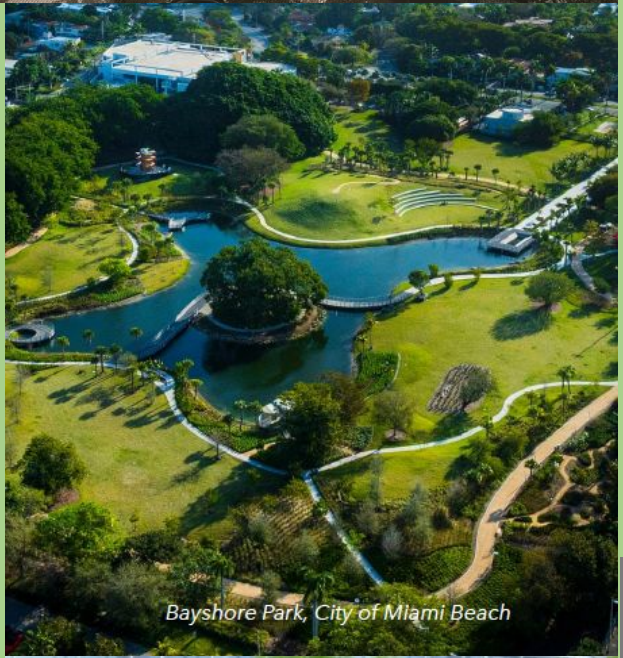

Bayshore Park, City of Miami Beach

FIU FLORIDA INTERNATIONAL UNIVERSITY

Green Stormwater Infrastructure: State of the Science

Tiffany Troxler, PhD

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Florida International University

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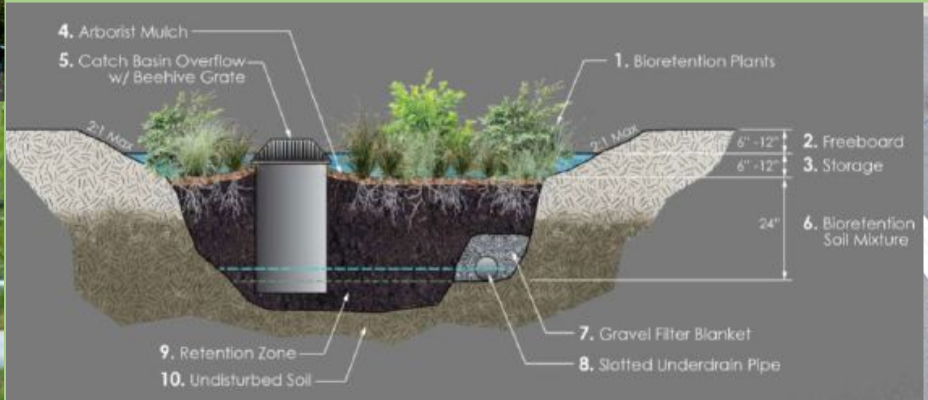
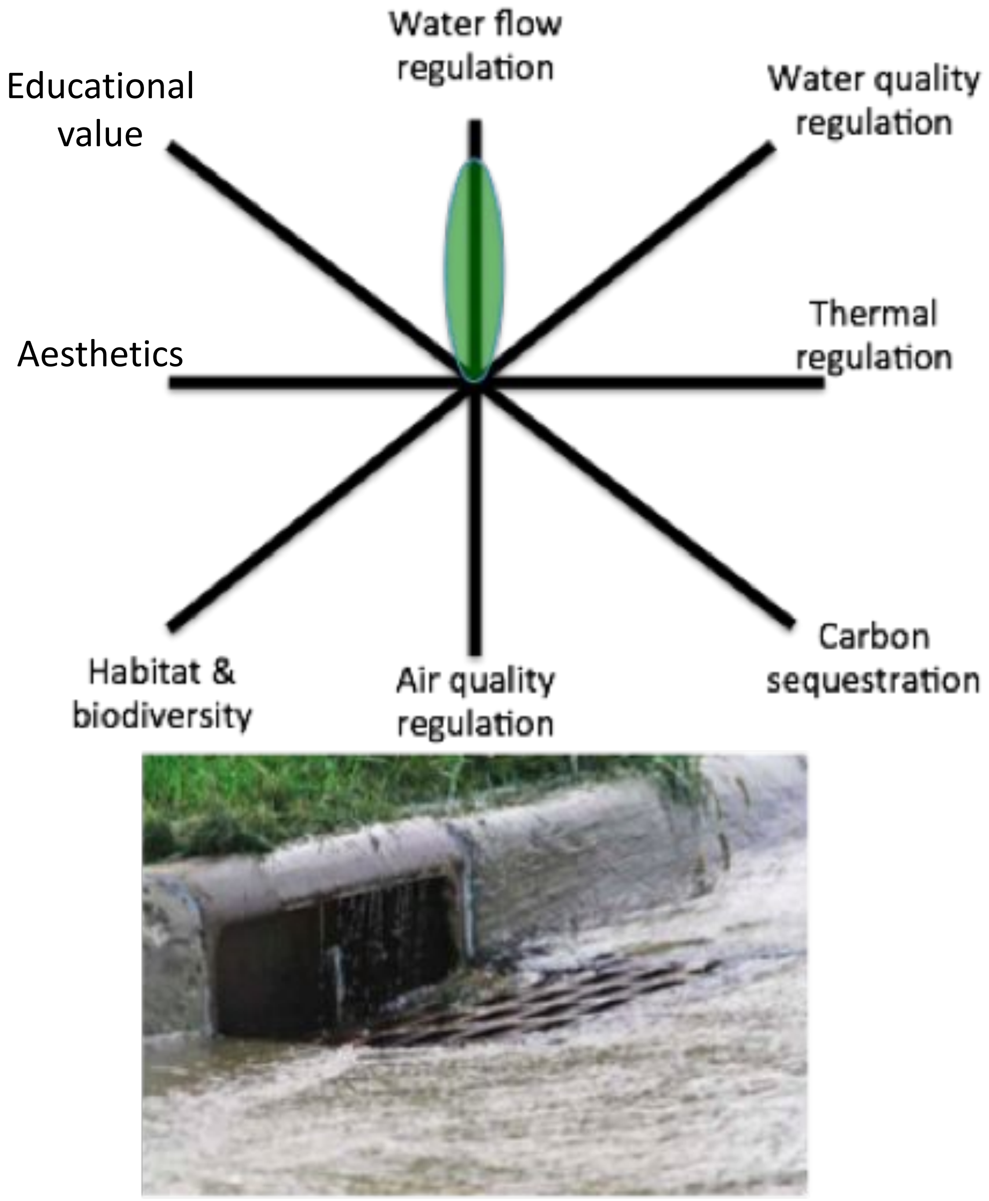
Southeast Florida Regional Climate Change Compact

RCAP 3.0 Implementation Workshop

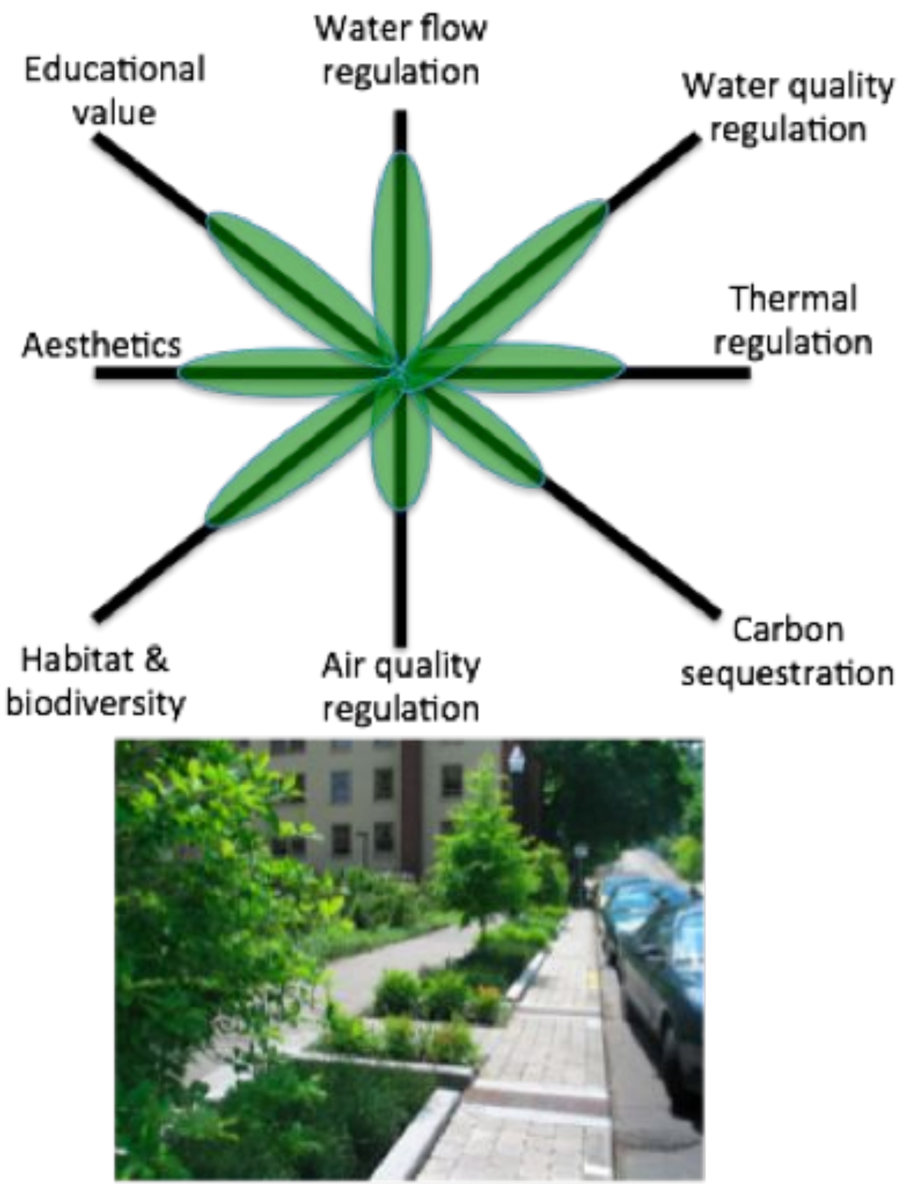


Integration of natural features as part of stormwater management to enhance environmental, health and economic co-benefits

Fewer benefits



Grey Infrastructure

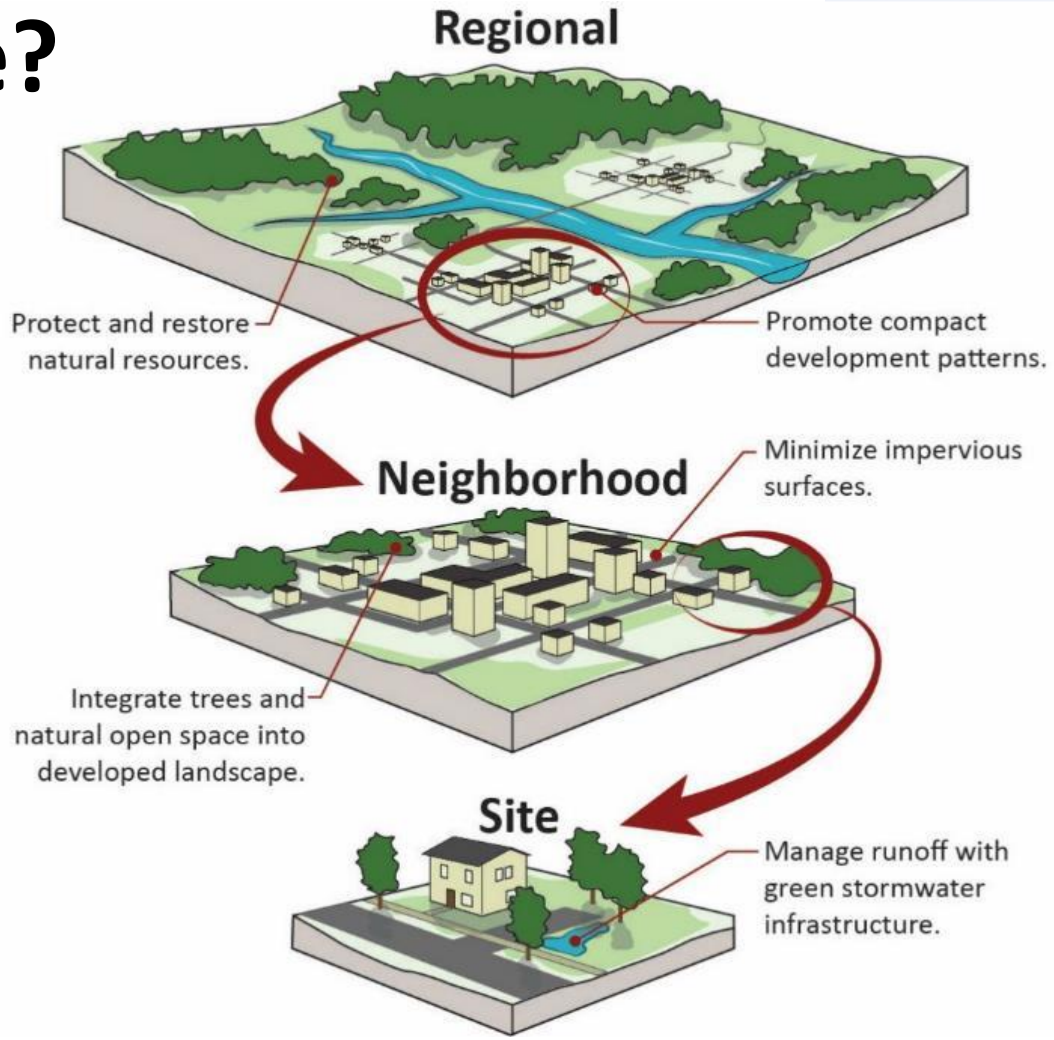


Green Infrastructure

Multiple, co-benefits

What is green infrastructure?

- Green infrastructure uses plants, soils, and other media to capture and treat stormwater at its source. It relies on the natural processes of filtration, infiltration, and evapotranspiration to manage stormwater.
- Green infrastructure can be implemented at multiple scales.



The U.S. Clean Water Act (Section 502(27); 33 U.S.C. 1362(27)) defines “green infrastructure” (GI) as “the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspire stormwater and reduce flows to sewer systems or to surface waters.”

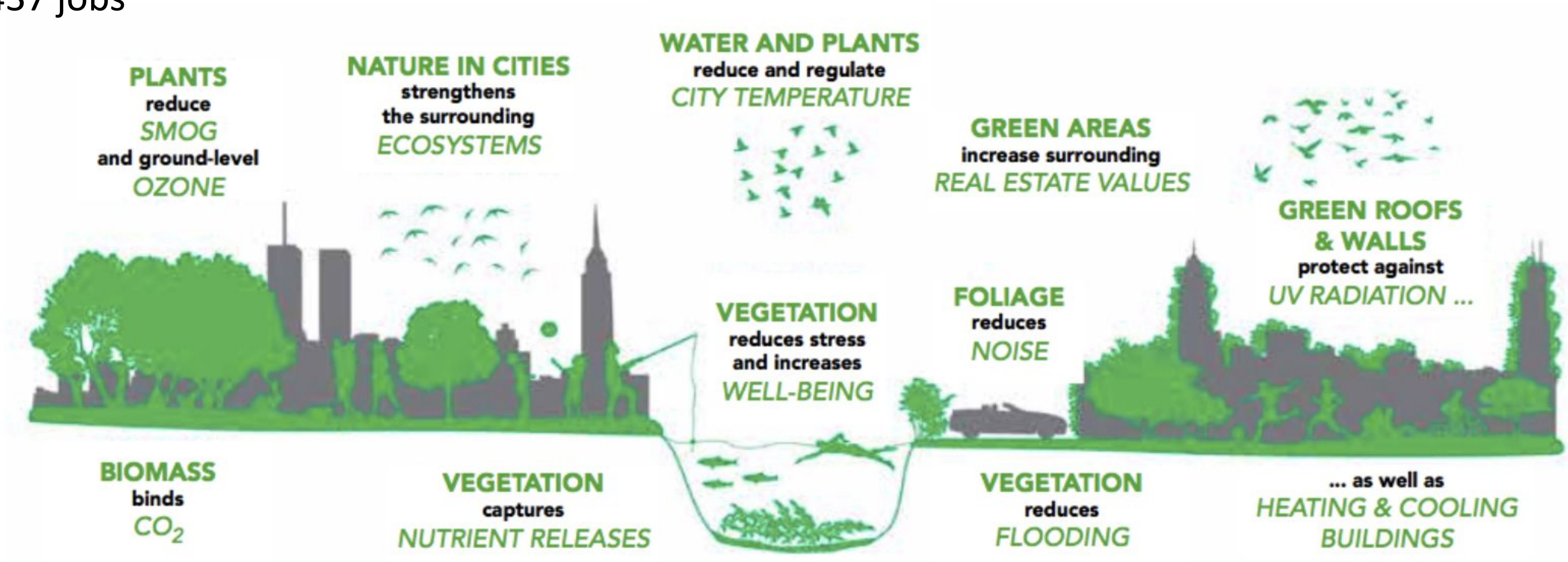
Green Infrastructure Practices

- Are designed to meet multiple stormwater management objectives, including runoff volume reduction and water quality protection
- Can be constructed individually, or as part of a larger scale approach
- Should be part of a decentralized management strategy that uses multiple localized controls, which combine into a 'treatment train' to provide comprehensive stormwater treatment

Integration of Nature-based features (including green stormwater infrastructure; GSI) can create more value from **flood mitigation projects**

From 2015 to 2020, GSI construction in the DC metropolitan region created (Galvin and BenDor 2023):

- $91M in average annual economic output
- $45 million in labor income
- $60M in value added
- 437 jobs



https://www.cocity.se/om-oss/urban-ecosystem-services/

Eco-Techno Spectrum of Green Infrastructure Features

Primarily ‘natural’ components,
Ecology dominated,
Larger-scale
(e.g. passive river restoration techniques)

Mostly human-built components
Engineering dominated,
Smaller-scale
(e.g. bioswales)

McPhillips and Matsler 2018

Green Infrastructure Benefits

Table 1 | Urban ecosystem services and nature-based solutions

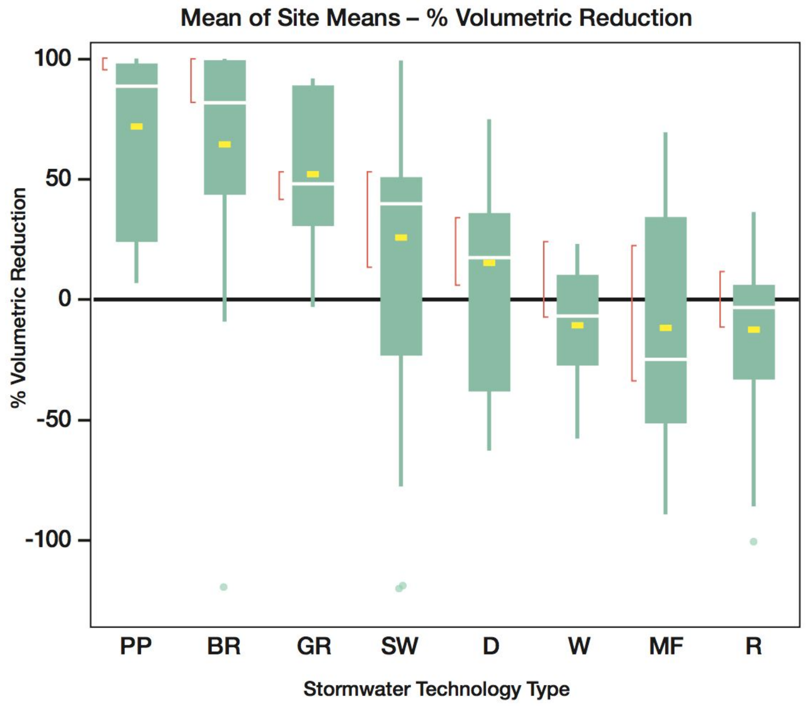
Urban ecosystem services	Nature-based solutions						
	Street trees	Parks and open space	Engineered stormwater controls[a]	Green roofs	Waterways and wetlands	Coastal habitats[b]	Urban gardens
Urban air quality	X	X					
Carbon sequestration	X	X					
Coastal protection						X	
Urban heat and heat extremes mitigation	X	X		X			
Stormwater and wastewater management	X	X	X	X	X		
Urban water supply	X	X	X				
Riverine flood impact reduction		X	X		X		
Recreation opportunities		X			X	X	
Mental health	X	X					X
Urban agriculture		X					X

We reviewed literature pertaining to ten ecosystem services associated with seven nature-based solutions. Gaps in this matrix identify combinations where there was not sufficient literature to review the impact of a specific solution on a given service and/or the nature-based solution has been determined to be minimally effective with respect to a particular ecosystem service. [a]Such as bioswales, rain gardens, retention ponds. [b]Such as oyster reefs, mangroves, dunes, marshes.

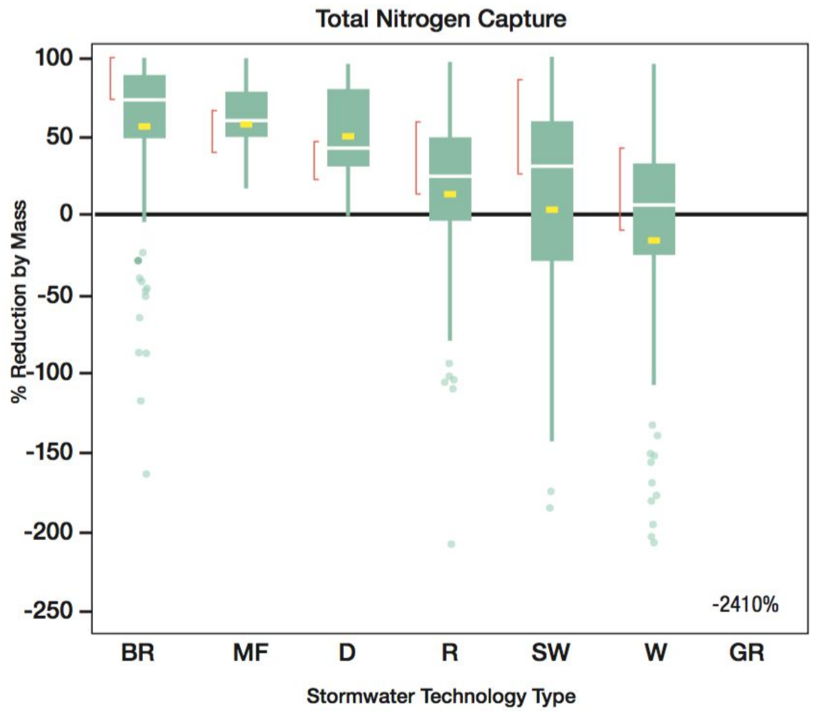
Keeler et al., 2019. Social-ecological and technological factors moderate the value of urban nature. Nature Sustainability

Research & Monitoring

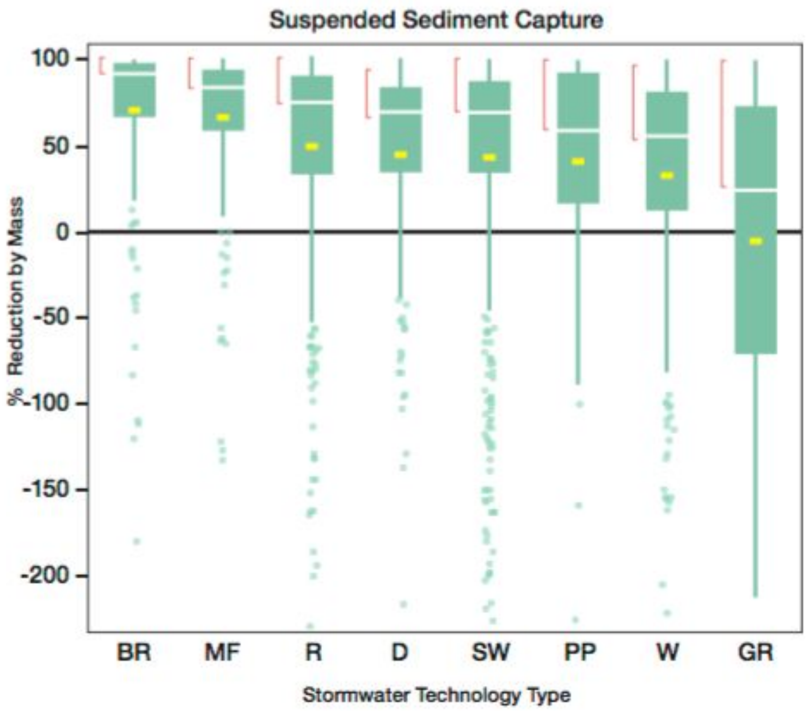
HOW DOES FUNCTION VARY BY GSI FORM?



PP - Porous Pavement: 72.0%
BR - Bioretention: 64.8%
GR - Green Roof: 52.3%
SW - Swale: 25.7%
D - Detention Pond: 15.5%
W - Wetland: -10.7%
MF - Media Filter: -11.6%
R - Retention Pond: -12.4%



BR - Bioretention: 57.3%
MF - Media Filter: 56.8%
D - Detention Pond: 49.4%
R - Retention Pond: 12.4%
SW - Swale: 3.71%
W - Wetland: 15.7%
GR - Green Roof: -2410%



BR - Bioretention: 70.8%
MF - Media Filter: 66.1%
R - Retention Pond: 49.7%
D - Detention Pond: 44.4%
SW - Swale: 43.0%
PP - Porous Pavement: 40.8%
W - Wetland: 33.0%
GR - Green Roof: -5.74%

Driscoll et al. 2015 Science Policy Exchange report – Data Sources http://www.bmpdatabase.org, EPA, EWRF & peer-reviewed lit

Floating flowers: Screening cut-flower species for production and phytoremediation on floating treatment wetlands (FTW) in South Florida

- Artificial ecosystems designed to mimic the nutrient removal of natural wetlands through the hydroponic cultivation of plants on floating rafts.

- Hydroponic cultivation growth of commercially-valuable could promote biomass harvesting and replanting efforts (and subsequent potential for nutrient removal).

- The study aimed to assess the growth success and nutrient remediation capacities of five cut-flower species on FTWs in controlled mesocosm systems

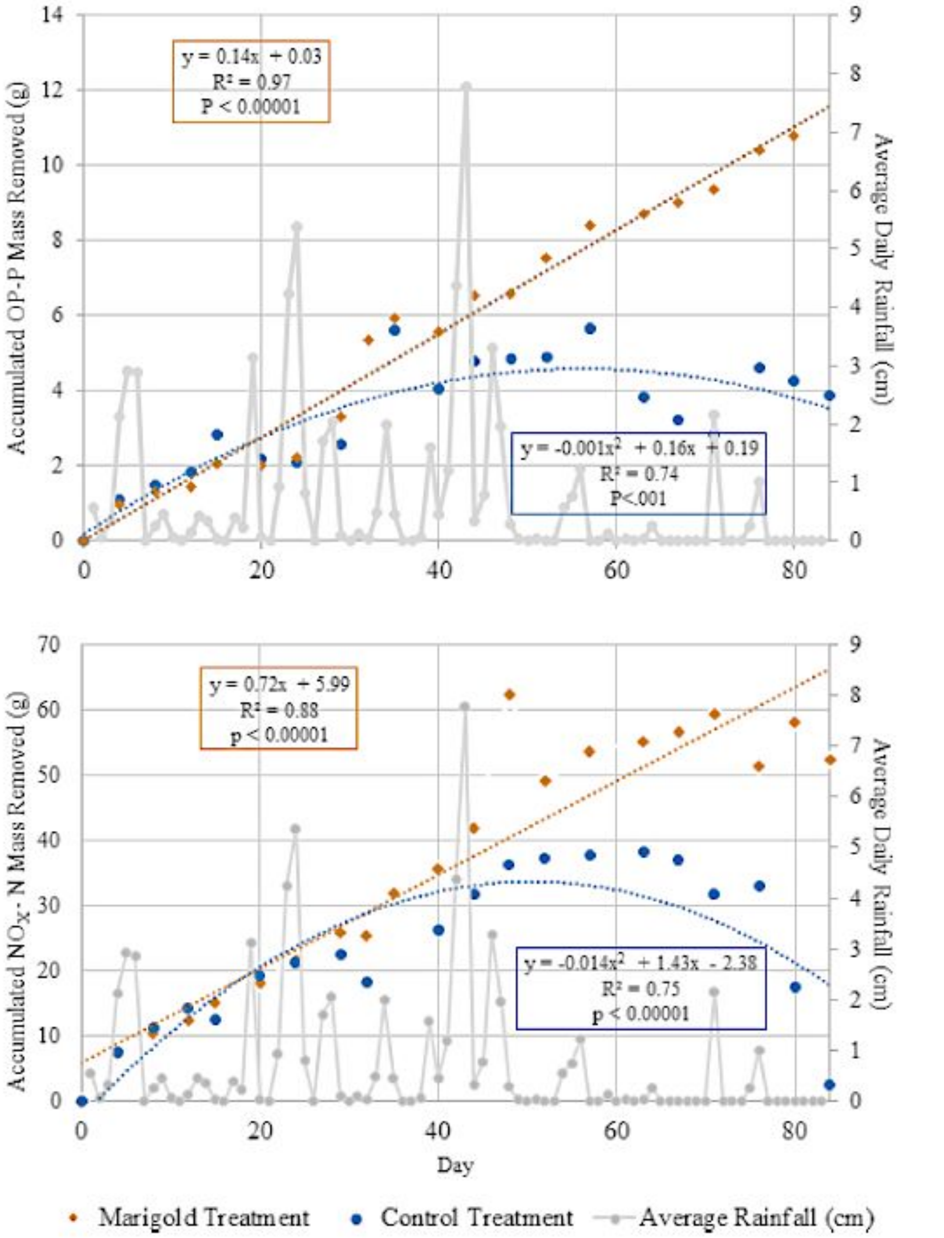
Locke-Rodriguez, J, T. Troxler, M. Sukop, L. Scinto, K Jayachandran. 2023. Environmental Advances.

Dr. Locke deploying FTW (above) and pics of the experiment and cut blooms (below)

Floating Treatment Wetland nutrient removal and economic potential

- Compared with Zinnias and sunflowers, Marigolds grew well in floating wetland mats
- Total phosphorus (TP) and total nitrogen (TN) removal rates were 0.062 g m^2 day^{-1} and 0.321 g m^2 day^{-1} , respectively
- Marigolds removed 52% more TP and 33% more TN compared to controls.
- Costs can be recovered after 1.5 harvests (selling price~$64 m-2 vs. supplies cost~$97 m-2)

Locke-Rodriguez et al. 2023.



Accumulated Mass Removed plotted for marigold and control treatments over time and nutrient removal rates

Modeling dynamic performance of urban infiltration trench systems: Methodology and a case study in Philadelphia

- Popular in dense urban areas primarily due to their small footprints that cope with the limited available space and subsurface utility conditions.
- The event-based modelling can lead to the most conservative design.
- However, GSI systems behave dynamically over seasons and under variable rainfall conditions.
- The study incorporated GSI dynamic performance into a simple modeling approach, simulated and compared both event-based and continuous simulation models were developed using SWMM, and calibrated/validated output against observed data.

Stone trench with embedded tree pits (i.e., tree trench) underneath a sidewalk on North 7th Street in Philadelphia, PA

Ebrahimian, A., N. Sokolovskaya, B. Wadzuk. 2021. Journal of Hydrology 594.

Modeling dynamic performance of urban infiltration trench systems: Methodology and a case study in Philadelphia

- Three years of infiltration trench observational data showed a seasonality and a head-dependency.
- Monthly adjustment factors were developed for saturated hydraulic conductivity (Ksat) and a head-dependent component for infiltration in the model.
- The model with adjustment factors corresponded well with observed data for number and duration of overflow events.
- The methodology can be extended to other generalized sets of monthly adjustment factors for different conditions or different infiltration trench systems. Longer time series of observed data can improve the accuracy of the results.

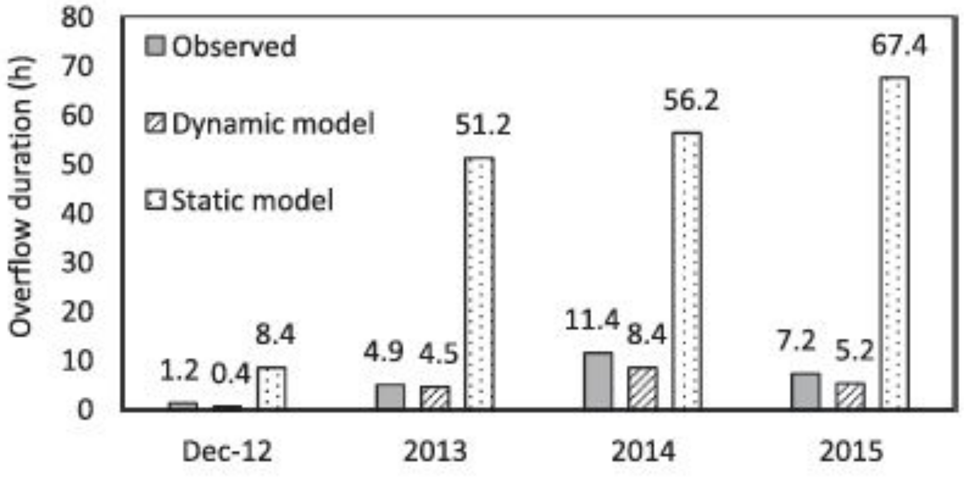


Fig. 8. Overflow duration at the infiltration trench.

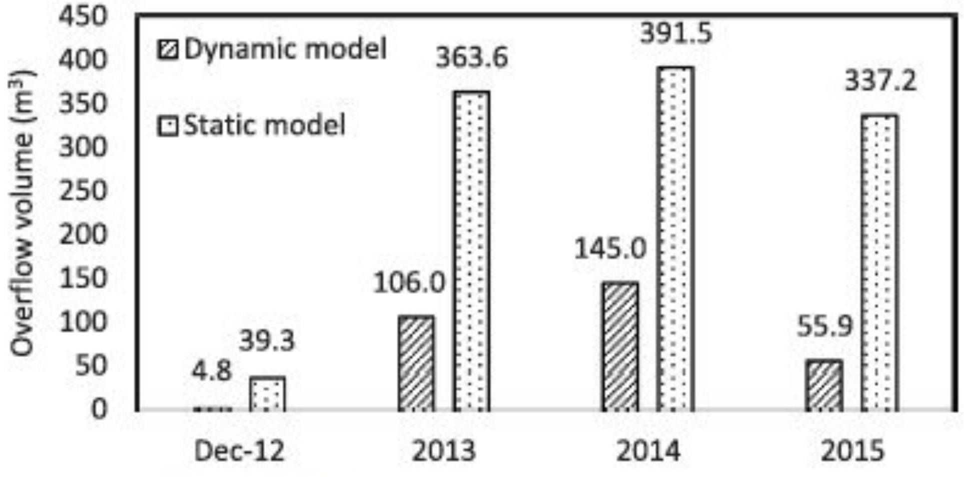


Fig. 9. Overflow volume at the infiltration trench.

Ebrahimian, A., N. Sokolovskaya, B. Wadzuk. 2021. Journal of Hydrology 594

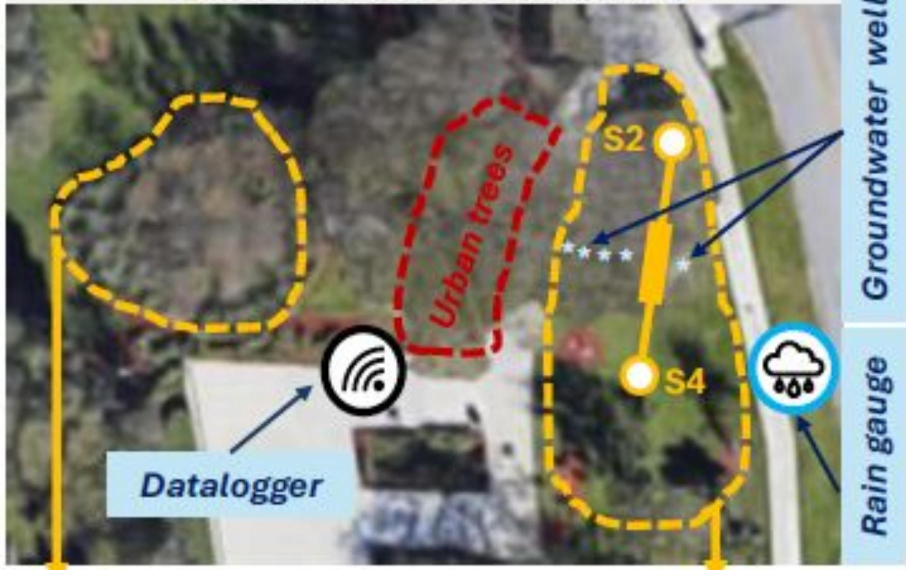
Green Stormwater Infrastructure at Arena Site

FIU Engineering & Computing | Institute of Environment

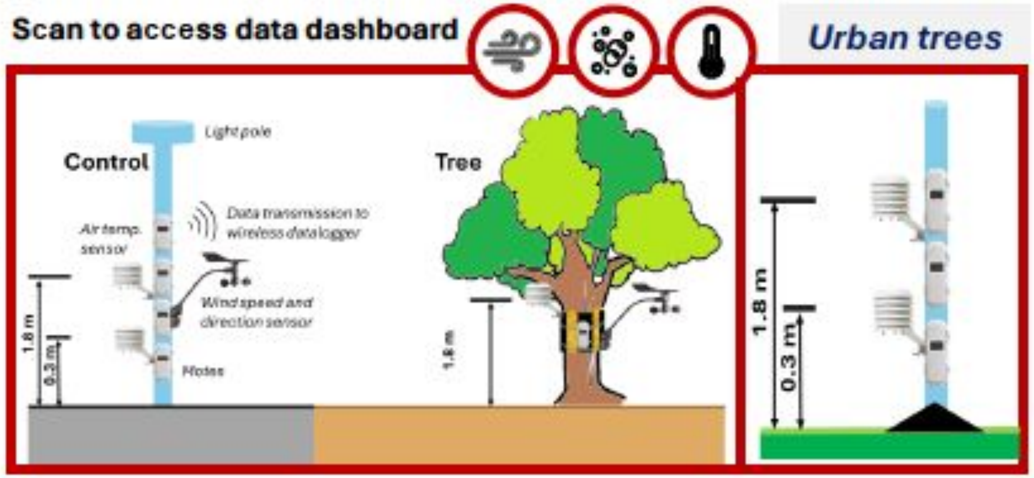
PI: Ali Ebrahimian, Ph.D. | alebrahi@fiu.edu
Co-PI: Leonard Scinto, Ph.D. | scintol@fiu.edu
Co-PI: Arturo Leon, Ph.D. | arleon@fiu.edu

Key Personnel: Lesmes A. M. Jerez, Ph.D.

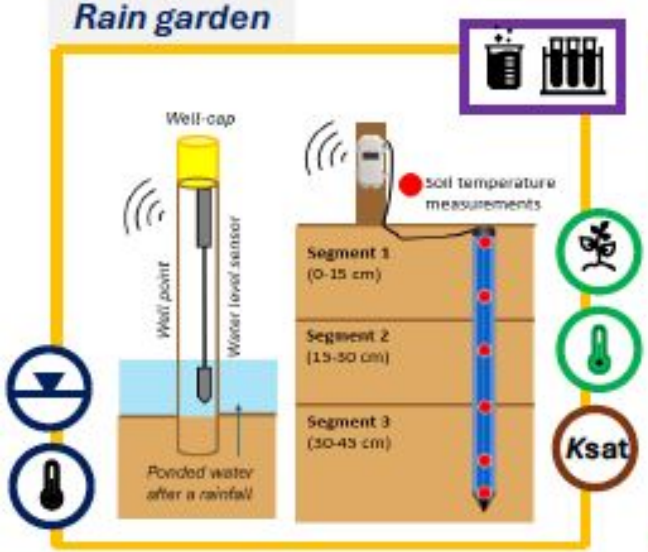
Plan view: Wireless monitoring



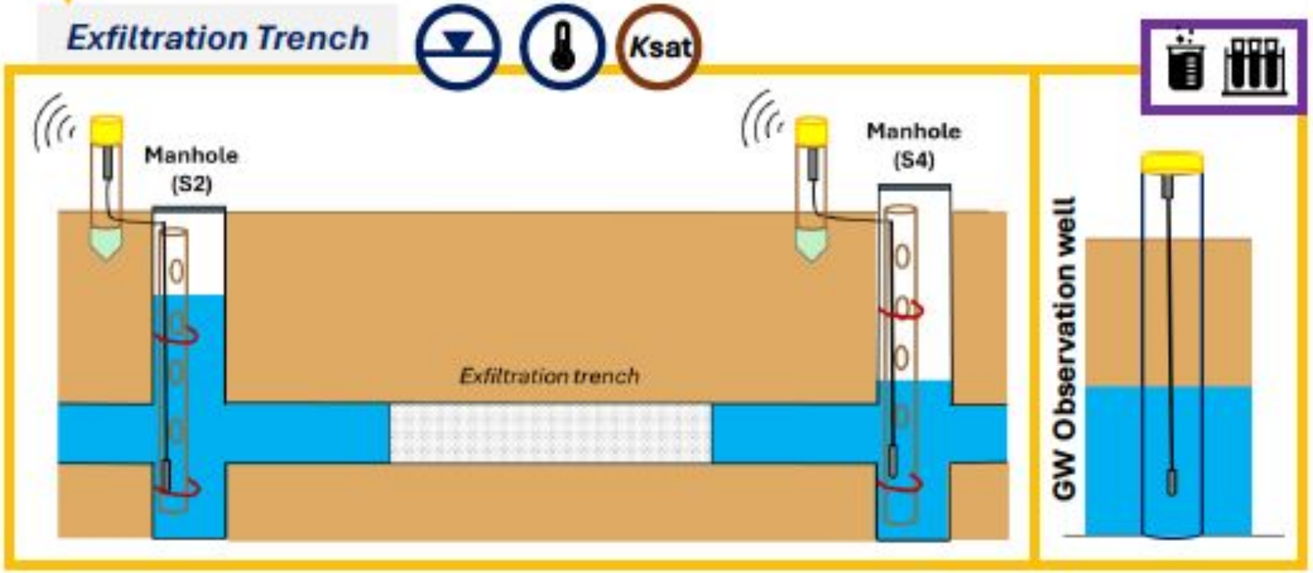
Scan to access data dashboard



Rain garden



Exfiltration Trench



What is this site about?

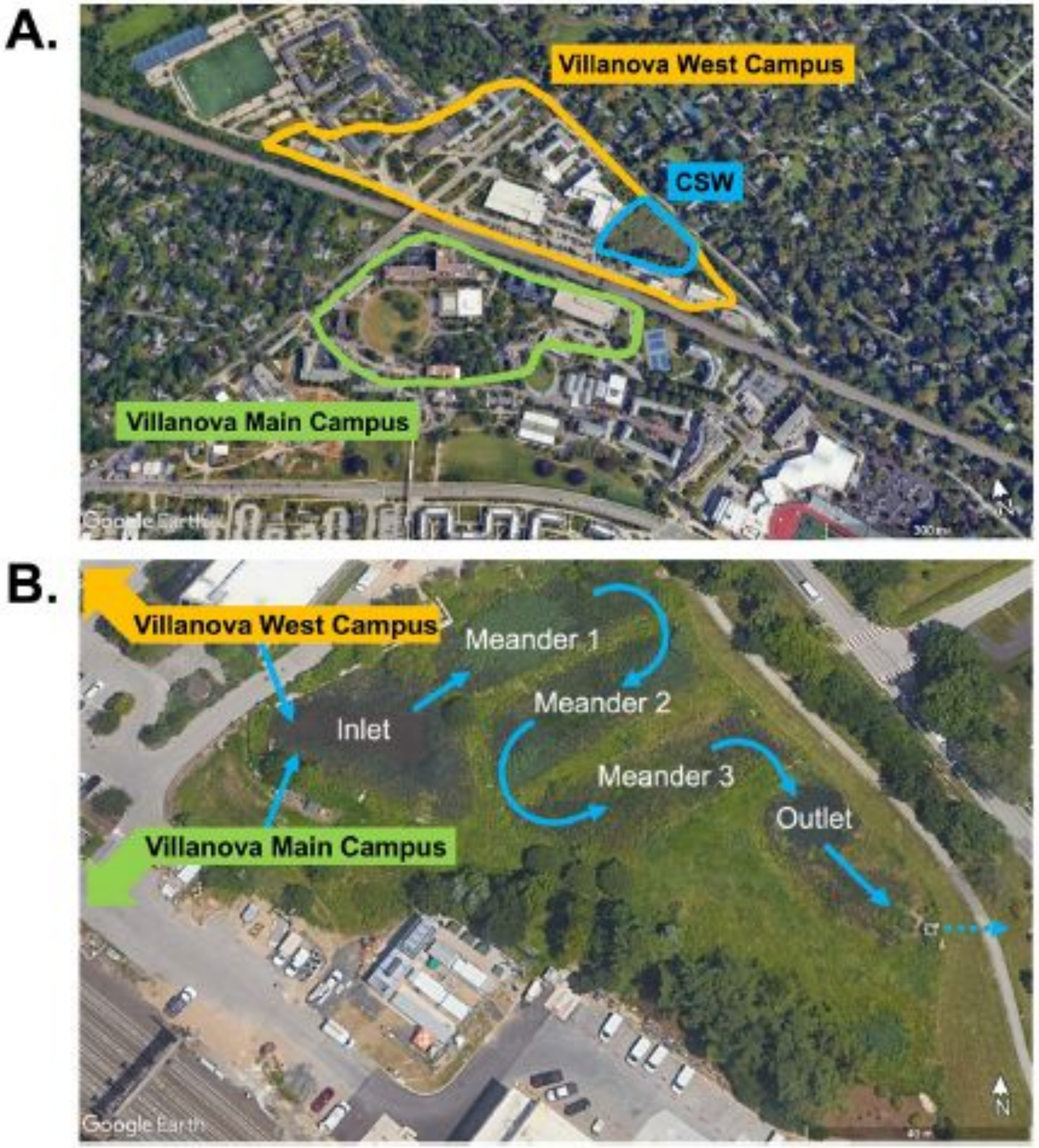
This site consists of various types of urban Green Stormwater Infrastructure (GSI), including a bioretention system (rain garden), exfiltration trench, and trees. These are nature-based solutions intended to mitigate urbanization impacts and provide environmental resilience by reducing stormwater runoff volume and flood risk, improving runoff water quality, and alleviating urban heat island effects among other ecosystem services.

Water sampling from groundwater observation wells by FIU students

Measurements of soil hydraulic characteristics in the rain garden

A Complete Water Balance of a Constructed Stormwater Wetland

- A novel and comprehensive water budget model was developed stormwater management capabilities of a constructed stormwater wetland (CSW) in Villanova, Pennsylvania.
- The CSW of interest was retrofitted from an existing retention basin with the hypothesis that under a wetland configuration, the system could manage a comparable amount of incoming flow and provide more ecosystem services.



A. The areas draining into the Constructed Stormwater Wetland (CSW) (outlined and labeled in blue) B. Flow path and direction indicated by blue arrows.

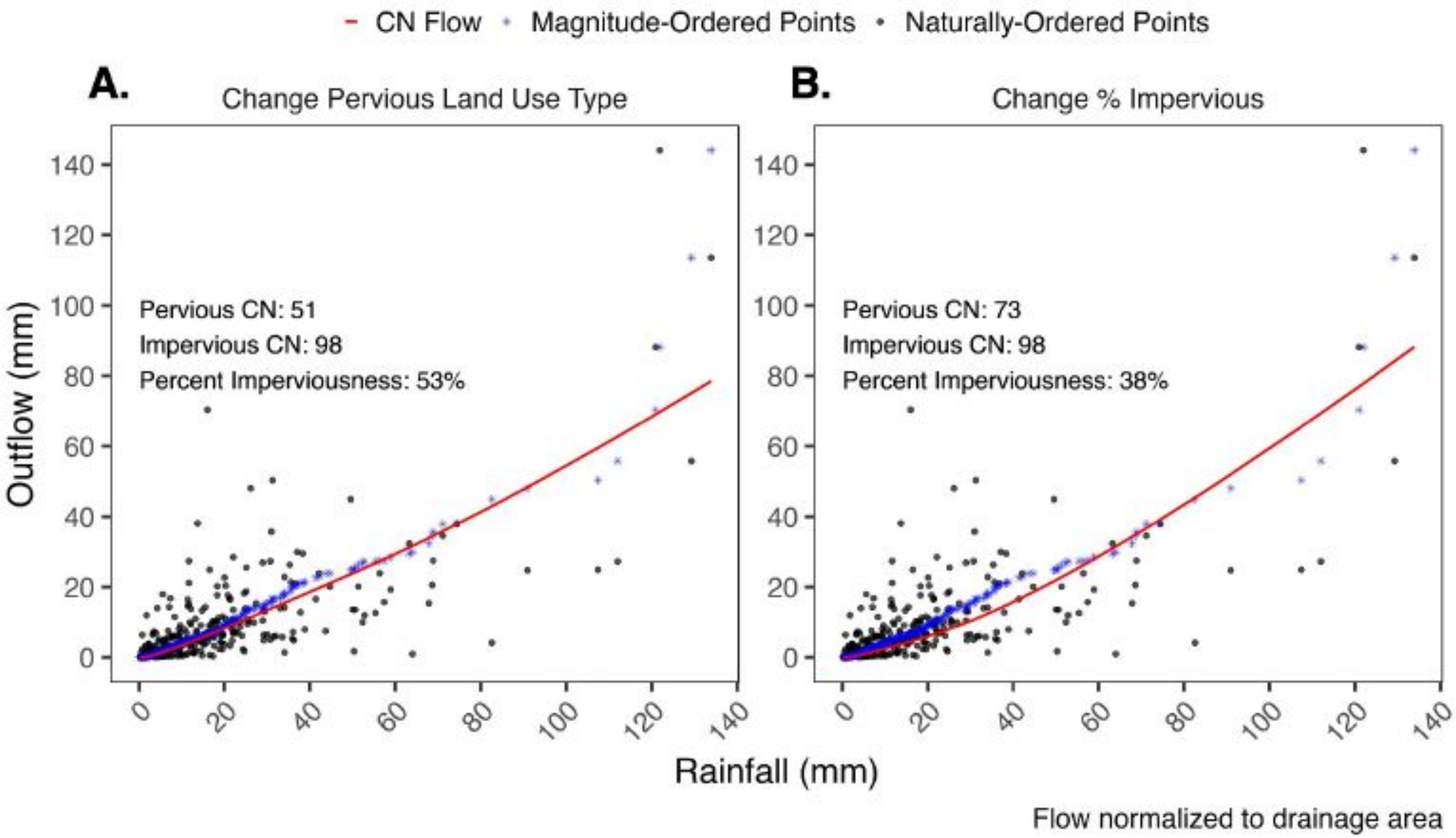
McGauley, M., G Zaremba, and B. Wadzuk. 2025. Water Resources Research.

A Complete Water Balance of a Constructed Stormwater Wetland

Effective urbanization (imperviousness) reversal by the constructed stormwater wetland in terms of:

a) A change in the land cover of the pervious area, but the same percentage of impervious surfaces and
b) A change in the amount of imperviousness, but the same land cover in the pervious area.

In other words, the hydrological signature of the large receiving area mimics that of an area with lower impervious surface with the constructed wetland in place (CN flow is similar).



NRCS curve number (CN) flow described in Woodward et al. (2003)

McGauley, M., G Zaremba, and B. Wadzuk. 2025. Water Resources Research.

Constructed wetland GSI monitoring

Scan to access real-time data dashboard

FIU Wetlands Preserve

Proposed groundwater observation well

Water level and temperature

Rainfall depth

Air temperature and relative humidity

Wireless datalogger

FIU Engineering & Computing FIU Institute of Environment

A. Ebrahimian, FIU Department of Civil and Environmental Engineering

Building a Community-Driven Coastal Watershed Resilience Plan to Maximize Flood + Wildlife Benefits in Miami-Dade County

A Projected funded by the National Fish and Wildlife Foundation with the following collaborators

https://www.miamibeachfl.gov/wp-content/uploads/2017/08/Blueways-Master-Plan.pdf

FIU

U MIAMI

South Florida Water Management District

MIAMI-DADE COUNTY

Miami Waterkeeper miamiwaterkeeper.org

DK&P

Everglades Law Center, Inc.

Envisioning and implementing transformative, stakeholder-driven projects leveraging interdisciplinary, multi-institutional collaborations

‘Urban design is a collaborative venture involving landscape architects, planners, architects, civil engineers, scientist, artists, developers, politicians, and residents.’
(Modified from University of Maryland’s Landscape Architecture Program)

Urban design studios required for landscape architecture degrees can offer opportunities for envisioning new, alternative approaches to stormwater management planning that are more transformative (e.g., innovative, restructuring, multi-scale, system-wide, anticipatory, multi-functional).

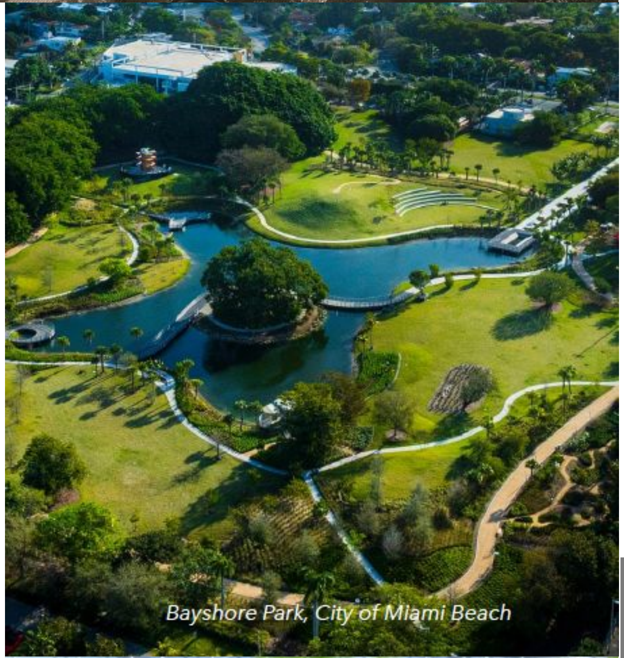
Fedele et al. 2019. Environmental Science and Policy;
Swart et al. 2023. Social Sciences.

Sea Level Solutions Interdisciplinary Research and Design Studio in North Beach, Miami Beach: graduate course cross-listed across College of Communications, Architecture & the Arts; College of Arts, Sciences & Education, College of Engineering & Computer Sciences, School of International & Public Affairs

Discussion Questions

What barriers are you facing in designing, implementing, maintaining or scaling green stormwater infrastructure?

If so, how are you overcoming them?


Bayshore Park, City of Miami Beach