Preparing for the Future:

Green Infrastructure Design Modifications and Smart Technologies for Building Resilience

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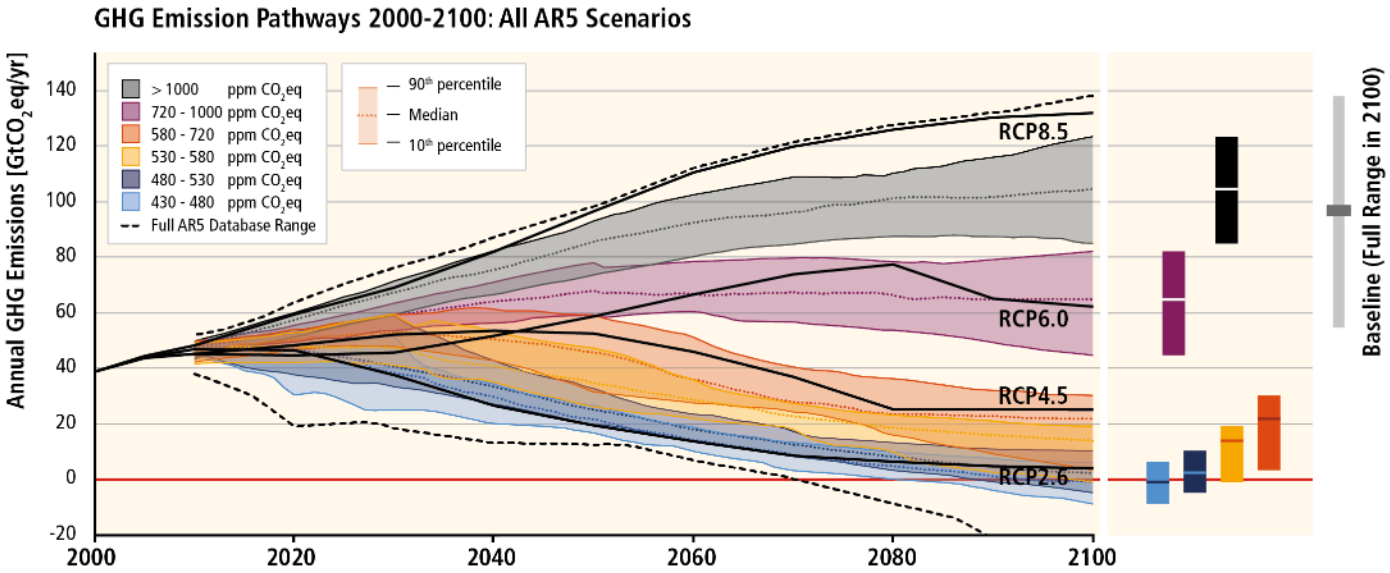
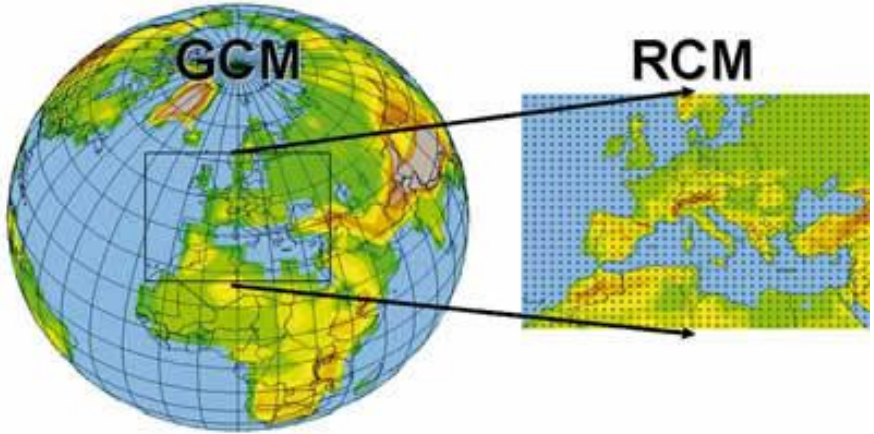
Representative Concentration Pathways (RCP)



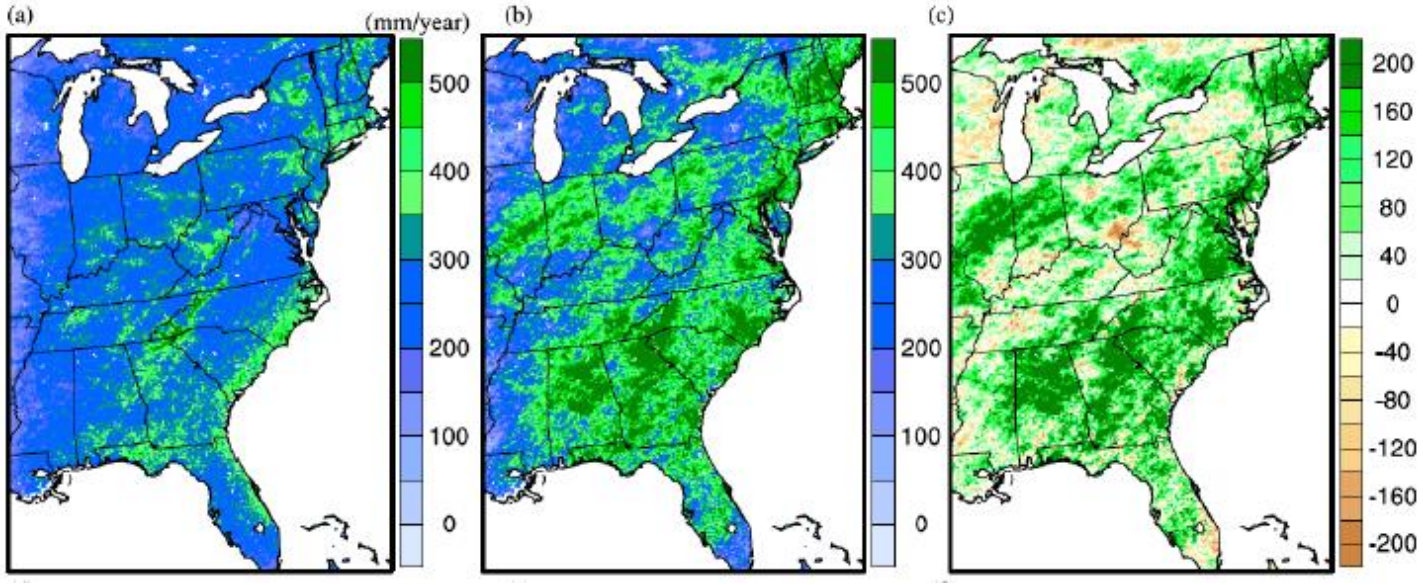
Future climate models

- General circulation models (GCMs)
- Regional climate models (RCMs)



World Meteorological Organization, Geneva, Switzerland. “Adapting to climate variability and change”

Extreme Precipitation



Gao et al. 2012

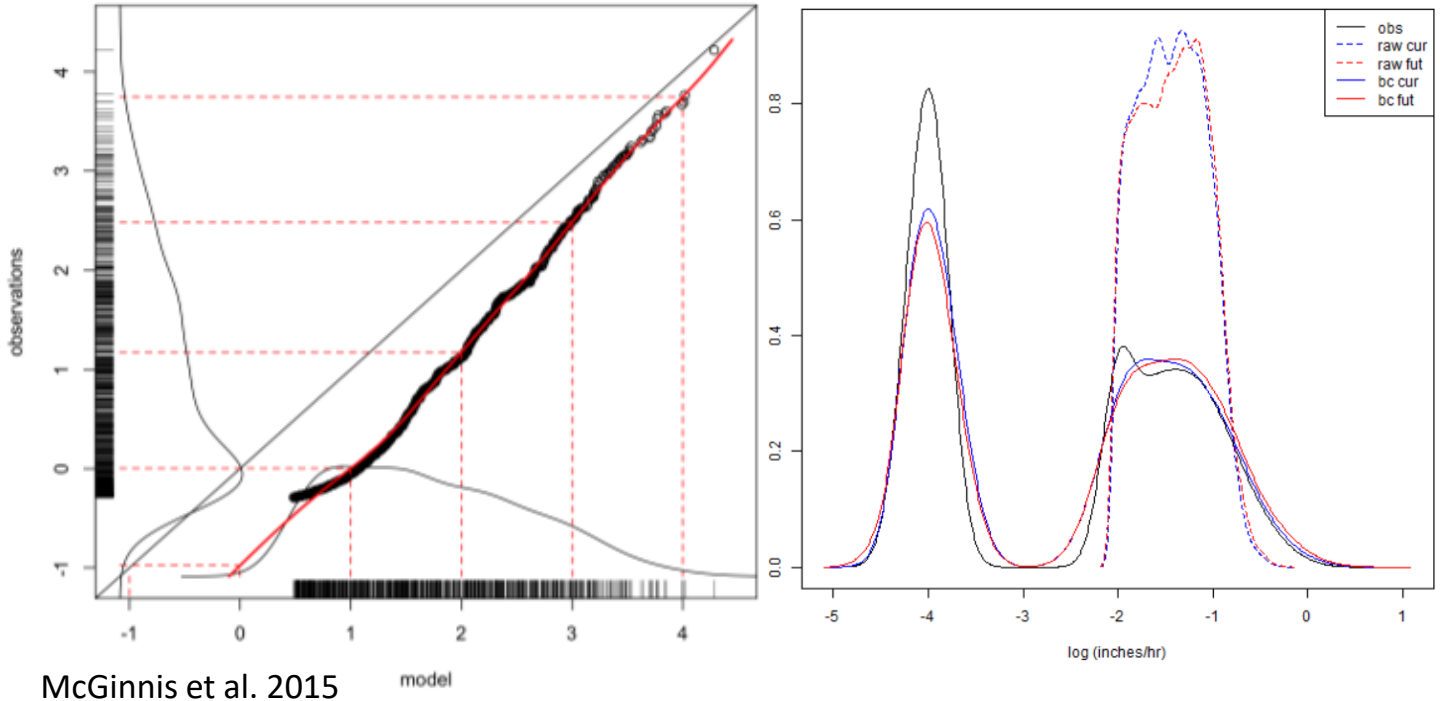
Sources of climate data

- North American Coordinated Regional Downscaling Experiment (NA-CORDEX)
  - Future (2035-2039)
  - Historic (1999-2013)
  - 10 model combinations
- NOAA's National Centers for Environmental Information (NCEI)
  - Observed (1999-2013)

Climate Models

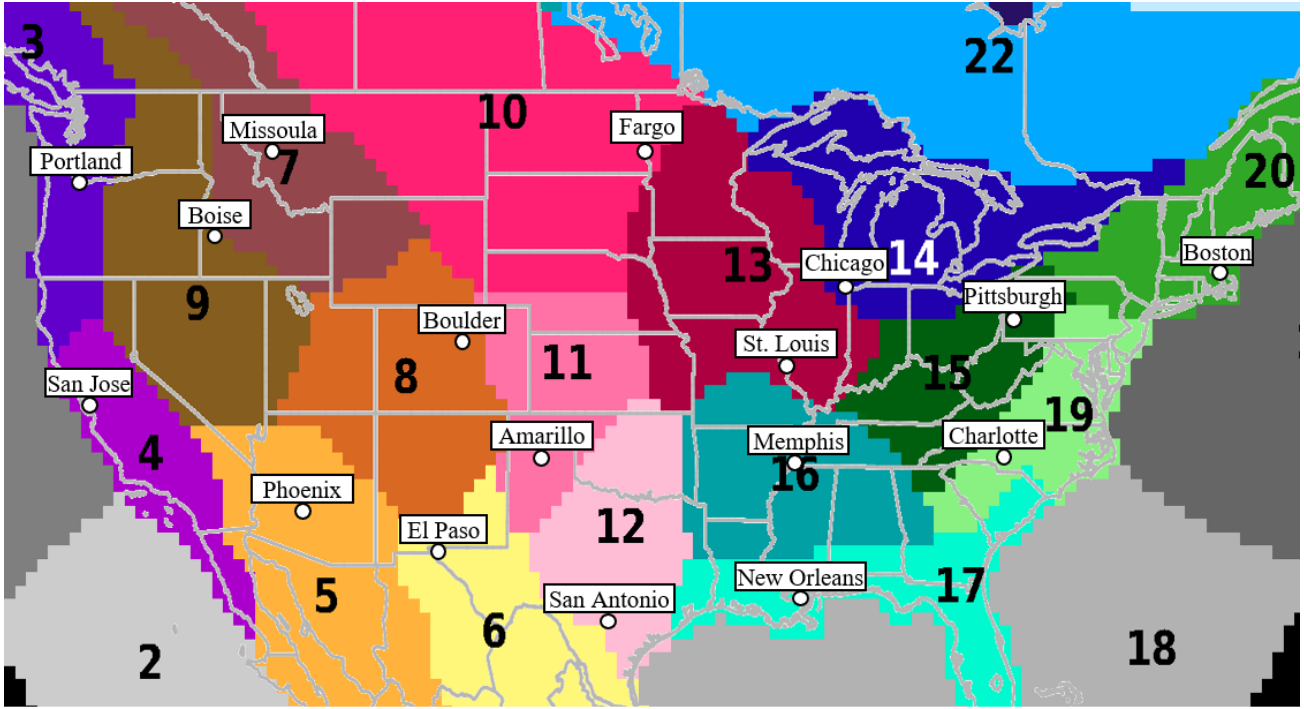
Model No.	GCM	RCM	RCP
1	CanESM2	CanRCM4	4.5
2	CanESM2	CanRCM4	8.5
3	GFDL-ESM2M	WRF	8.5
4	GFDL-ESM2M	WRF	8.5
5	HadGEM2-ES	WRF	8.5
6	HadGEM2-ES	WRF	8.5
7	MPI-ESM-LR	RegCM4	8.5
8	MPI-ESM-LR	RegCM4	8.5
9	MPI-ESM-LR	WRF	8.5
10	MPI-ESM-LR	WRF	8.5

Correcting Model Bias (Kernel Density Distribution Mapping (KDDM)



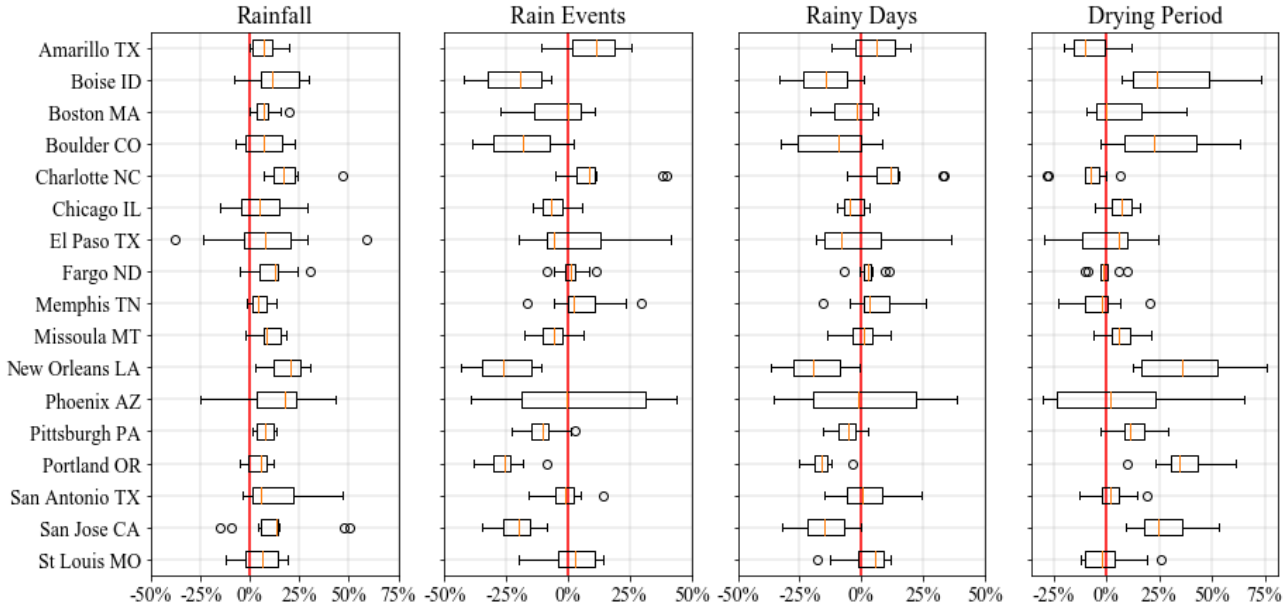
McGinnis et al. 2015

Locations



Climate regions provided by Bukovsky (2011)

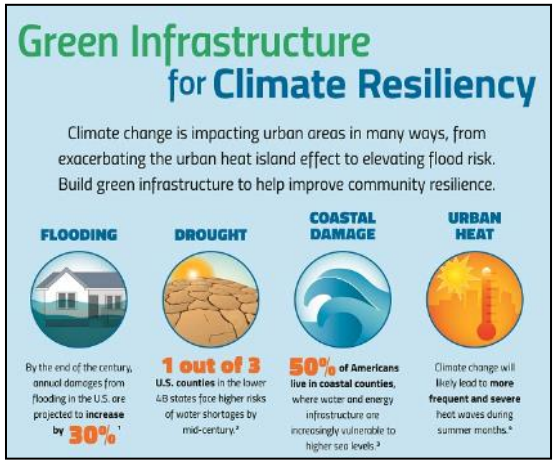
Annual rainfall statistics



Percent change between observed (1999-2013) and future (2035-2049) mean annual rainfall, mean annual rain events, mean annual rainy days, and mean drying period for the 17 locations.

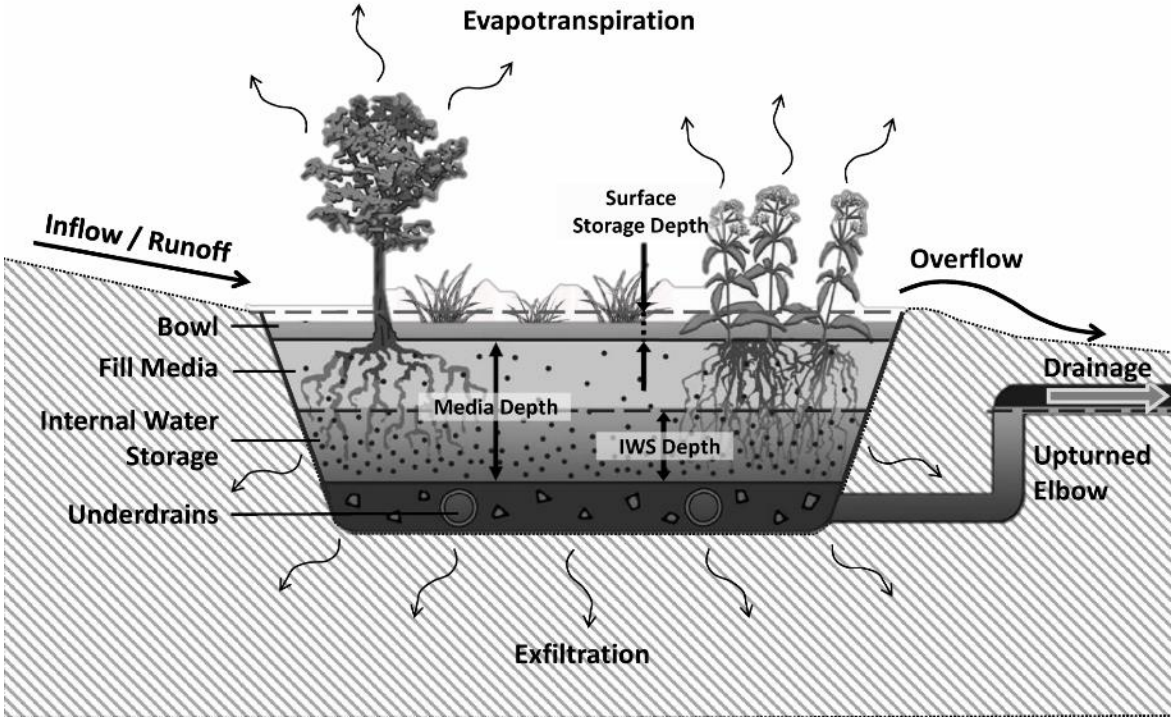
Resiliency

- To what degree can green infrastructure buffer these impacts (attenuate signal)?

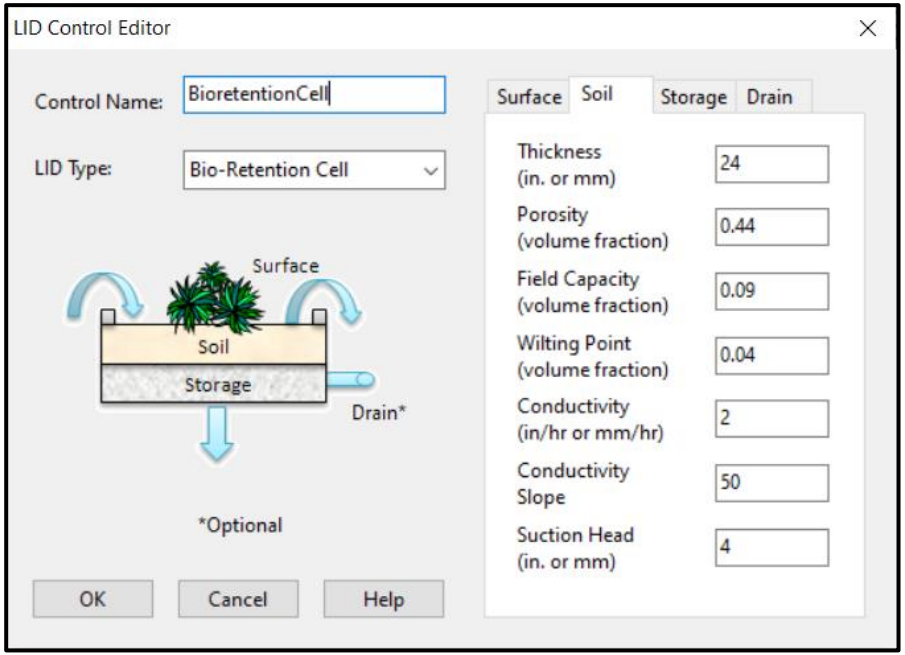


Source:
U.S. EPA

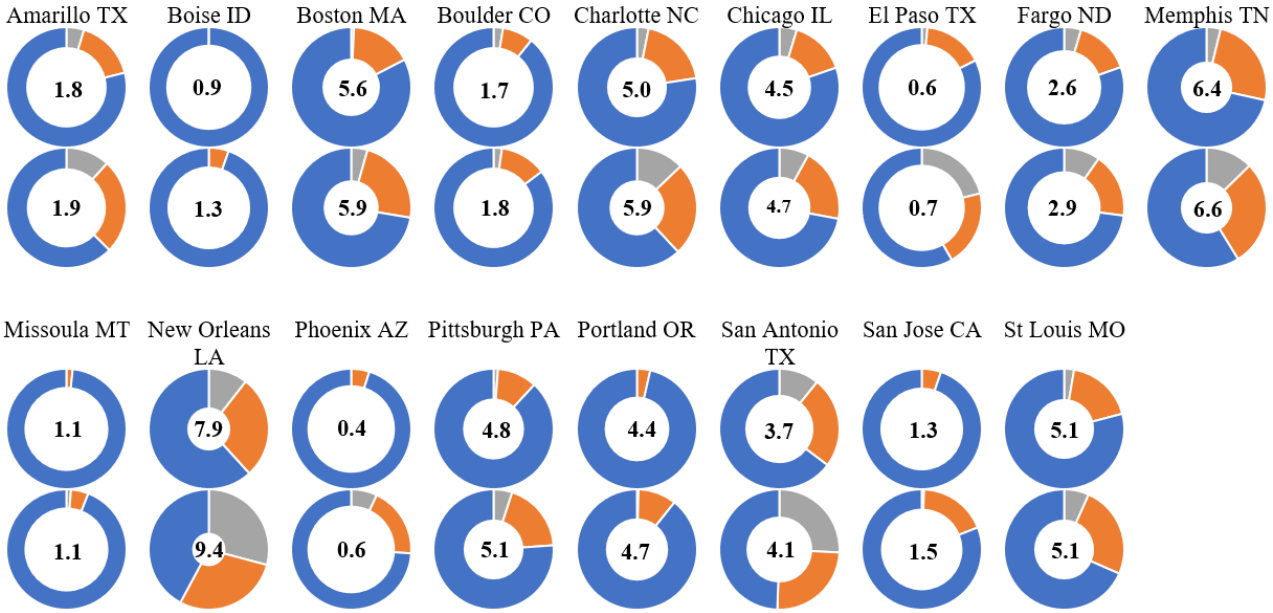
Bioretention Schematic



Model Scenarios



Annual volume

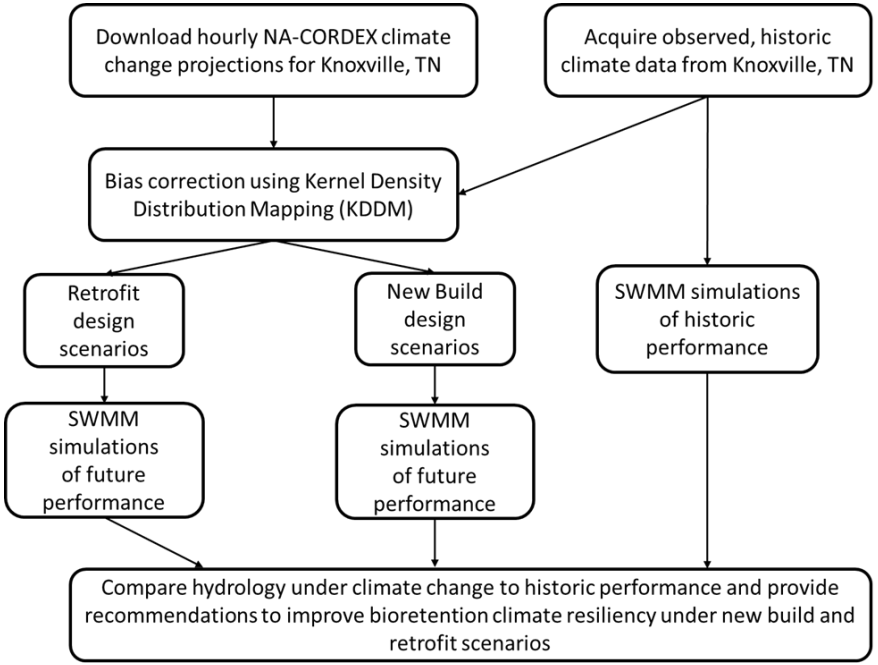


Annual Volume (1000 cu yd/yr) – shown in center of each donut chart
Observed (top) and future (bottom) overflow (grey), underdrain outflow (orange), and infiltration loss (blue) for all 17 locations.

Objective & Approach

- **Objective:**
  - Investigate the impact of future (2040-2044) climate change on bioretention systems compared to performance under historic climate (2010-2014)
  - Determine how design modifications, site conditions influence their climate resiliency
- **Probabilistic Approach:**
  - Used a simple SWMM model to simulate a 1-acre impervious area draining to a bioretention cell
  - Ten climate projections used as model inputs and compared to results using historic rainfall data

Workflow


Download hourly NA-CORDEX climate change projections for Knoxville, TN
Acquire observed, historic climate data from Knoxville, TN
Bias correction using Kernel Density Distribution Mapping (KDDM)
Retrofit design scenarios
New Build design scenarios
SWMM simulations of historic performance
SWMM simulations of future performance
SWMM simulations of future performance
Compare hydrology under climate change to historic performance and provide recommendations to improve bioretention climate resiliency under new build and retrofit scenarios

New Build Scenario Design Configurations:

Ponding: All BASE parameters held constant except Berm Height

Configuration	Berm Height (cm)
P1	15
P2	30
P3	61

Media Depth: All BASE parameters held constant except Thickness (soil layer)

Configuration	Thickness (cm)
DEP1	61
DEP2	91
DEP3	122

Media Conductivity: All BASE parameters held constant except Conductivity

Configuration	Conductivity (mm/hr)
CON1	51
CON2	76
CON3	102

Surface Area: All BASE parameters held constant except Area

Configuration	Area (percent of drainage area)
A1	5%
A2	10%
A3	15%

Composite Configurations: All BASE parameters held constant except the following:

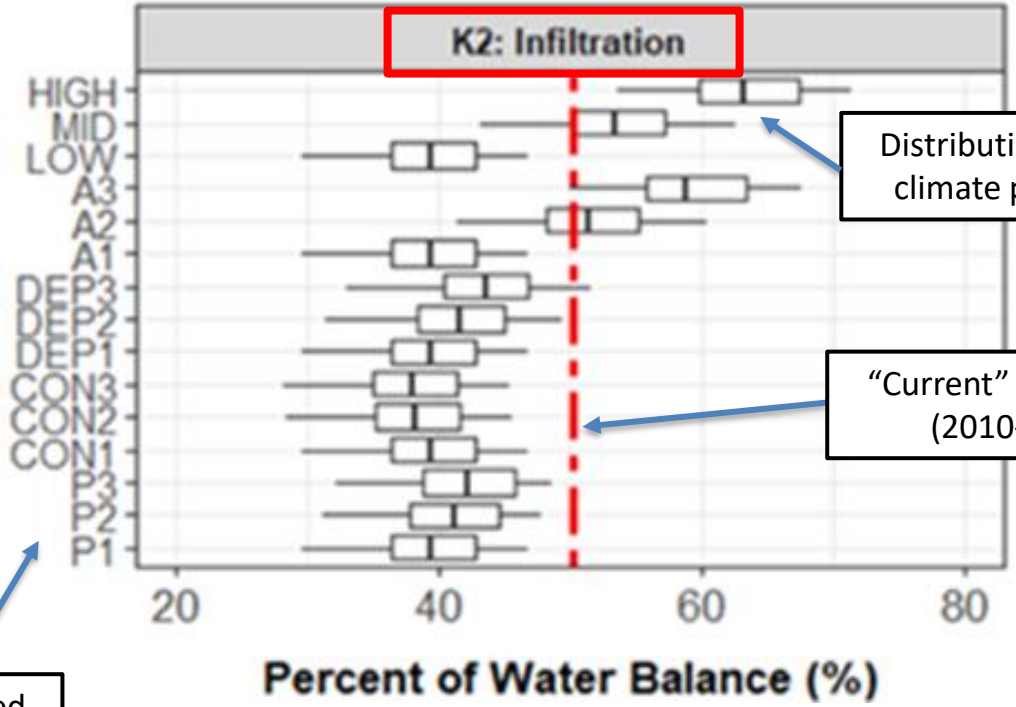
Configuration	Berm Height (cm)	Thickness (cm)	Conductivity (mm/hr)	Area (% Catchment)
LOW	15	61	51	5%
MID	30	91	76	10%
HIGH	46	122	102	15%

Retrofit Scenario Design Configurations:

Retrofit Configurations: All BASE parameters held constant except the following:

Configuration	Berm Height (cm)	Thickness (cm)
R1	15	91
R2	30	76
R3	46	61
R4	61	46

Results: New Build Scenario



Distribution from ten climate projections

"Current" Infiltration (2010-2014)

Modified designs

Retrofit Scenarios

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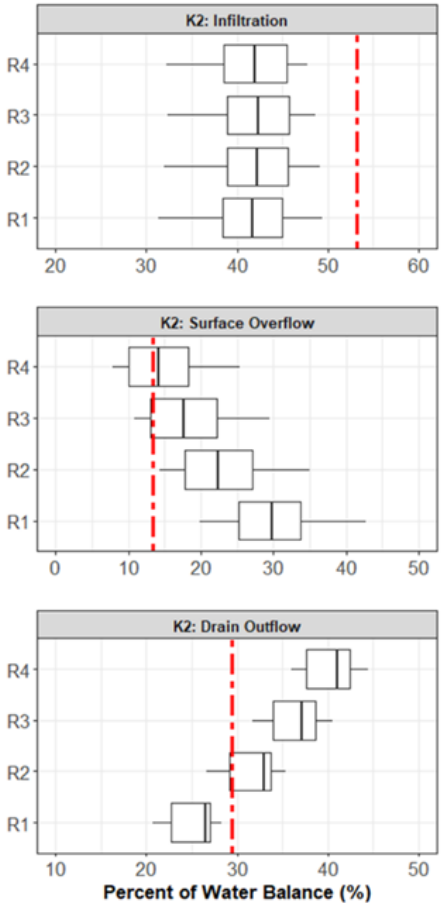

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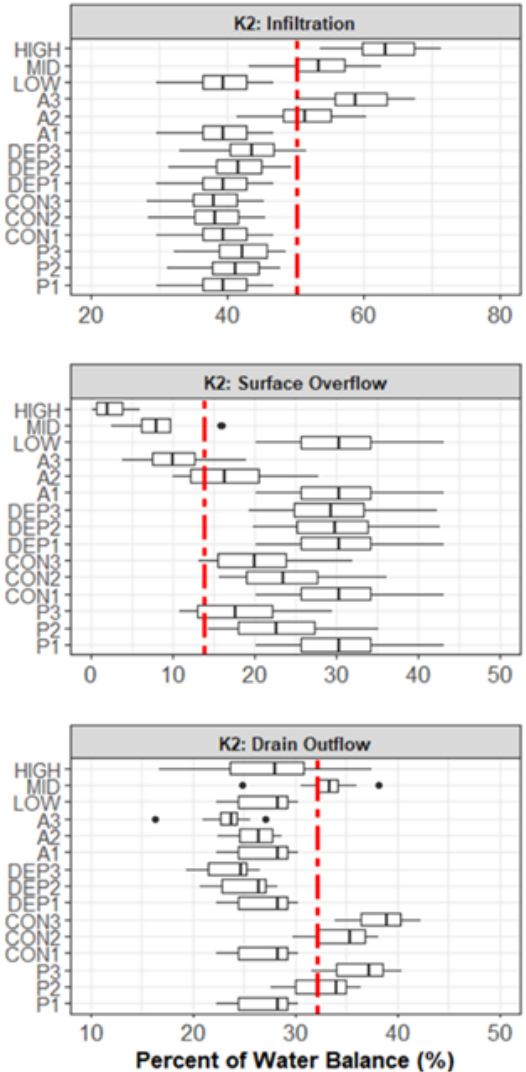

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Modifying GI Designs?

1. Largest deviations from current design resulted in greatest performance returns
   - Concurrent increases to ponding depth, media thickness, conductivity, and surface areas
   - Larger initial investment in new builds
   - “Conservative” modifications were not sufficient
2. Proposed retrofits reduced surface overflows, but introduce treatment, safety risks
3. Local site conditions (soils) influenced outcomes & adaptations

Number of “Dry Days”

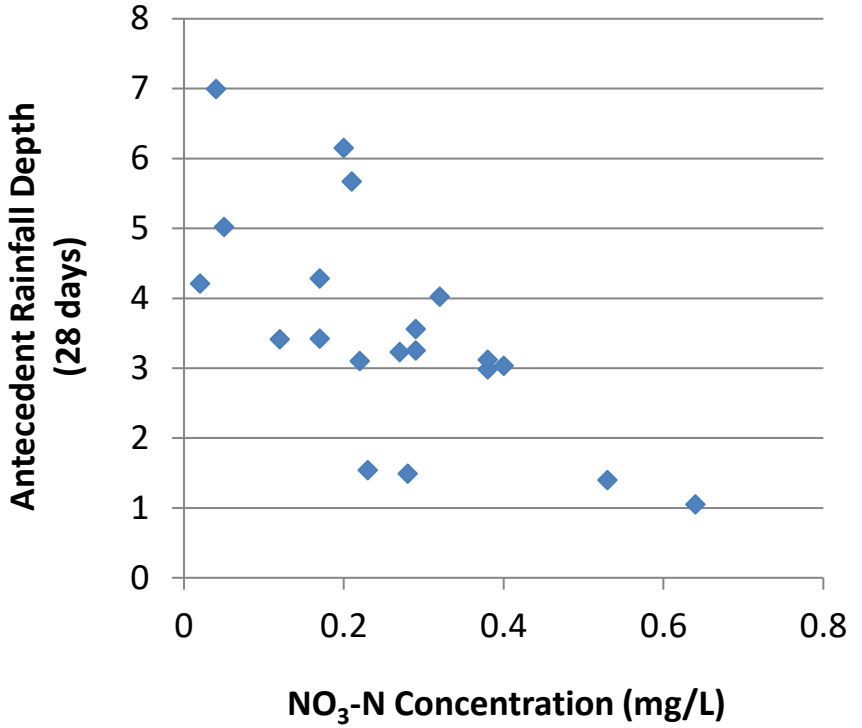
- Defined as: Soil moisture not sufficient to meet potential evapotranspiration
- Effect of extended drought on biotic components of system?

Microbial dynamics in drought

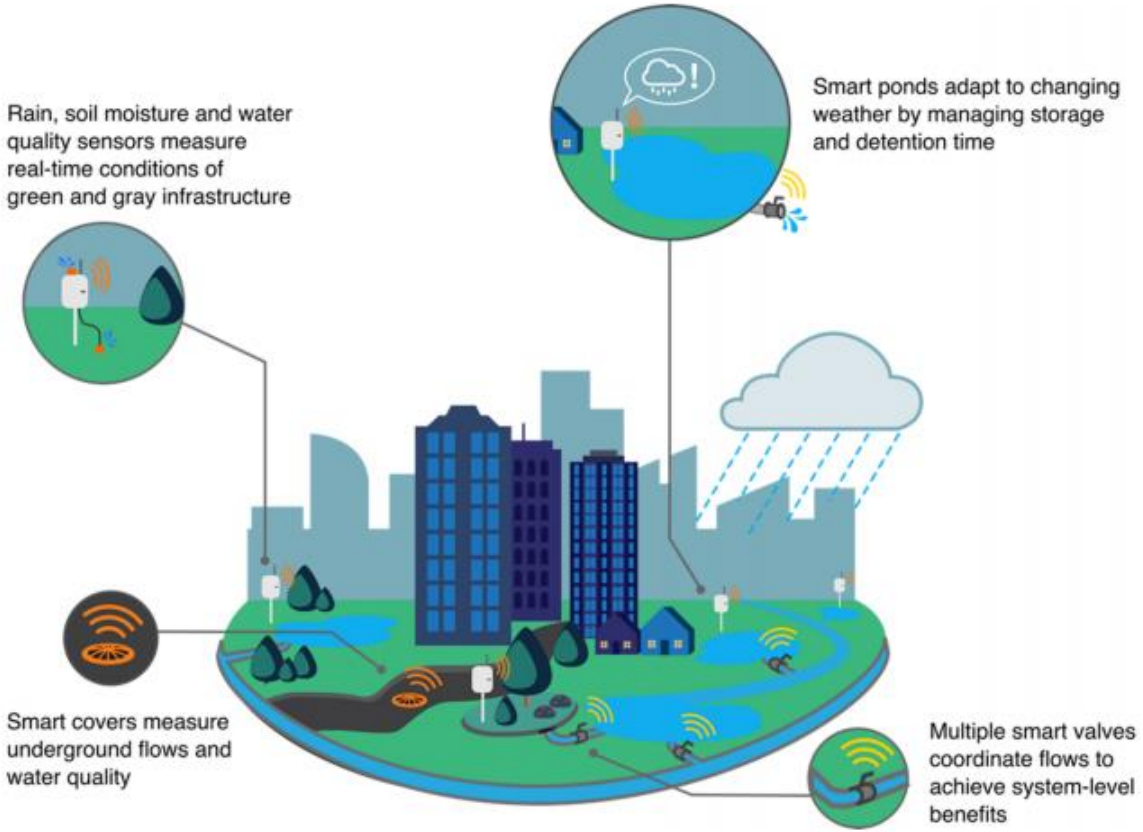
- Impacts to community
- Cells can burst, releasing nitrogen
- Effects of drying-wetting noted for extended period
  - Fierer and Schimel (2002)
- Increase loss of nitrate / total nitrogen with increased antecedent dry periods
  - Hatt et al. (2007)

Field Studies

- 12 field studies of bioretention in North Carolina
- Nitrate vs antecedent rainfall
  - Significant negative correlation 7 of 12 sites
  - -0.73 to -0.35



Smart Stormwater Infrastructure



Credit: Kerkez et al. 2016

Column Design

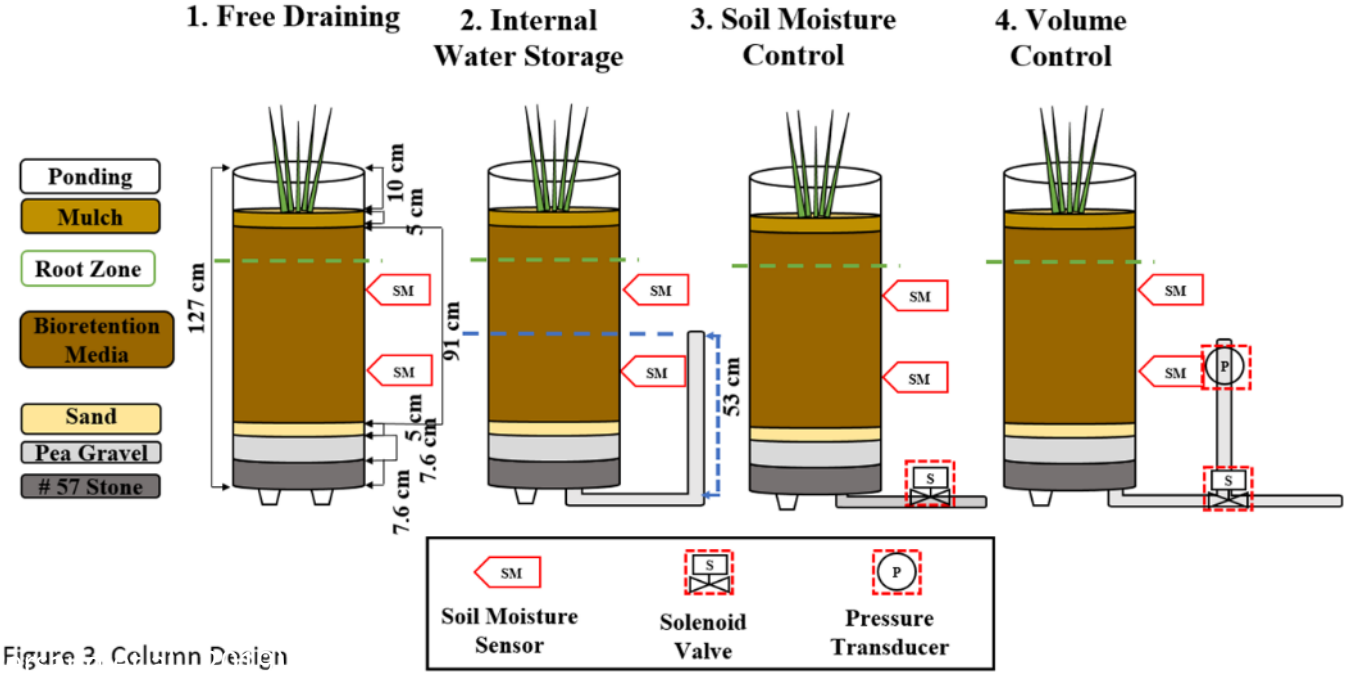
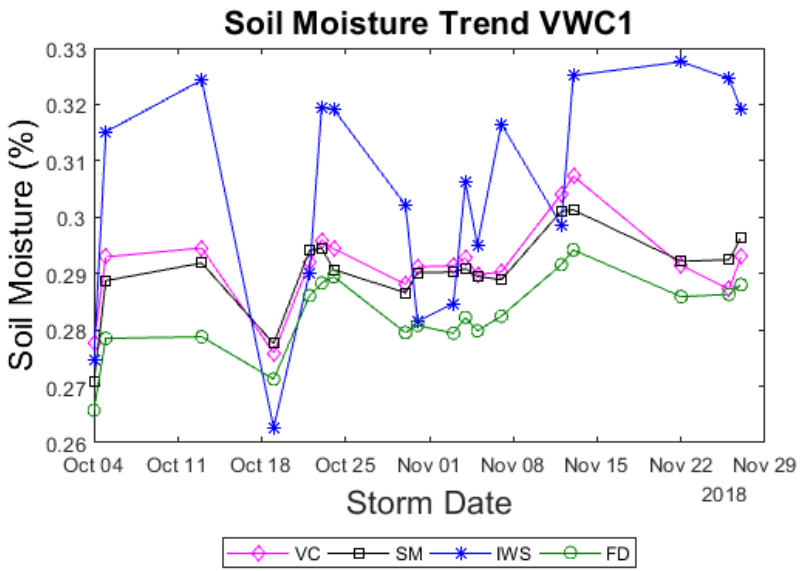
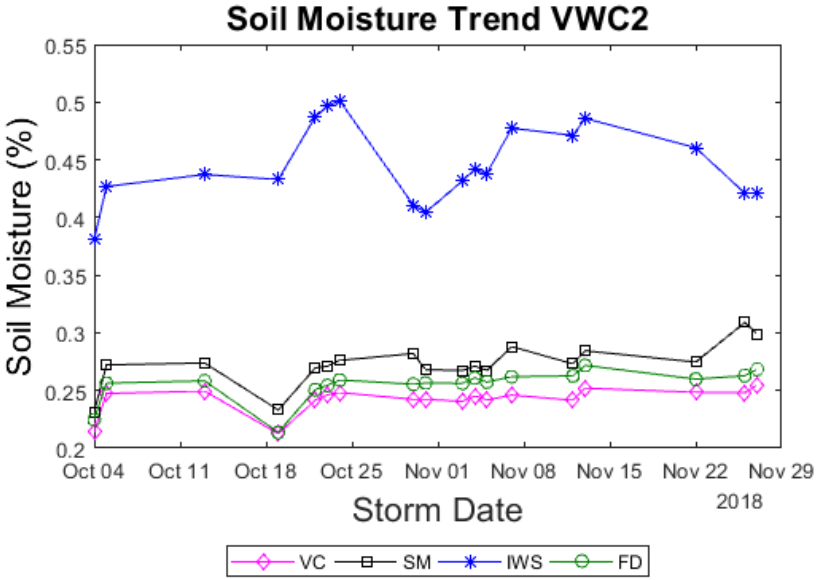


Figure 3. Column Design

Column Design

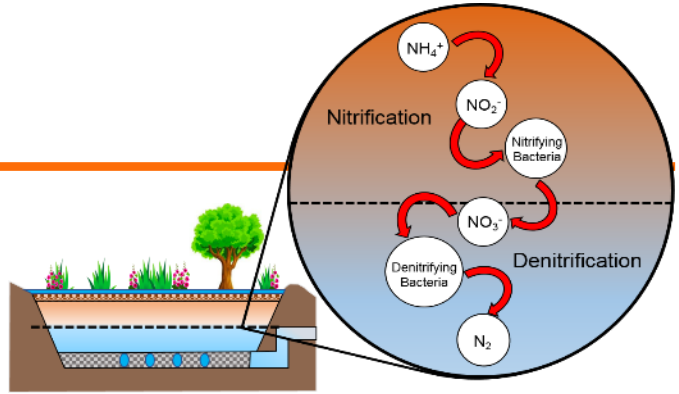
Soil Moisture Dynamics

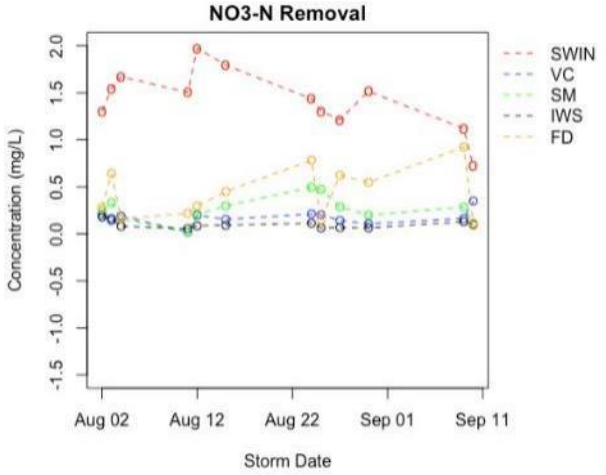




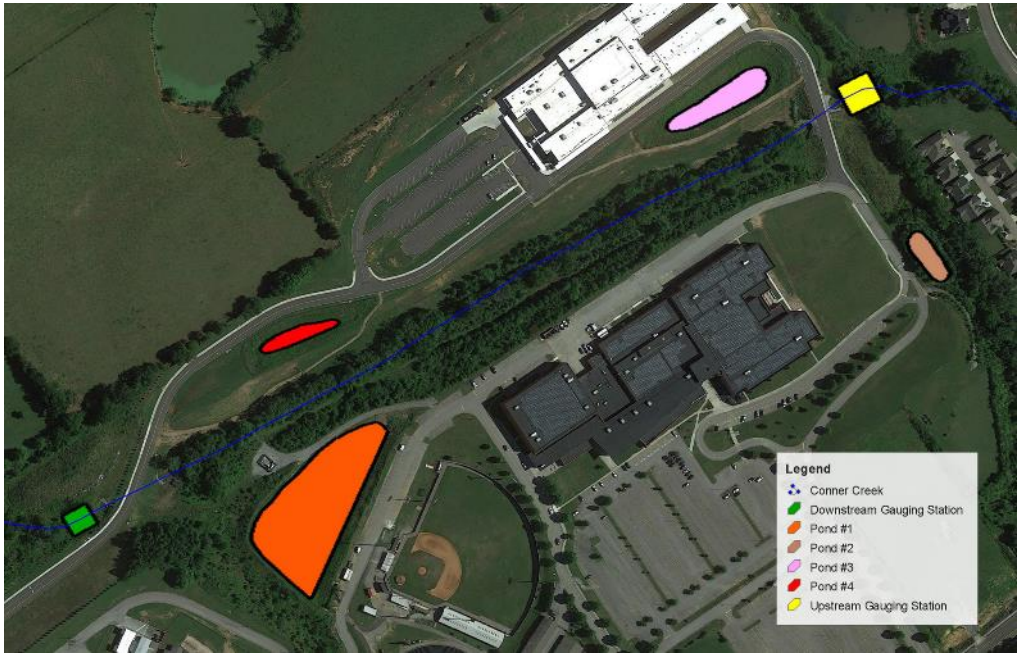
Water Quality Summary

- Free Draining performed best for NH_4^+-N removal while the more anaerobic environment in Internal Water Storage led to the best NO_x removal.
- Soil Moisture Controlled and Volume Controlled treatments were able to balance these environments
- ***Actively controlled treatments have the potential to strike a balance between Free Draining and Internal Water Storage systems***

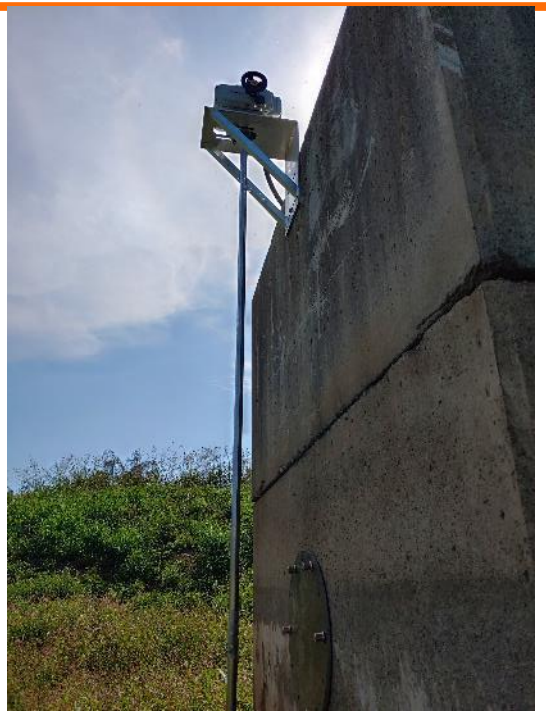




Study Site


Legend
Conner Creek
Downstream Gauging Station
Pond #1
Pond #2
Pond #3
Pond #4
Upstream Gauging Station

Investigation of Site-Level Barriers



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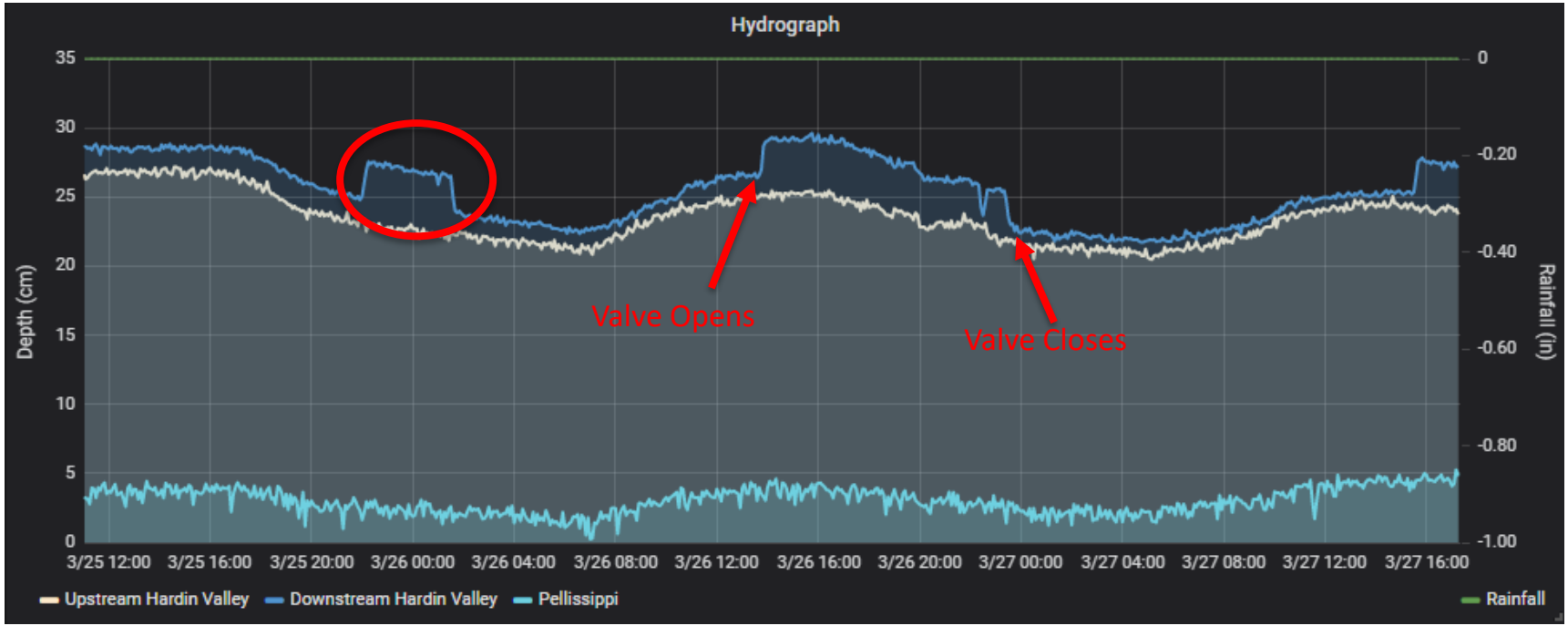

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