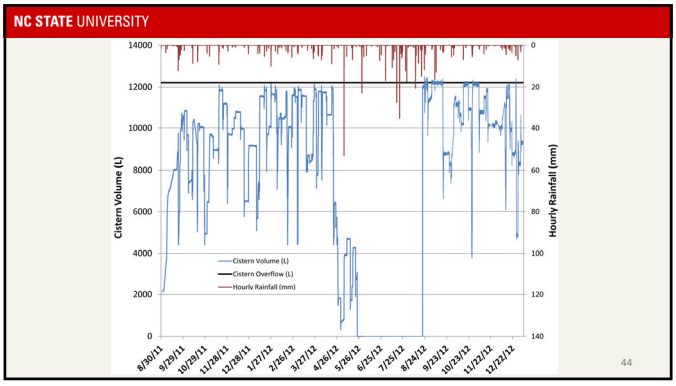
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Cistern Volume (L)
Hourly Rainfall (mm)
Cistern Volume (L)
Cistern Overflow (L)
Hourly Rainfall (mm)
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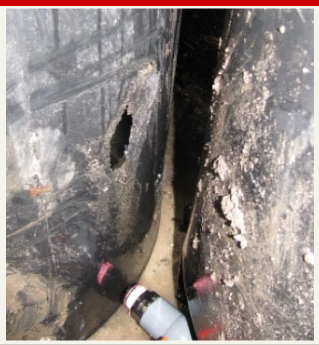

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Coming back soon from Dr. Sarah Waickowski (Clemson) and Mitch Woodward (NC State Cooperative Extension)…

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Takeway: RTC is a Solution

- Remote monitoring reduces visits
- Predictive maintenance alerts
- Real-time weather adaptation
- Performance optimization via data

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Acknowledgments

NORTH CAROLINA SPACE GRANT
Sea Grant NORTH CAROLINA
NORTH CAROLINA LAND & WATER FUND
WILSON NORTH CAROLINA
Hendersonville NORTH CAROLINA
DEQ North Carolina Department of Environmental Quality

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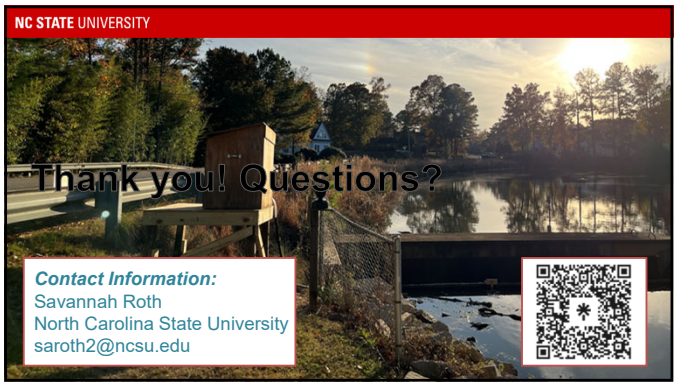
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Thank you! Questions?
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