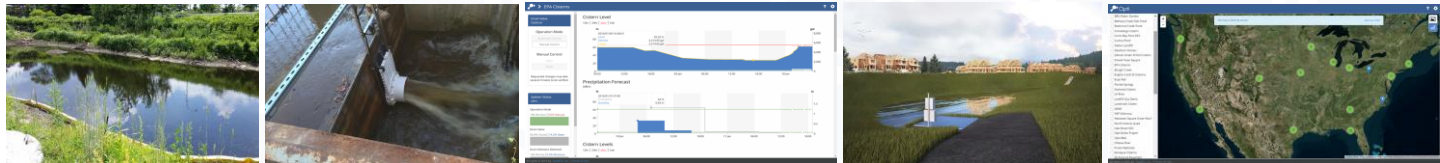


Monitoring and Improving Infrastructure Performance with Adaptive Control

WATER RESILIENT CITIES CONFERENCE
Climate Change, Infrastructure, Economies, and
Governance in the Great Lakes Basin
– Cleveland, OH



Marcus Quigley | Chief Executive Officer



Presentation Overview

1. Stormwater and Green Infrastructure Monitoring

- Overview of SW/GI Monitoring
- Continuous Performance Monitoring
- Examples and Case Studies

2. Stormwater and Green Infrastructure Control

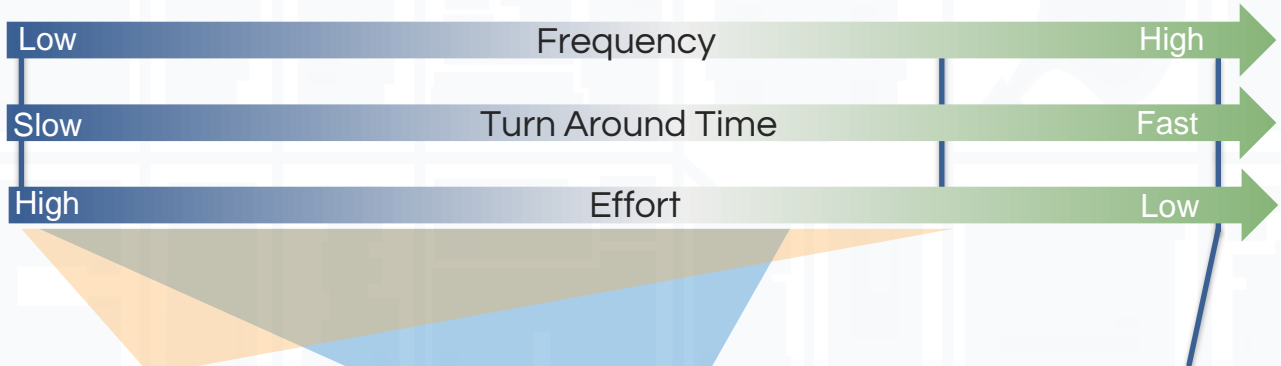
- Introduction to Continuous Monitoring and Adaptive Control
- Case Studies

3. Questions

The background features a light blue grid pattern overlaid on a white background. Within the grid, there are faint, stylized silhouettes of various urban structures, including buildings and a prominent satellite dish in the upper right quadrant. The overall aesthetic is clean and modern, suggesting a focus on urban infrastructure and technology.

Stormwater and Green Infrastructure Monitoring

Traditional & Continuous Monitoring



Manual Measurements
Manual Sample Collection



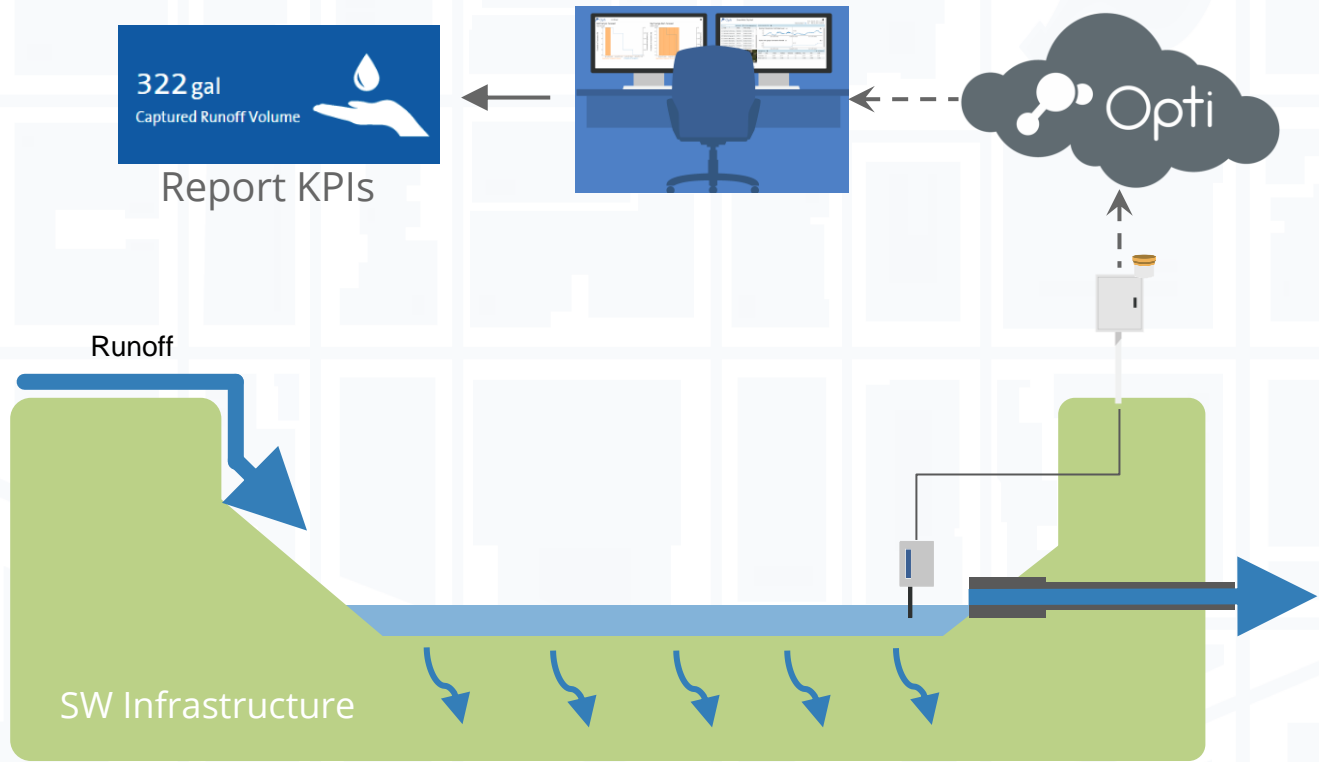
Auto Sampling
On-site Data Logging



Continuous Monitoring

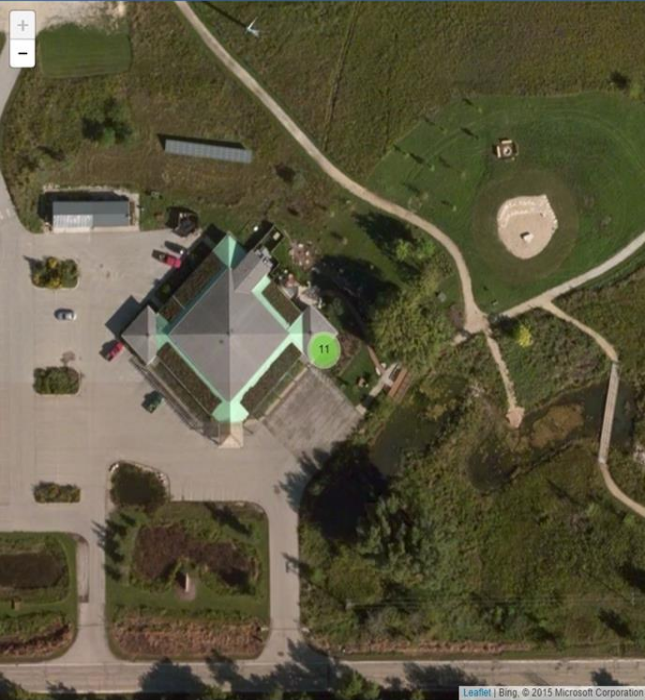


Continuous Performance Monitoring



Performance Reporting of GI

Mequon OptiStratus



Leaflet | Bing, © 2015 Microsoft Corporation

Rain Events ▾

Event starting: 2015-09-17 at 14:22 ✎

1.28 in

Total Event Precipitation



58.9 hr

Event Duration



1010 gal

Watershed Runoff Volume



0.44 in/hr

Event Max Precipitation Intensity



0 ft³

Runoff Not Treated



0.515 m³/m³

Event Start Soil Moisture



1130 gal

Treated Runoff Volume



1130 gal

Event Soil Water Content Change



0.12 ft³/ft²

Treated Runoff Per Drainage Area



60.3 °F

Temperature



0.12 ft³/ft³

Treated Runoff Per Soil Volume



What does it look like in practice?

Opti

Reset

Projects (43)

- 1267 - Sun Prairie - WI
- 50th and Pine Pavement
- 5112 - Kilbuck - PA
- Aqua Storm Control
- Asgrow Frac Tanks
- BBG Water Garden
- Bethany Creek Falls Pond
- Butternut Creek Pond
- Conowingo Cistern
- Curtis Bay Piers DSS
- Curtiss Pond
- Dalton Landfill
- Dearborn Homes
- Denver Green School Cistern
- Drexel Town Square
- EPA Cisterns
- Ebright Creek
- Engine 3 and 25 Cisterns
- Expo Rail
- Florida Springs
- Gwinnett Cistern
- LA River
- Landfill Gas Demo
- Landmark Cistern
- NFWF
- NSF-Villanova
- Newtown Square Green Roof
- North Science Quad
- Oak Street SSD
- Opti Demo Project
- Opti R&D
- Ottawa River
- Prado Wetlands
- Ranaqua Cisterns
- SE Precinct Pavement
- St. Joseph Wetlands
- St. Mary's
- TreePeople Cisterns - Pilot-to-Scale

1267 - Sun Prairie - WI

43rd Place

43rd Place (View Only)

50th and Pine Pavement (View Only)

50th and Pine Porous Pavement

5112 - Kilbuck - PA

6th Ave

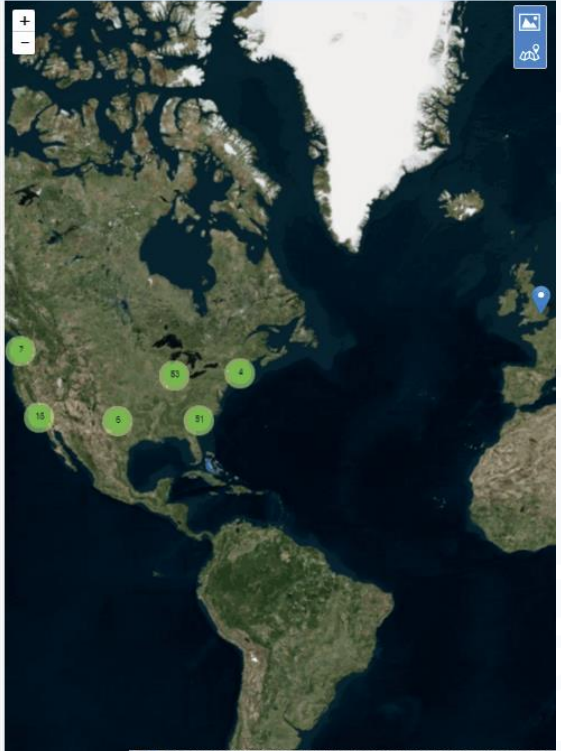
6th Ave (View Only)

Alapaha River at Statenville, GA

Alapaha River near Alapaha, GA

Aqua Storm Control Demo

Asgrow Frac Tanks



Leaflet | Bing, Image courtesy of NADA, © 2012 Inetimo, Esri, DeLorme, GeoBC, (C) 2011, Microsoft Corporation

Milwaukee, WI

Greenfield City Hall – 7:20 am Today

Greenfield City Hall

12:00 18:00 20 Apr 06:00 12:00 18:00 21 Apr 06:00

Greenfield City Hall Camera

[Latest Image](#) | 12hr | 24hr



04/21/2016 07:15

Connectivity
(48hr)
99.8% Online | 0.2% Offline

Gateway 1
99.9% Online | 0.1% Offline

Gateway 2
99.9% Online | 0.1% Offline

Control Panel Door
(48hr)
66.6% Closed | 33.4% Open

KPI

99.2 % 

Percent of time successfully controlled by Opti

System Control

6" Butterfly Valve

Operation Mode

Automatic Control

Manual Control

Drain Valve

Requested changes may take several minutes to be verified.

Great Lakes Radar

(NOAA)

[Latest Image](#) | 12hr | 24hr



Dashboard Detail

Continuous Performance Monitoring

Greenfield City Hall

Connectivity
(48hr)

Gateway 1

99.5% Online |
0.5% Offline

Gateway 2

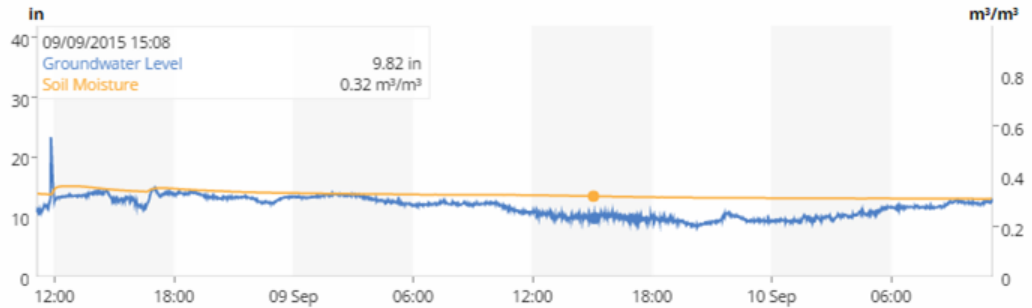
99.4% Online |
0.6% Offline

Control Panel
Door
(48hr)

99.3% Closed |
0.7% Open

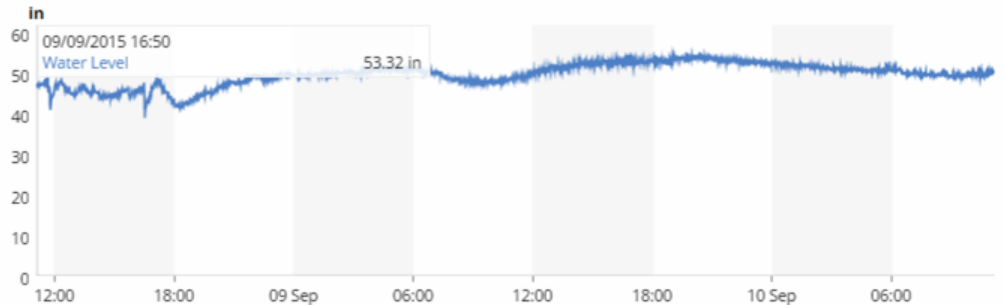
Southern Bioretention Cell

12hr | 24hr | **48hr** | 1wk



Southern Catch Basin Level

12hr | 24hr | **48hr** | 1wk



Dashboard Detail

Continuous Performance Monitoring



Greenfield City Hall

Connectivity

(48hr)

Gateway 1

99.5% Online |

0.5% Offline

Gateway 2

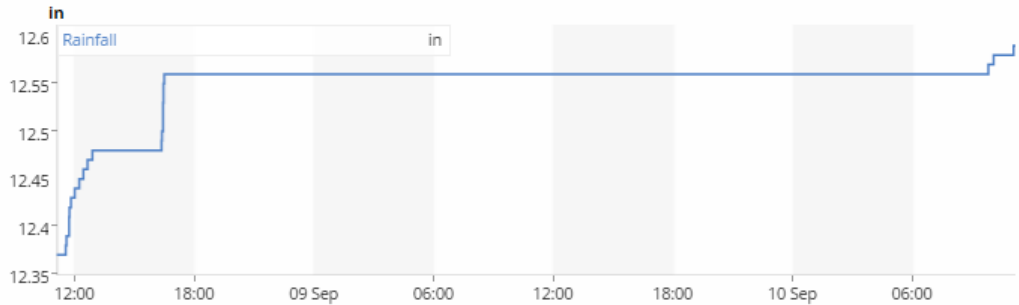
99.4% Online |

0.6% Offline

On-Site Rainfall

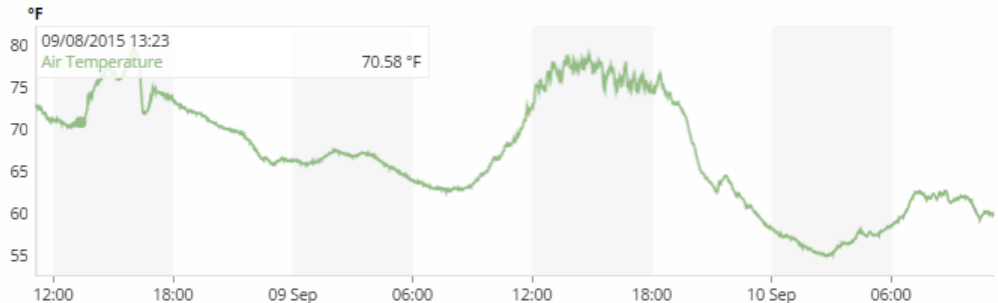
Cumulative to Date

12hr | 24hr | **48hr** | 1wk



Ambient Air Temperature

12hr | 24hr | **48hr** | 1wk



Orange County

Prado Wetlands



ReNUWit

Re-Inventing the Nation's Urban Water Infrastructure

Opti

Reset

▼ Projects (1)

Prado Wetlands

▼ Groups (1)

Admin



The map is filtering results.

Remove Filter



Leaflet | Bing, Image courtesy of LAR-IAC, © 2016 Microsoft Corporation

All rights reserved

Prado Wetlands

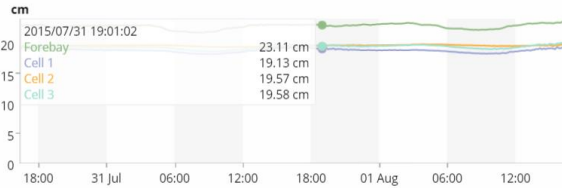
Data Aggregation

Wetlands Monitoring



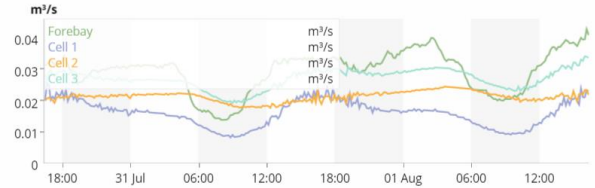
Water Level

12hr | 24hr | **48hr** | 1wk



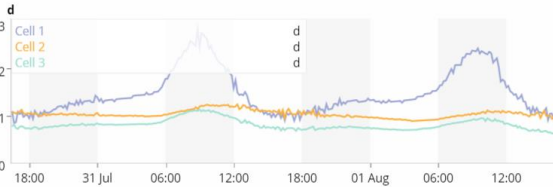
Outlet Flow Rate

12hr | 24hr | **48hr** | 1wk



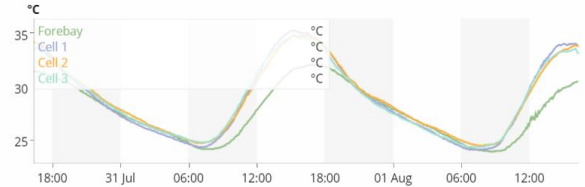
Hydraulic Residence Time

12hr | 24hr | **48hr** | 1wk



Water Temperature

12hr | 24hr | **48hr** | 1wk



pH

12hr | 24hr | **48hr** | 1wk

Dissolved Oxygen

12hr | 24hr | **48hr** | 1wk

University Blvd Ponds - Silver Spring, MD



5:08 pm April 20, 2016



Control Panel

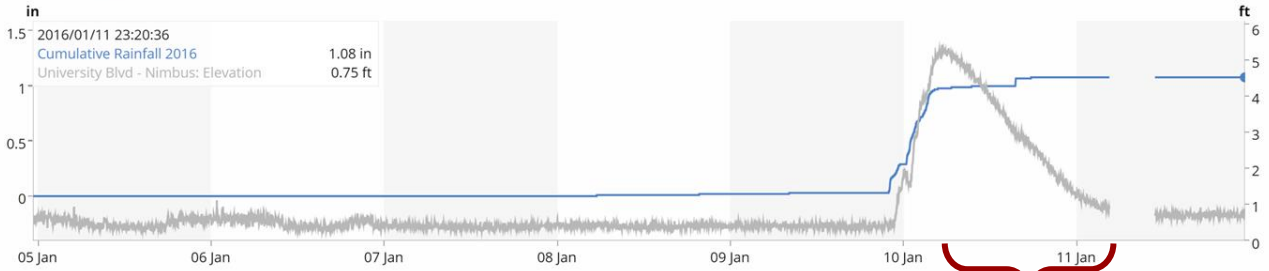
Real Time Water Quality Data (baseline)

NFWF - University Blvd (WQ Display)



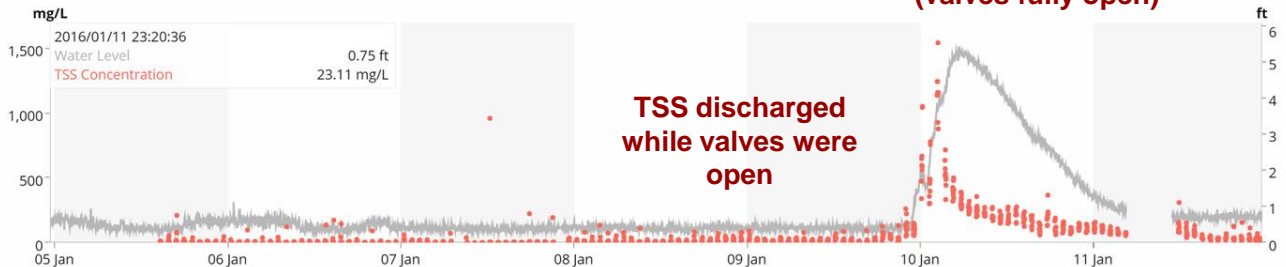
Rainfall

12hr | 24hr | 48hr | [1wk](#)



Pond Level and TSS

12hr | 24hr | 48hr | [1wk](#)



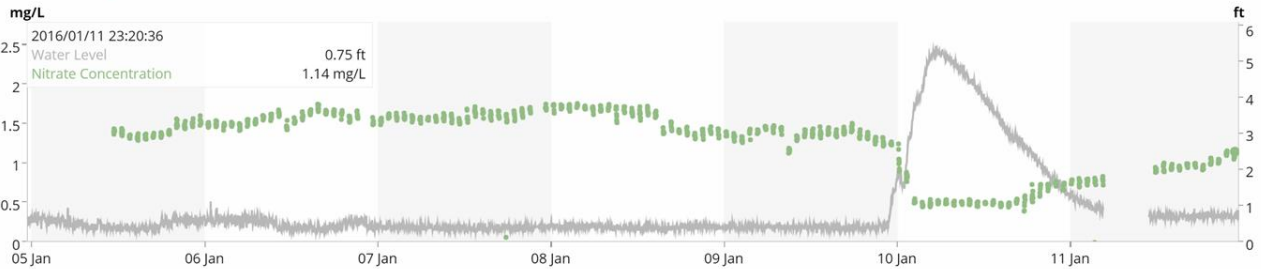
Real Time Water Quality Data (baseline)

NFWF - University Blvd (WQ Display)



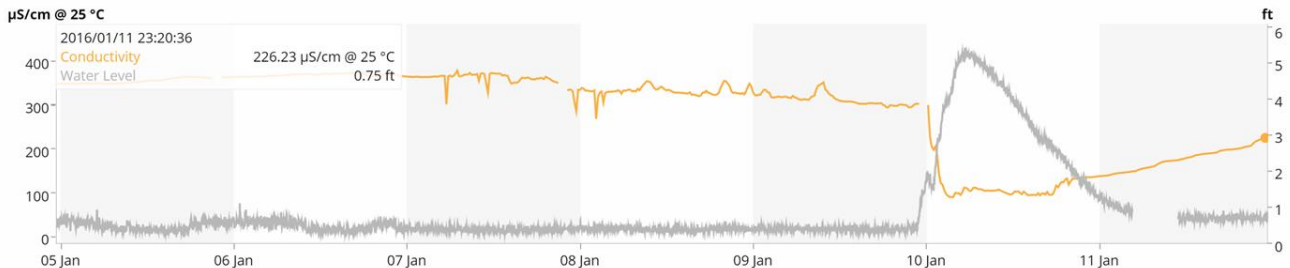
Pond Level and Nitrate

12hr | 24hr | 48hr | [1wk](#)



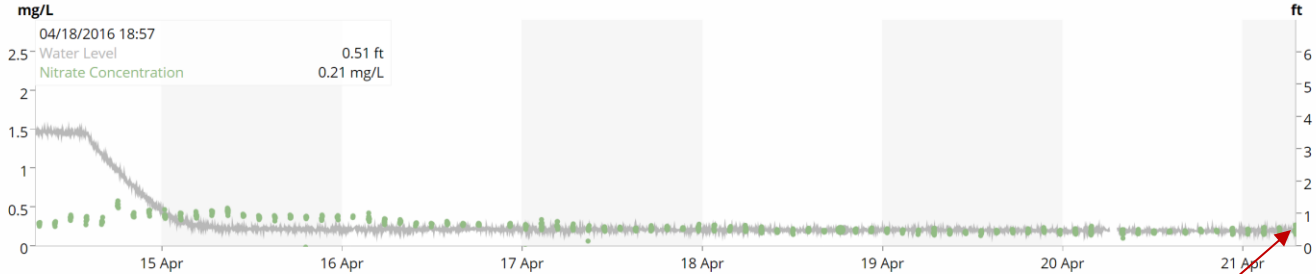
Pond Level and Conductivity

12hr | 24hr | 48hr | [1wk](#)



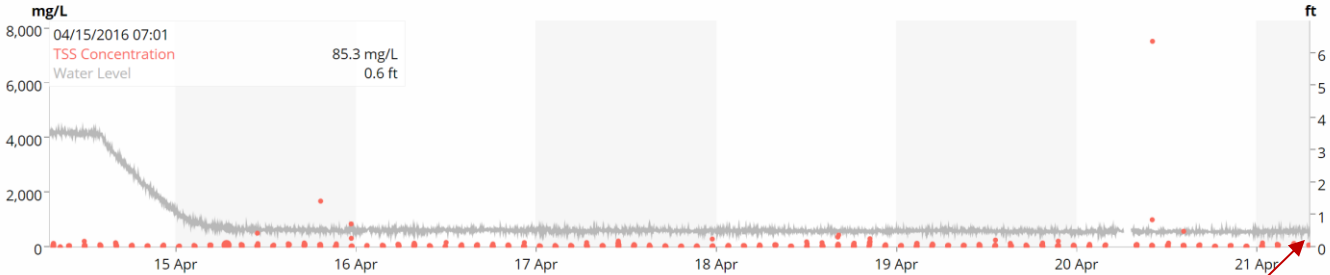
What was University Pond Doing While You Were Eating Breakfast?

DRAFT Water Quality Display



Pond Level and TSS

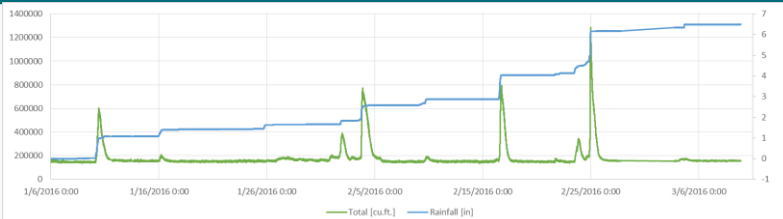
12hr | 24hr | 48hr | [1wk](#)



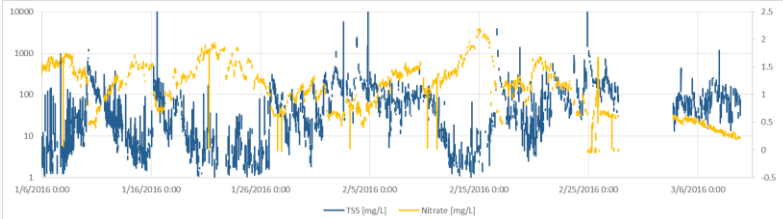
4/21/2016 7:14 am
0.16 mg/l Nitrate

4/21/2016 7:14 am
59.95 mg/l TSS

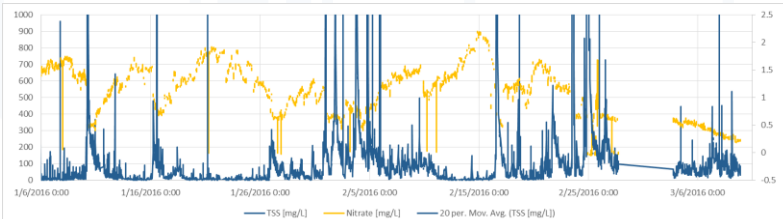
University Pond – Montgomery County Q1 – 2016



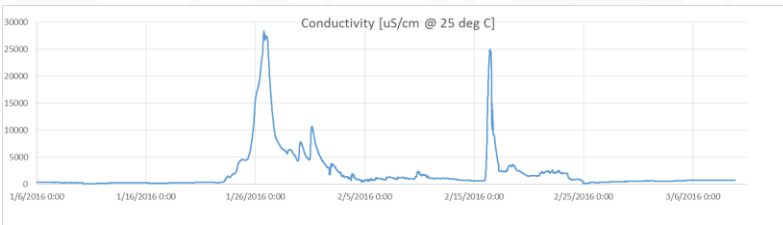
Rainfall and Storage



TSS and Nitrate
(log scale)



TSS and Nitrate
(linear scale)



Conductivity

Direct Community Stakeholder Engagement – Public API



HOME WHO WE ARE WHAT WE DO CUSTOMERS DEVELOPERS BUSINESS MEDIA LEARNING CENTER



PWSA AWARDS \$250,000 IN GRANTS FOR GREEN INFRASTRUCTURE PROJECTS

[Click here for a summary of our recipients.](#)

1 2 3 4

- PAY YOUR BILL
- UPDATE CONTACT INFO
- CONTACT PWSA
- REPORT A PROBLEM
- EMPLOYMENT
- GOING GREEN
- ADVANCED METERING INFRASTRUCTURE

WHAT'S HAPPENING

PWSA AWARDS \$250,000 IN GRANTS FOR GREEN INFRASTRUCTURE PROJECTS
8/25/15 @ 11:23 am

PWSA WILL REPAIR A SEWER ON CAREY WAY IN THE SOUTH SIDE
8/11 & 8/12, 7am-5pm
8/16/15 @ 11:27 am

PWSA PAVING SCHEDULE
August 10th – August 14th/2015
8/7/15 @ 12:27 pm

PWSA WILL REPLACE A FIRE HYDRANT AND VALVE ON SHADY AVENUE IN SQUIRREL HILL
8/7/15 @ 1:12 pm

PWSA WILL COMPLETE SURFACE RESTORATION PAVING ON 7th AVENUE IN
8/7/15 @ 1:12 pm

PROJECT INFO

Red Oak Dr & Hayson Ave
PWSA is awarding \$250,000 for the Red Oak Drive & Hayson Avenue Sewer Improvement Project.
8/6/15 @ 11:23 am

Fair Oaks
PWSA is awarding \$250,000 for the Fair Oaks Sanitary and Storm Sewer Separation Project.
7/22/15 @ 8:28 pm

Upper Lawrenceville
PWSA is awarding \$250,000 for the Upper Lawrenceville Water Replacement Project.
7/15/15 @ 1:55 pm

TWITTER/OUTAGES

PGH Water & Sewer @pgh2o
@pgh2o
@pgh2o Crew is on Hester Dr & Springfield St repairing a 6" main.
Waiting to hear about an ETA.

PGH Water & Sewer @pgh2o
@pgh2o
@pgh2o is also repairing a 6" main in Carnegie Place b/t Reynolds & Penn Ave

GREEN INFRASTRUCTURE FUNDING AT WORK



3.4M GALLONS
of stormwater treated



11.5 INCHES
of cumulative precipitation



99% OF GOALS
are being achieved

real-time as of September 21, 2015 at 10:23 am

Powered by **opti**

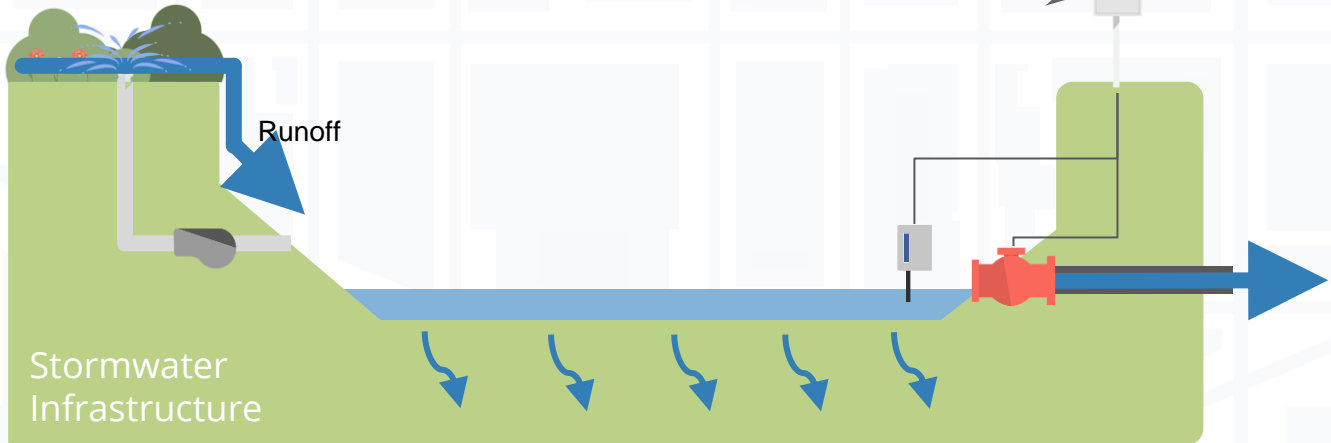
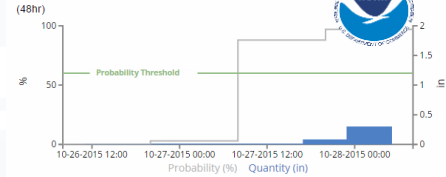
The background features a light blue grid pattern overlaid on a white background. Within the grid, there are various stylized, semi-transparent shapes representing buildings and infrastructure. A prominent feature is a satellite dish in the upper right quadrant. The overall aesthetic is clean and modern, suggesting an urban or technological theme.

Stormwater and Green Infrastructure Control

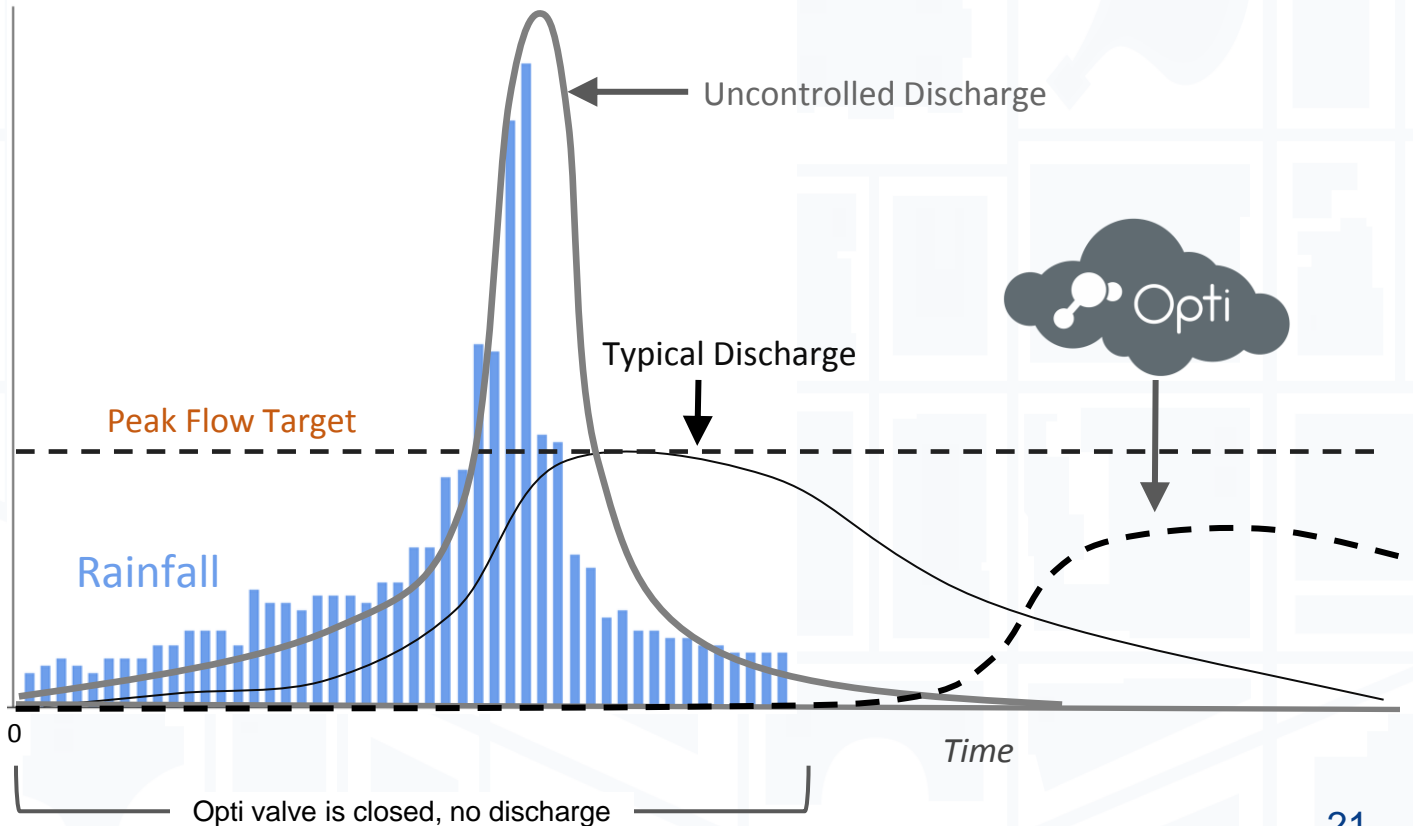
Adaptive Control



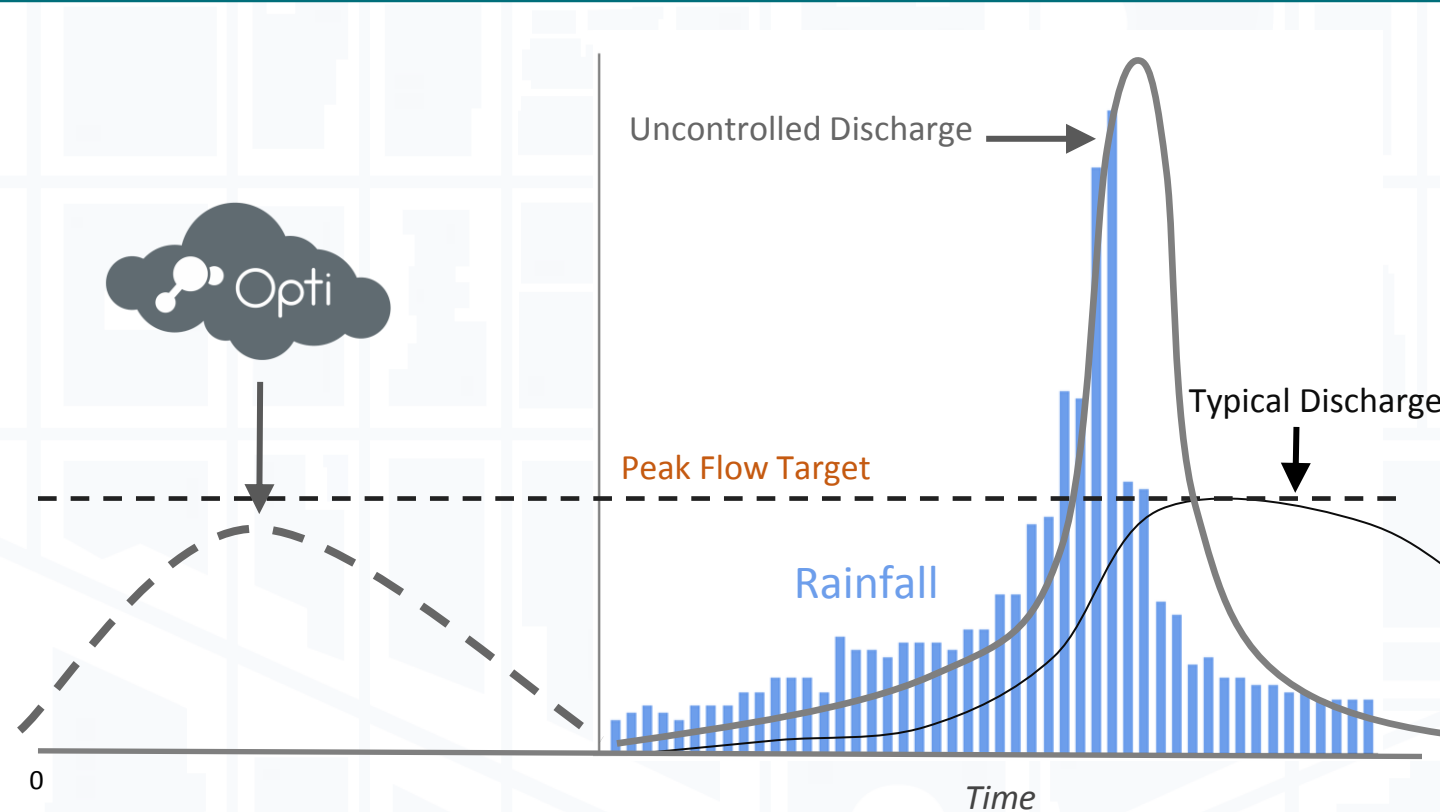
Precipitation Forecast



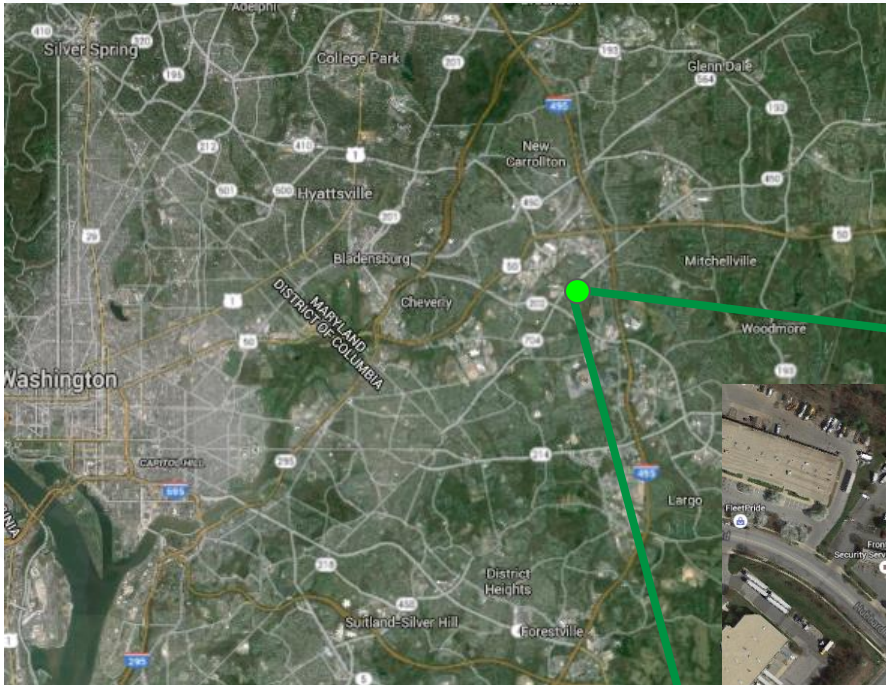
Control the Hydrograph



Release water at the right time As late as before the next event



Case Study: Nutrient Control in Chesapeake Bay Region



Frost Pond
Prince Georges County, MD
60 Acre Drainage Area
19 Acre Impervious
Approx. 0.5 ac
Dry Pond built in 1988



Frost Pond



Conventional Retrofit Dig a Bigger Hole!

Storm Water Management Retrofit Evaluation																											
Pond No.: 02_87216A_01		Pond Name: Frost Property Pond # 1			Date: 6/7/12																						
ADC Map: 13D08		Address: Mueserbush Court & Barlowe Road			Rating: C																						
Pond Ownership: DPWT		Subwatershed: Washington Metropolitan Area																									
Lat/Long: 1349326.7108		460068.3144		Sub-Catchment: Anacostia River																							
MDE HUC 12 NO.: 021402050816		Watershed Impairment: Yes - Annacostia																									
Year Constructed: 1998																											
Notes:																											
Online pond, though there is enough area to grade wet cells, while maintaining WUS																											
BMP Description:																											
<table border="1"> <thead> <tr> <th rowspan="2">Existing BMP Type</th> <th rowspan="2">Drainage Area (acres)</th> <th rowspan="2">Pond Surface Area (sq ft)</th> <th colspan="2">Impervious Cover (I)</th> <th rowspan="2">Does Facility Meet MDE 2001 Water Quality Req.</th> <th rowspan="2">Adequate ROW</th> <th rowspan="2">Adequate Access</th> </tr> <tr> <th>Acres</th> <th>%</th> </tr> </thead> <tbody> <tr> <td>Extended Detention Dry Pond</td> <td>60.27</td> <td>28629</td> <td>19.15</td> <td>31.77%</td> <td>No</td> <td>Yes</td> <td>Yes</td> </tr> </tbody> </table>										Existing BMP Type	Drainage Area (acres)	Pond Surface Area (sq ft)	Impervious Cover (I)		Does Facility Meet MDE 2001 Water Quality Req.	Adequate ROW	Adequate Access	Acres	%	Extended Detention Dry Pond	60.27	28629	19.15	31.77%	No	Yes	Yes
Existing BMP Type	Drainage Area (acres)	Pond Surface Area (sq ft)	Impervious Cover (I)		Does Facility Meet MDE 2001 Water Quality Req.	Adequate ROW	Adequate Access																				
			Acres	%																							
Extended Detention Dry Pond	60.27	28629	19.15	31.77%	No	Yes	Yes																				
Water Quality Volume (WQv) Required for New Development:																											
Acres-feet		Depth of excavation to provide Wq ^v		Proposed Retrofit		Notes																					
1.69		3.21		Wet Pond / Shallow		Create wet pools while maintaining WUS																					
WQv Calculation:																											
PE (Rainfall Target, in inches): 1																											
RV (Runoff Volume) = 0.05_0.009(I), where I is % Impervious Cover:																											
QE (Runoff Depth in inches to be treated QE = PE*RV)																											
WQv = (PE)(RV)(A)/12, where A is the DA in acres																											
*Determined by multiplying the pond surface area by a factor of 0.80 to account for side slopes, then dividing by the WQv																											
Projected Retrofit Cost:		\$303,153																									



Excavate 3.21' to create 1.69 ac-ft of storage

Opti Retrofit Adaptively Control Flow



With a valve and control logic

Created >2 ac-ft of
extended detention volume



Lifecycle Costs

Lifecycle Costs

Including Consulting, Design, and Construction

Cost Summary	Opti	Passive	Opti Savings Over Passive (Passive - Opti)/Passive
Total Capital Cost	\$26,000	\$303,000	90%+
Gross Annualized Costs (includes maintenance)	\$10,000	\$5,000	
Present Value of 25 year Lifecycle Cost	\$166,939	\$373,470	55%

Opti's lifetime cost to treat one impervious acre is **\$8,700 compared to \$20,000** for a passive retrofit.

References:

Construction and annual costs from Opti and from a comparison bid for passive retrofit and maintenance of the same pond.

*NPV uses a discount rate of 5%

90% reduced capital cost for highly effective water quality retrofit.

**What ecosystem services
will you deliver with the
additional \$276K?**

Preparing for Rain: Pre-Event Forecast

System Control

Operation Mode

Automatic Control

Manual Control

Valve Control

Open

Close

Requested changes may take several minutes to be verified.

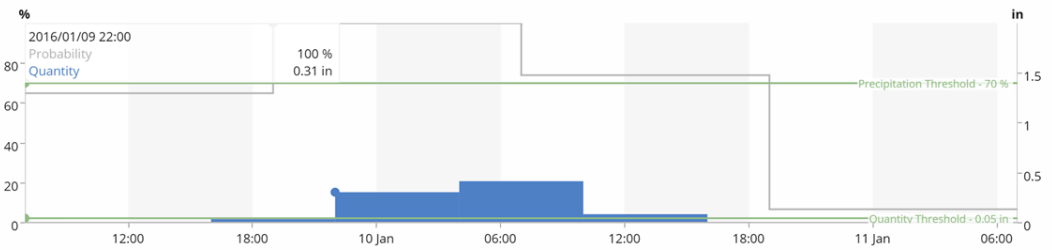
Storm Status

Forecast Rainfall (in)
2016-01-09 11:59:41
0.8

Forecast Runoff (gal)
2016-01-09 11:59:41
440621.7

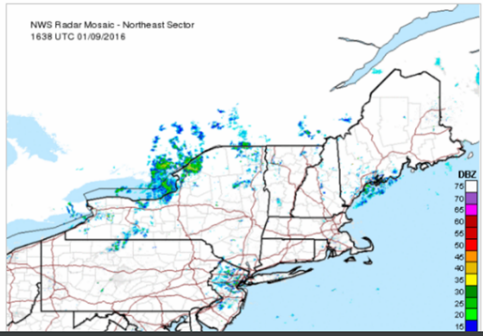
Post-Event Retention (up to)

Precipitation Forecast (48hr)



Northeast Radar (NOAA)

[Latest image only](#) | 12hr | 24hr



Opti interprets forecast

Example Storm: January 9 to 11, 2016

System Control

Operation Mode

Automatic Control

Manual Control

Valve Control

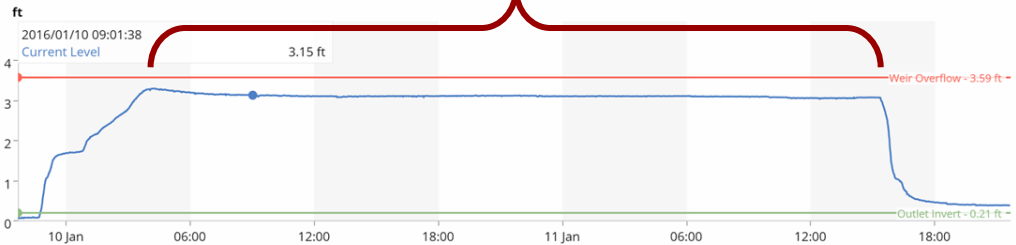
Open

Close

Requested changes may take several minutes to be verified.

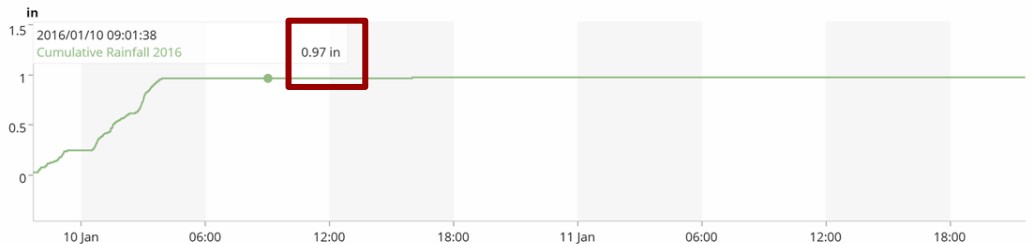
Pond Level

12hr | 24hr | **48hr** | 1wk



Rain Gage

12hr | 24hr | **48hr** | 1wk



Pond Volume

12hr | 24hr | **48hr** | 1wk

Storm Status

Forecast Rainfall (in)

2016-01-11 21:38:35
0.0

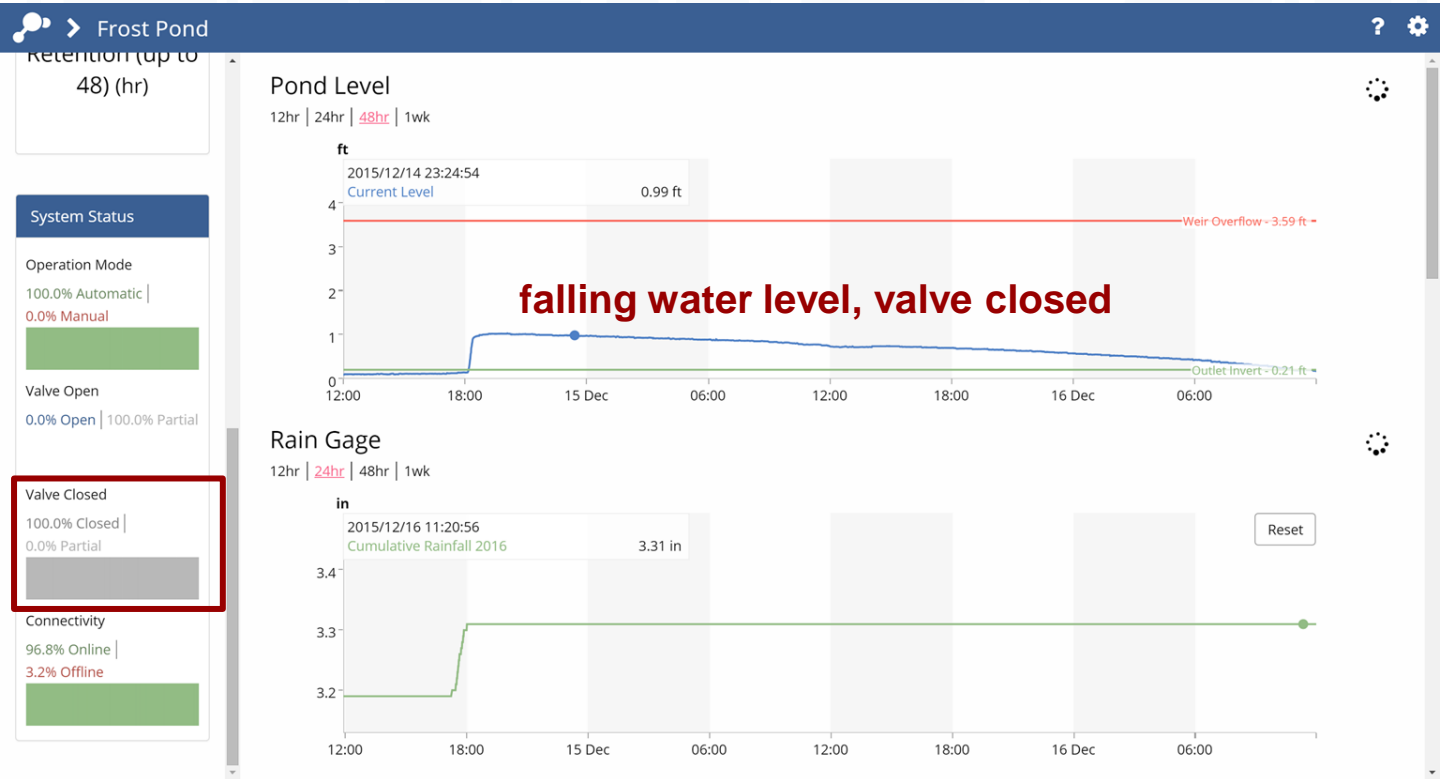
Forecast Runoff (gal)

2016-01-11 21:38:35
0.0

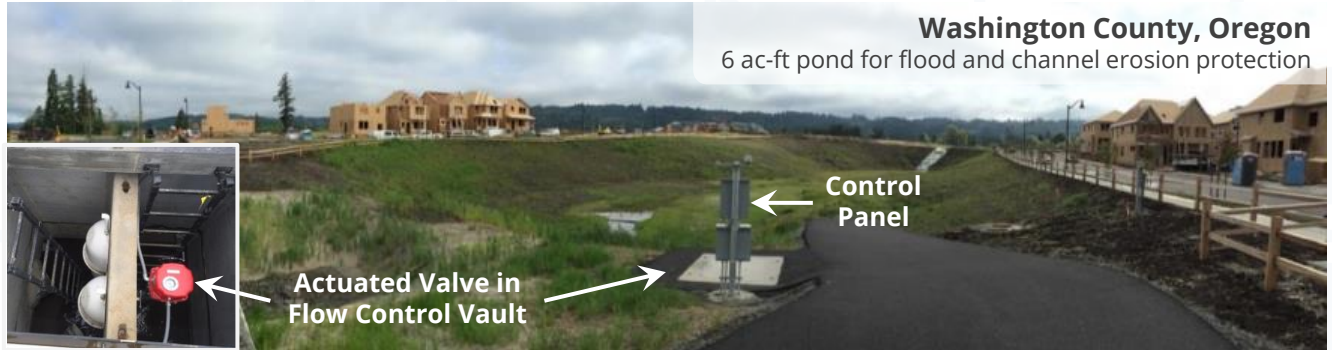
Post-Event Retention (up to)

Downstream benefits for range of events

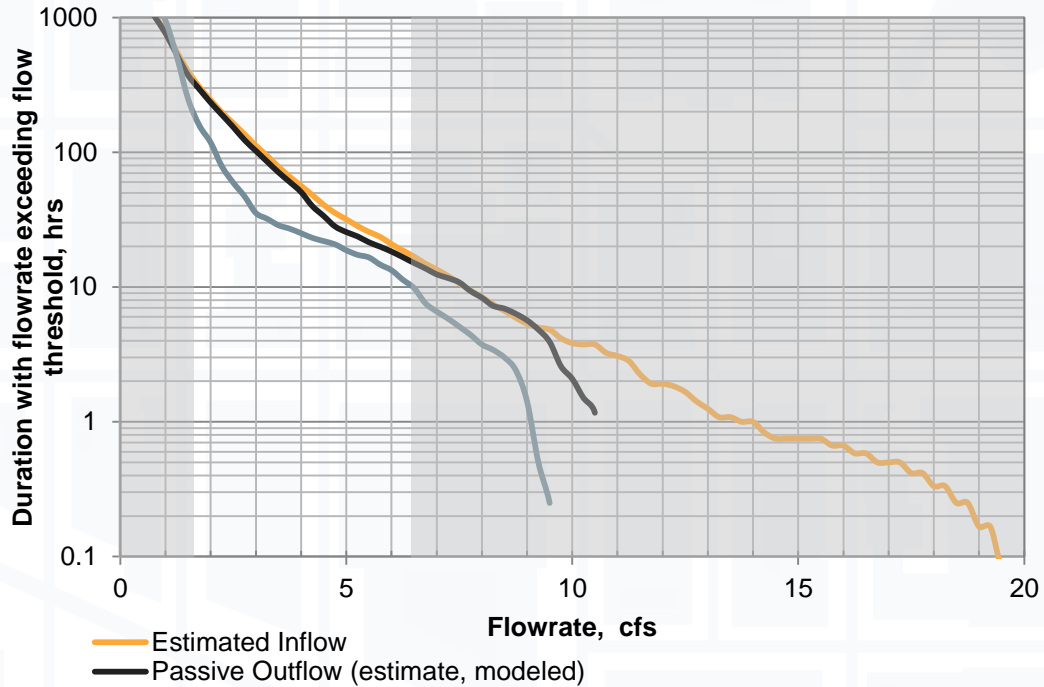
Small Event with 100% Infiltration



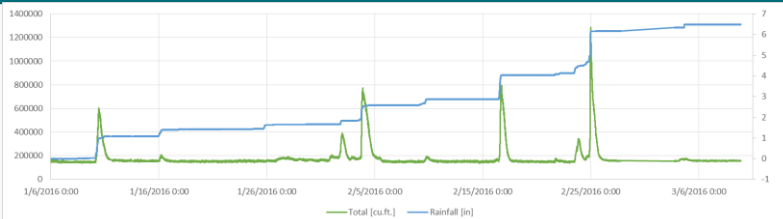
Washington County, OR Water Quality and Flow Control



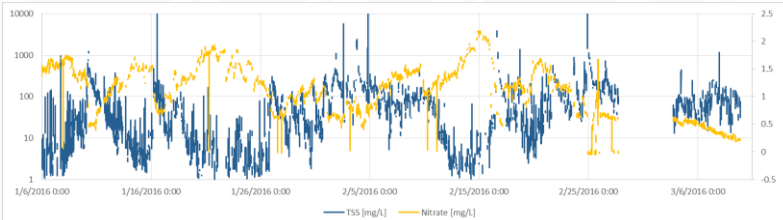
Flow Duration Control



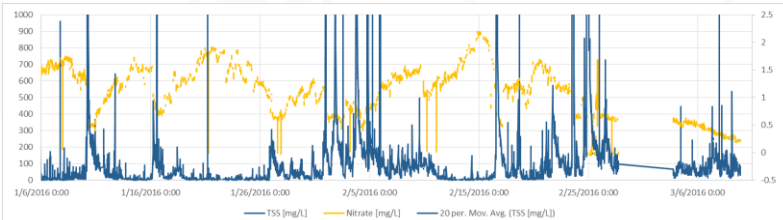
University Pond – Montgomery County Q1 - 2016



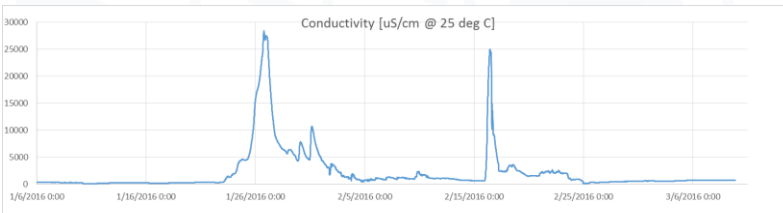
Rainfall and Storage



TSS and Nitrate (log scale)



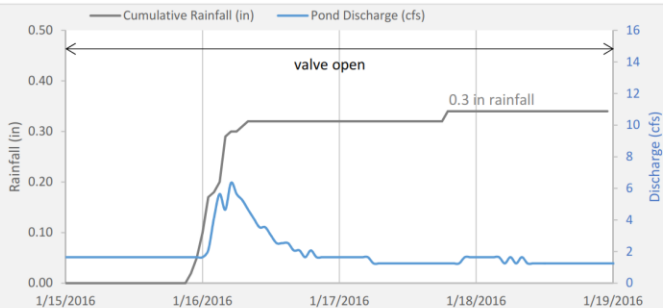
TSS and Nitrate (linear scale)



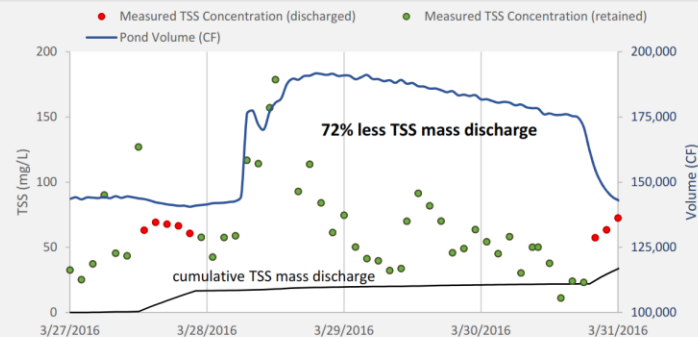
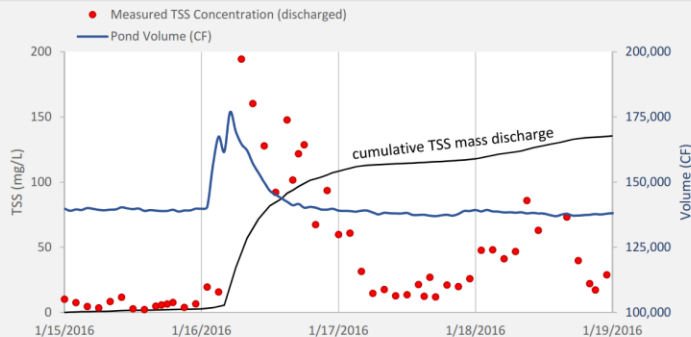
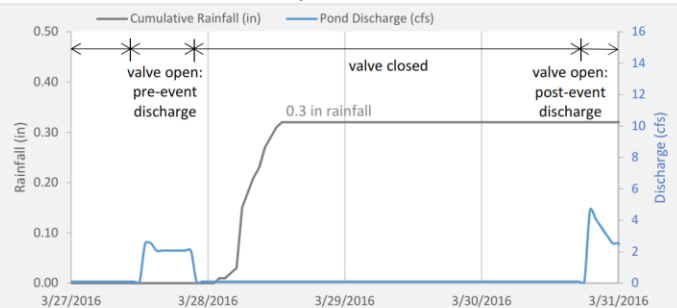
Conductivity

Real-time TSS Monitoring of Passive vs. Adaptive Control in Maryland

Passive Wet Pond



Opti Wet Pond



Same facility, Similar storms - 72% reduced mass of TSS discharged with adaptive control.

Los Angeles



TETRA TECH



TREEPEOPLE



Multi-Agency Collaborative, Phase 2 Collaborative Governance Around a Pilot-to-Scale Initiative



AGENCIES

- City of Los Angeles Sanitation
- Los Angeles Department of Water and Power
- Los Angeles County Department of Public Works

LOCATION

City of Los Angeles and
Los Angeles County

KEY OUTCOMES

- **Water quality improvement**
(EWMP compliance)
- **Local water supply augmentation**
(Stormwater Capture Master Plan and One Water synergy)
- **Flood control and nuisance flood mitigation**
(Los Angeles County Flood Control Act implementation)

Los Angeles

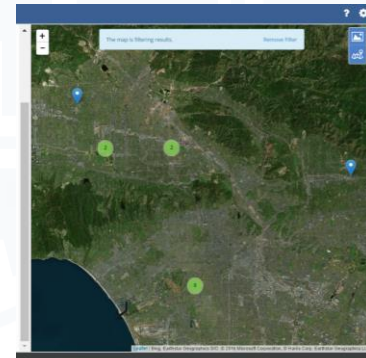
Water Collected From Roof



Water used for irrigation
Discharged in advance of the
storm



Goal: 1,000s of
cisterns
throughout
LA



Collaborative LA Project



Los Angeles Times

Monitor and Adapt

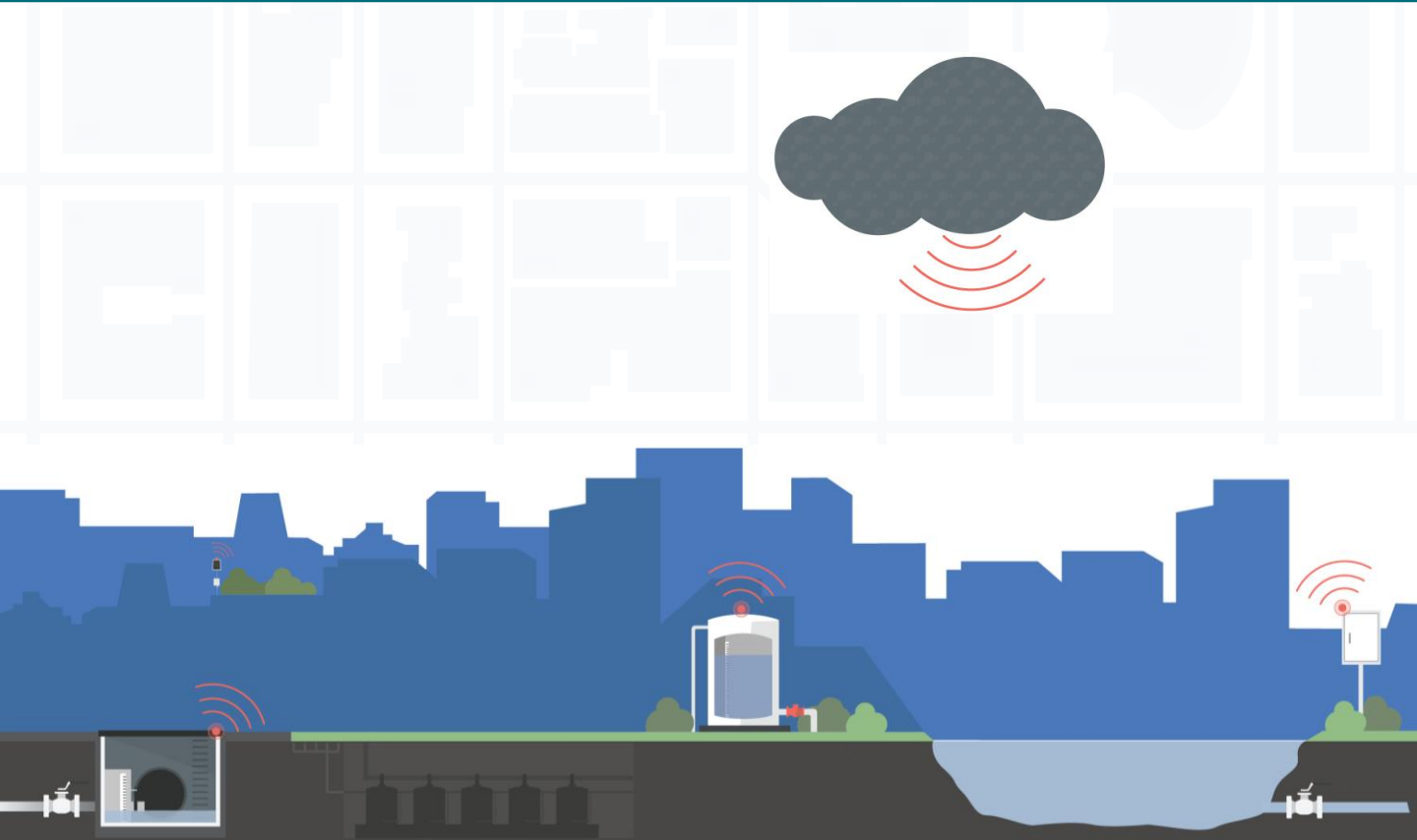
1. Continuously monitor and understand performance
2. Adapt operation based on performance data
3. Adapt future designs based on data
4. Iterate

Reduce risk and increase certainty of improving water quality and hydrology.

Dramatically reduce cost.

Use assets effectively.

Questions





Appendix

The background features a light gray grid pattern. Within the grid cells, there are various faint, light blue geometric shapes, including rectangles, squares, and irregular polygons. A prominent feature is a satellite dish icon located in the upper right quadrant of the grid. The word "Modeling" is centered in the grid in a dark blue font.

Modeling

Nationwide Modeling Study

Data Source:

NOAA National Climatic Data Center
625 meteorological stations
Hourly rainfall data from 1956 to 2006

Analysis Steps:

1. EPA SWMM continuous simulations for rainfall-runoff and storage hydraulics
2. Compare discharge from passive and active storage scenarios
3. Calculate key performance indicators (KPIs)

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Summary Statistics for 1-in Storm

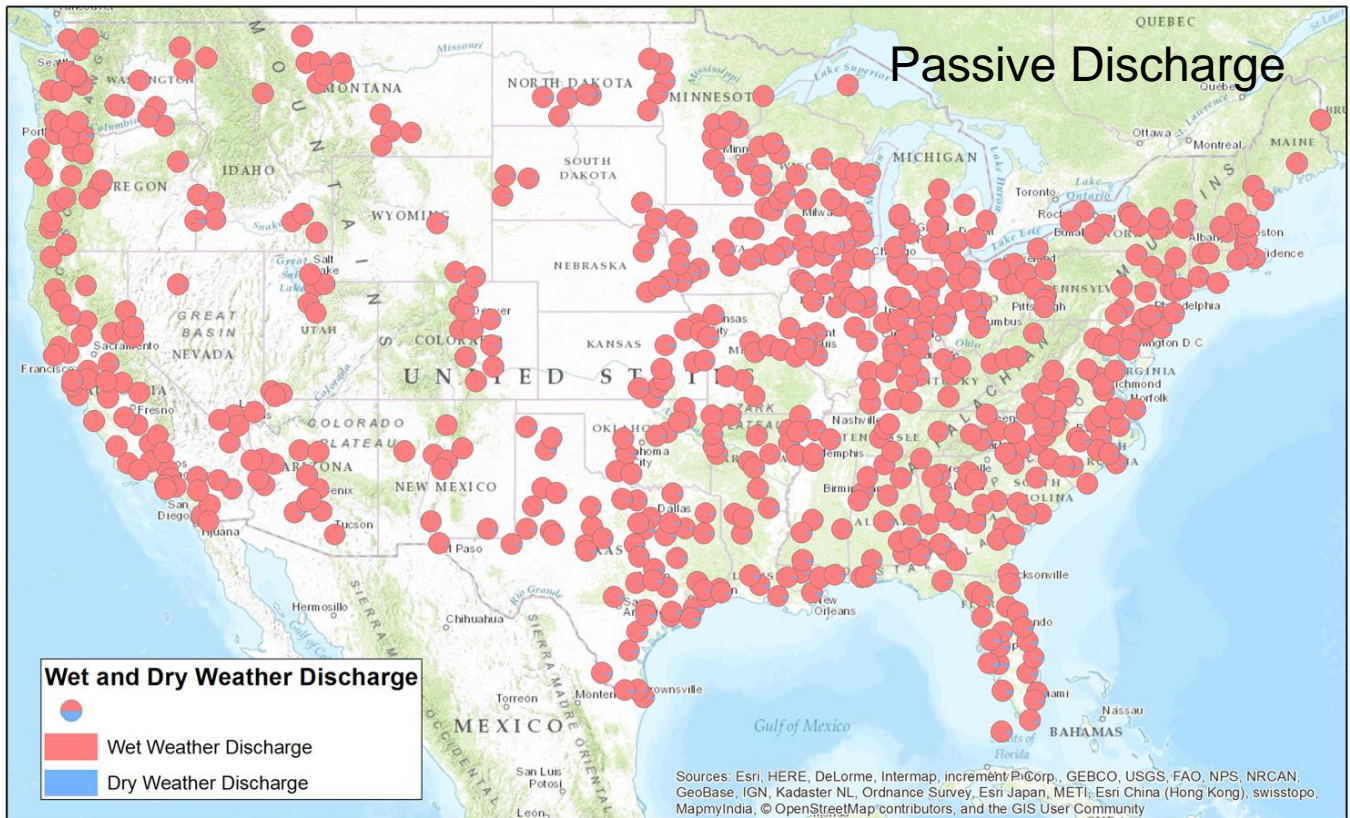
Median values for all 625 stations

Simulation	Metric	Passive Storage	Opti Active Storage
Water Quality: Maximize Retention Time	Long term average retention time	12 hours	196 hours
	Average water available for use ¹	0	590,000 gal/acre/year
	Average wet weather storage utilization	26%	68%
	Percent time runoff retained	3%	59%
CSO/Flooding: Minimize Wet Weather Discharge	Average wet weather discharge	0.052 cfs	0.021 cfs
	Average wet weather discharge during inflow > 0.25 cfs	0.265 cfs	0.171 cfs
	Wet weather capture	2%	61%
	Percent time runoff retained	2%	91%

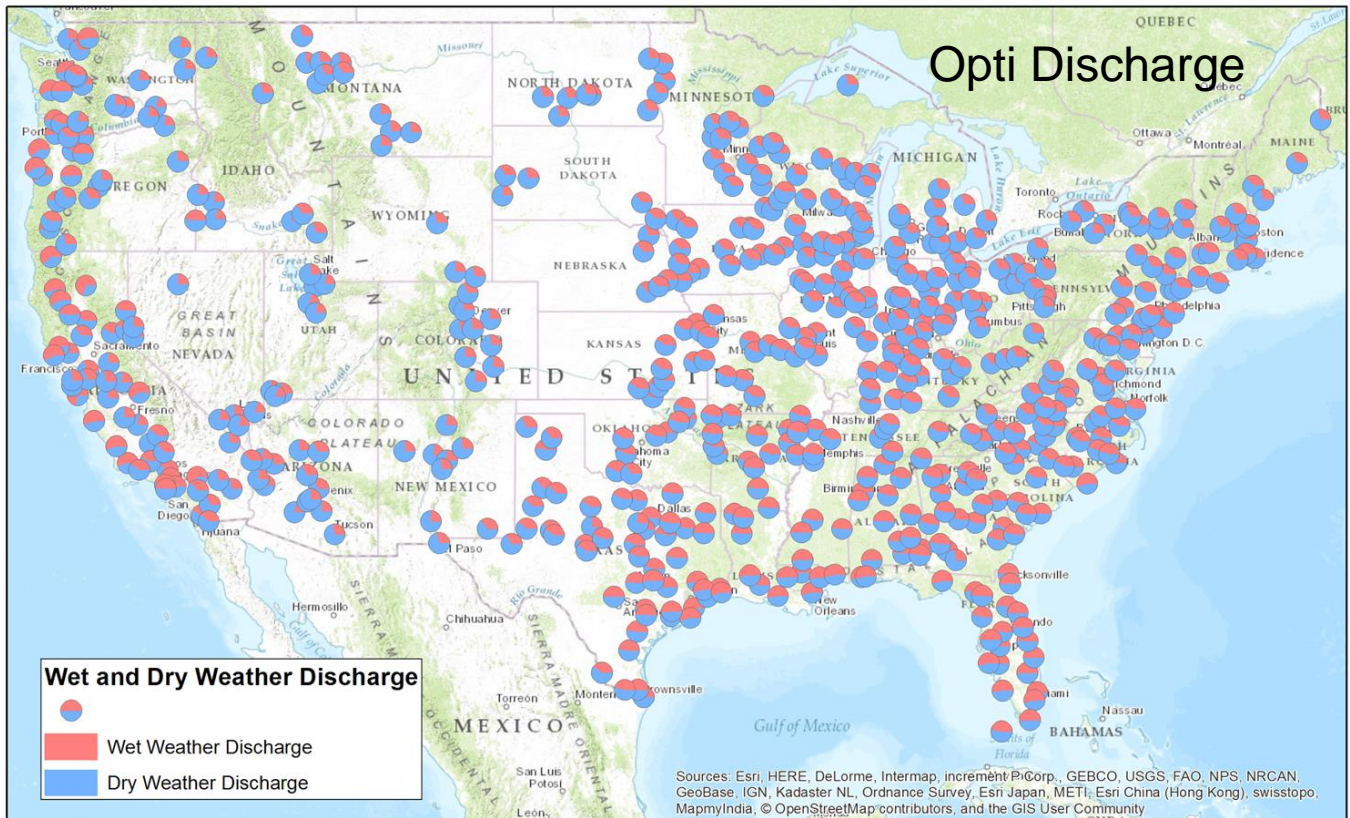
Note: median values shown for 1 inch storage size

1: No withdrawals were simulated. In the passive system, no water was available for use because the outflow valve was always open. In the Opti system, water captured and not released during wet weather was considered available for use. The value shown is the annual average capture volume.

Volume Discharged During Wet vs. Dry Weather



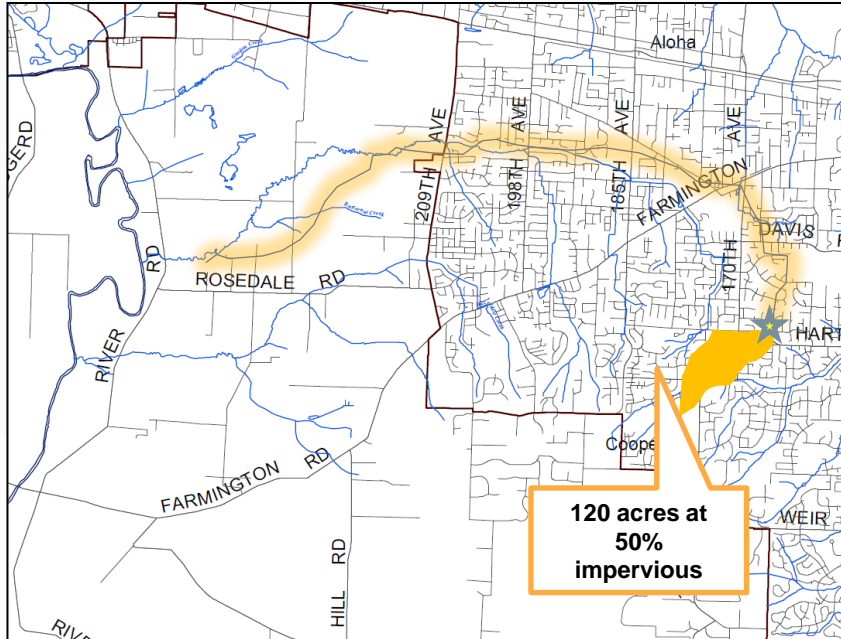
Volume Discharged During Wet vs. Dry Weather





Additional Case Studies

Case Study: Butternut Creek, Portland OR – Hydromodification



Case Study: Butternut Creek, Portland OR – Hydromodification



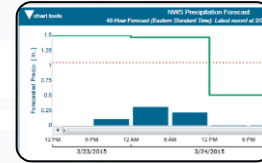
Before



After

Flow Control – Simplified Logic

Watch and prepare in advance of forecasted event



Release at minimum rate before and during event, if needed, to make capacity available



Return to target dry weather state within allowable timeframe



Continually adapt to current conditions and forecast

Flow Control – Web Dashboard

Butternut Creek Pond

System Control

12" Slide Gate Valve

Operation Mode

Automatic Mode

Manual Mode

Valve Position

Open

Open value 75%

Open value 50%

Open value 25%

Close

Requested changes may take several minutes to be verified.

System Status

(48hr)

Operation Mode

100.0% Automatic | 0.0% Manual

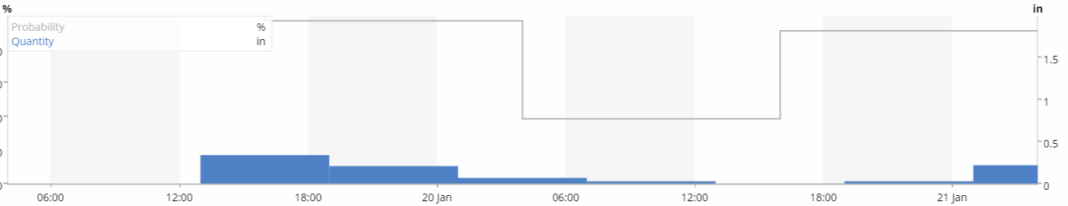
Valve Percent Open

17.6% 0 | 55.5% 25 | 26.2% 50 |

0.7% 75 | 0.0% 100

Precipitation Forecast

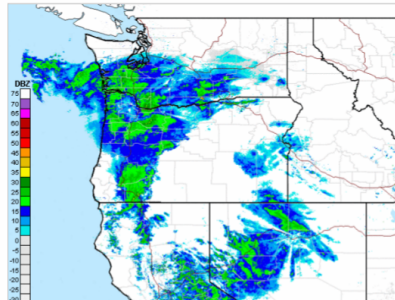
(48hr)



Pacific Northwest Radar

(NOAA)

[Latest image only](#) | 12hr | 24hr



Flow Control – Example Storm



Reset

Projects (43)

- 1267 - Sun Prairie - WI
- 50th and Pine Pavement
- 5112 - Kilbuck - PA
- Aqua Storm Control
- Asgrow Frac Tanks
- BBG Water Garden
- Bethany Creek Falls Pond
- Butternut Creek Pond
- Conowingo Cistern
- Curtis Bay Piers DSS
- Curtiss Pond
- Dalton Landfill
- Dearborn Homes
- Denver Green School Cistern
- Drexel Town Square
- EPA Cisterns
- Ebright Creek
- Engine 3 and 25 Cisterns
- Expo Rail
- Florida Springs
- Gwinnett Cistern
- LA River
- Landfill Gas Demo
- Landmark Cistern
- NFWF
- NSF-Villanova
- Newtown Square Green Roof
- North Science Quad
- Oak Street SSD
- Opti Demo Project
- Opti R&D
- Ottawa River
- Prado Wetlands
- Ranaqua Cisterns
- SE Precinct Pavement
- St. Joseph Wetlands
- St. Mary's
- TreePeople Cisterns - Pilot-to-Scale



1267 - Sun Prairie - WI



43rd Place



43rd Place (View Only)



50th and Pine Pavement (View Only)



50th and Pine Porous Pavement



5112 - Kilbuck - PA



6th Ave



6th Ave (View Only)



Alapaha River at Statenville, GA



Alapaha River near Alapaha, GA



Aqua Storm Control Demo



Asgrow Frac Tanks

