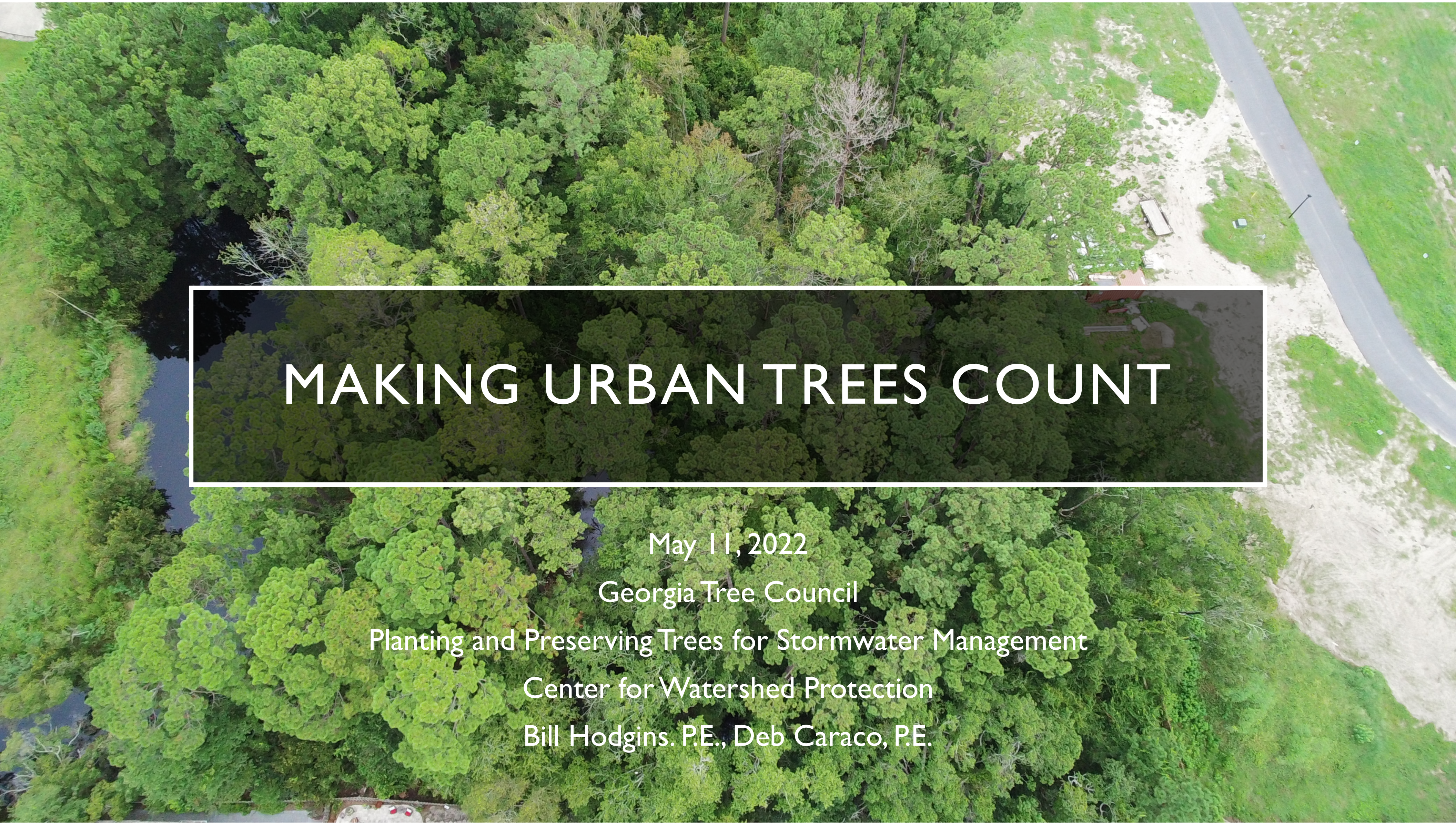

MAKING URBAN TREES COUNT

May 11, 2022

Georgia Tree Council

Planting and Preserving Trees for Stormwater Management

Center for Watershed Protection

Bill Hodgins. P.E., Deb Caraco, P.E.

A Novel Research Framework to Assess Water Quality Impacts of Urban Trees

Neely L. Law, PhD
Deb Caraco, P.E.
Bill Hodgins, P.E.

Mitch Pavao-Zuckerman, PhD
Sarah Ponte Cabral
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Susan Day, PhD*
Amy Blood*

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WATERSHED YIELD AND RAINFALL INTENSITY

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WATERSHED YIELD AND RAINFALL INTENSITY

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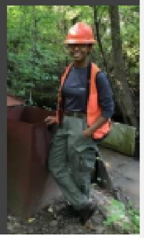
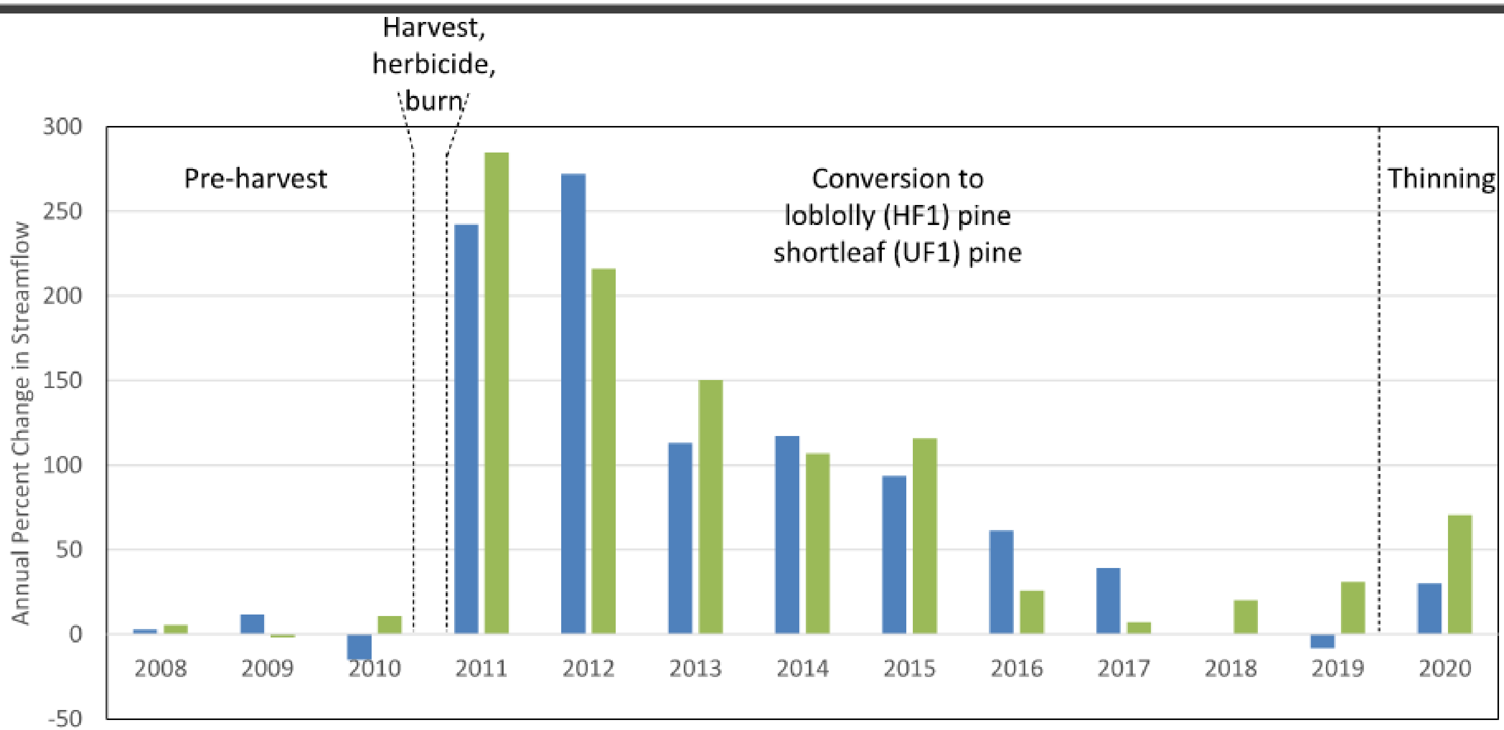
Removing Trees Tripled streamflow, recovered by year 8





HF1 UF1

Boggs, J., Sun, G., and McNulty, S. Effects of Timber Harvest on Water Quantity and Quality in Small Watersheds in the Piedmont of North Carolina. *J. For.* 114(1):27–40 http://dx.doi.org/10.5849/jof.14-102

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TREE SPECIES IMPACTS

SFM1x Sap Flow Meter, ICT International
https://ictinternational.com/products/sfm1/sfm1-sap-flow-meter/

- Red Maple
- Loblolly Pine
- White Oak
- Tulip Poplar
- Sweetgum
- Virginia Pine

- Found species specific transpiration and response to soil moisture
- Drought response
- Water use response to vapor pressure deficit varied by species
- Highlighted the need for species specific transpiration studies

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Boggs, J., Sun, G., Domec, J-C., and McNulty, S. Variability of tree transpiration across three zones in a southeastern U.S. Piedmont watershed. *Hydrological Processes*. 2021;35:e14389 https://doi.org/10.1002/hyp.14389

RELEVANCE TO URBAN STORMWATER MANAGEMENT

- Plant-based monitoring of total daily water use
  - Sap flow meter to measure water use
  - Soil moisture meters for infiltration
  - Weather station for relative humidity, temperature, rainfall, wind

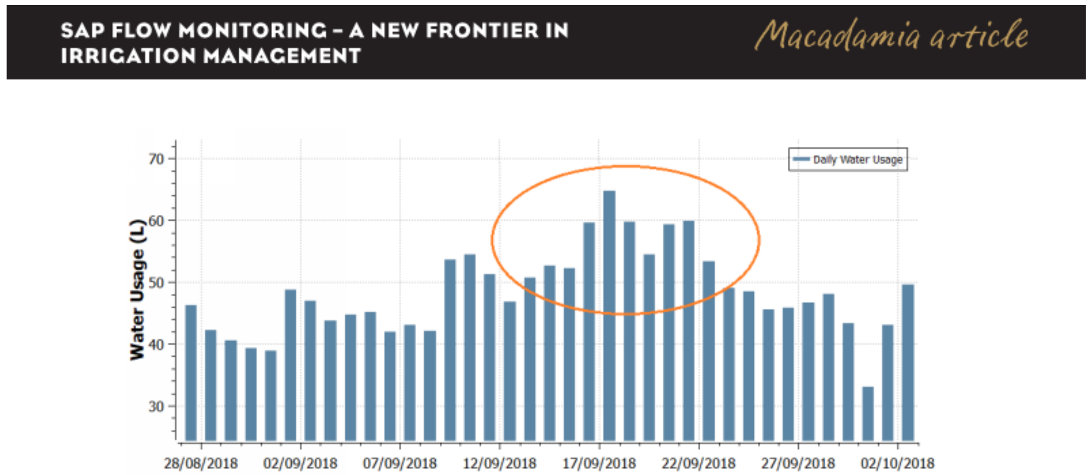

Figure. *Daily water-use estimates for a macadamia tree (cv816, 19.1 cm stem diameter) for the September period (27/08/18 to 2/10/18). Peak anthesis occurred for this tree from 12 to 23 September and the sap flow meters measured a marked increase in water use during this period (orange ellipse).*
Note. Data supplied by Scott Norval from Rural Funds Management from trees monitored in Swan Ridge orchard 10 km north of Bundaberg.

Manson, D., Bundaberg, S., Downey, A. 2018. Sap Flow Monitoring – A New Frontier In Irrigation Management. Australian Macadamia Society. https://app-ausmacademia-au-syd.s3.ap-southeast-2.amazonaws.com/resource/Sap%20flow%20monitoring%20a%20new%20frontier%20in%20irrigation%20management_.pdf

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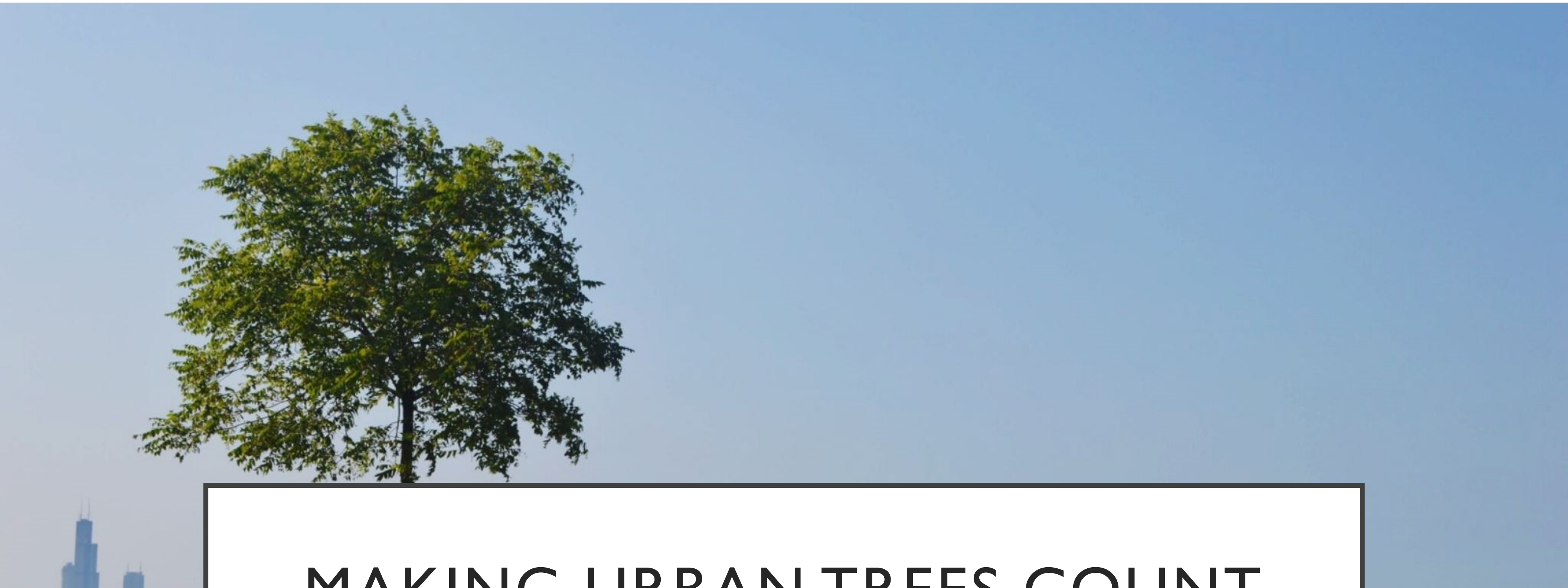

MAKING URBAN TREES COUNT

"Or counting urban trees for stormwater credit"

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NOVEL RESEARCH FRAMEWORK

Recommendations of the Expert Panel to Define BMP Effectiveness for Urban Tree Canopy Expansion

Karen Cappiella, Sally Claggett, Keith Cline, Susan Day, Michael Galvin, Peter MacDonagh, Jessica Sanders, Thomas Whitlow, Qingfu Xiao

Accepted conditionally by Forestry Work Group, June 23, 2016
Approved by Watershed Technical Work Group, September 1, 2016
Final Approval by Water Quality Goal Implementation Team, September 12, 2016

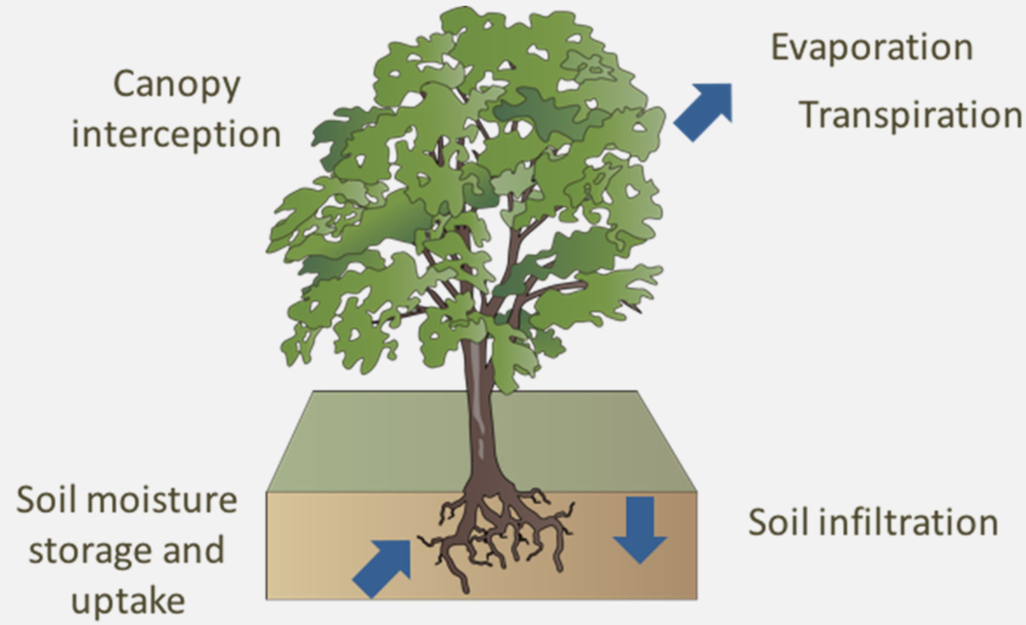
Prepared by
Neely L. Law, PhD, Center for Watershed Protection, Expert Panel Chair
Jeremy Hanson, Virginia Tech, Expert Panel Coordinator

KEY RESEARCH QUESTIONS

1. Do urban forest characteristics that influence ecohydrology occur in common configurations and can these configurations be captured through the development of an urban forest typology?
2. Will more complex urban forest types (e.g., those having more canopy layers, greater density, more understory plants or shrubs, litter layers, etc.) reduce runoff volume to a greater extent than simpler configurations?
3. How do different tree species affect runoff response?

WATER BALANCE

- This study quantifies:
- Precipitation
- Throughfall (to measure interception)
- Evapotranspiration
- Runoff/Infiltration breakdown



HYPOTHESES

- **H1**: Urban forest characteristics that influence ecohydrology occur in common configurations and these configurations can be captured through the development of an urban forest typology.
- **H2**: More complex urban forest types (e.g., those having more canopy layers, greater density, more understory plants or shrubs, litter layers, etc.) will result in greater runoff volume reduction.

STUDY AREA

Criteria:
- Site accessibility
- Safety for the research equipment
- Recommended by Montgomery County

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SPECIES	CLOSED CANOPY	CLUSTER OF TREES OVER TURFGRASS	SINGLE TREE OVER TURFGRASS
Tree Species 1: Red maple, Acer rubrum	X	X	X
Tree Species 2: Tulip poplar, Liriodendron tulipifera	X		
Tree Species 3: Sweet Gum, Liquidambar styraciflua	X	X	

SITE CHARACTERISTICS

- Maryland School for the Blind: Closed Canopy
- Asbury Methodist: Cluster/Single Trees Over Turfgrass
- Different mix of species in each setting
- A. rubrum in all locations

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INSTRUMENTATION/ MEASUREMENT

	Weather Stations	Under Canopy Outside Canopy
	Soil Moisture Meters	Under Tree Canopy Top 30 cm of soil
	Sap Flux Sensors	Thermal Dissipation Probes Proxy for Transpiration
	Soil Samples	Bulk Density Texture Organic Matter

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ANTICIPATED E/T RESULTS

- Trees in the closed canopy type will have greater, rates and amount, of sap flow (transpiration) than the trees that are located over turfgrass.
- Red maple will have a lower rate of transpiration compared to tulip poplar but will have greater overall amounts of transpiration and a resultant stronger effect on runoff reduction .
- Drivers of ET (Vapor Pressure Deficit (VPD); Soil Moisture)

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TRANSPIRATION METHOD

- Transpiration Measurement
- Sap flux is a *proxy* for transpiration rates
- Granier-type thermal dissipation probe sap flux sensors inserted radially in stem

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TRANSPIRATION METHOD

- Transpiration Measurement
- Sap flux is a *proxy* for transpiration rates
- Granier-type thermal dissipation probe sap flux sensors inserted radially in stem
- Voltage Difference is converted to grams H_2O/cm^2-d
  - J_s (g m^{-2} s^{-1}) = $119((\Delta T_{max} - \Delta T)/ \Delta T)^{1.231}$

TRANSPIRATION METHOD

- Transpiration Measurement
- Sap flux is a *proxy* for transpiration rates
- Granier-type thermal dissipation probe sap flux sensors
- Voltage Difference is converted to grams H_2O/cm^2-d
- Area of Sapwood needed to determine the volume of H_20; alternative method used literature values to relate DBH to sapwood area.

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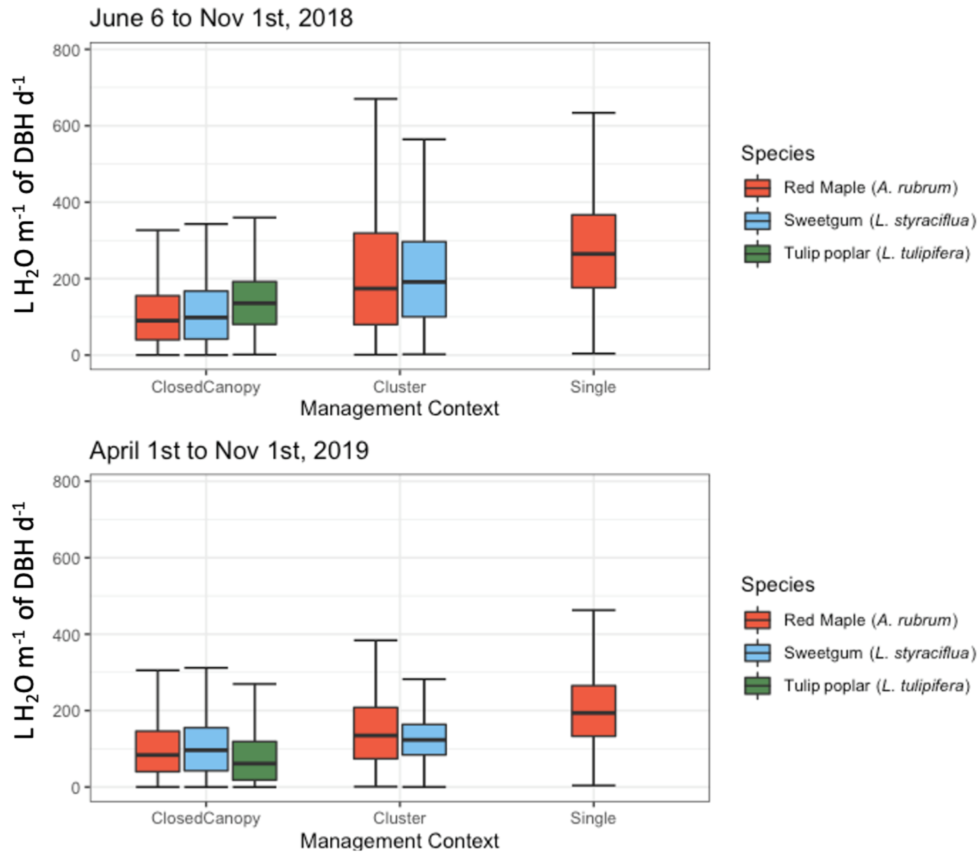
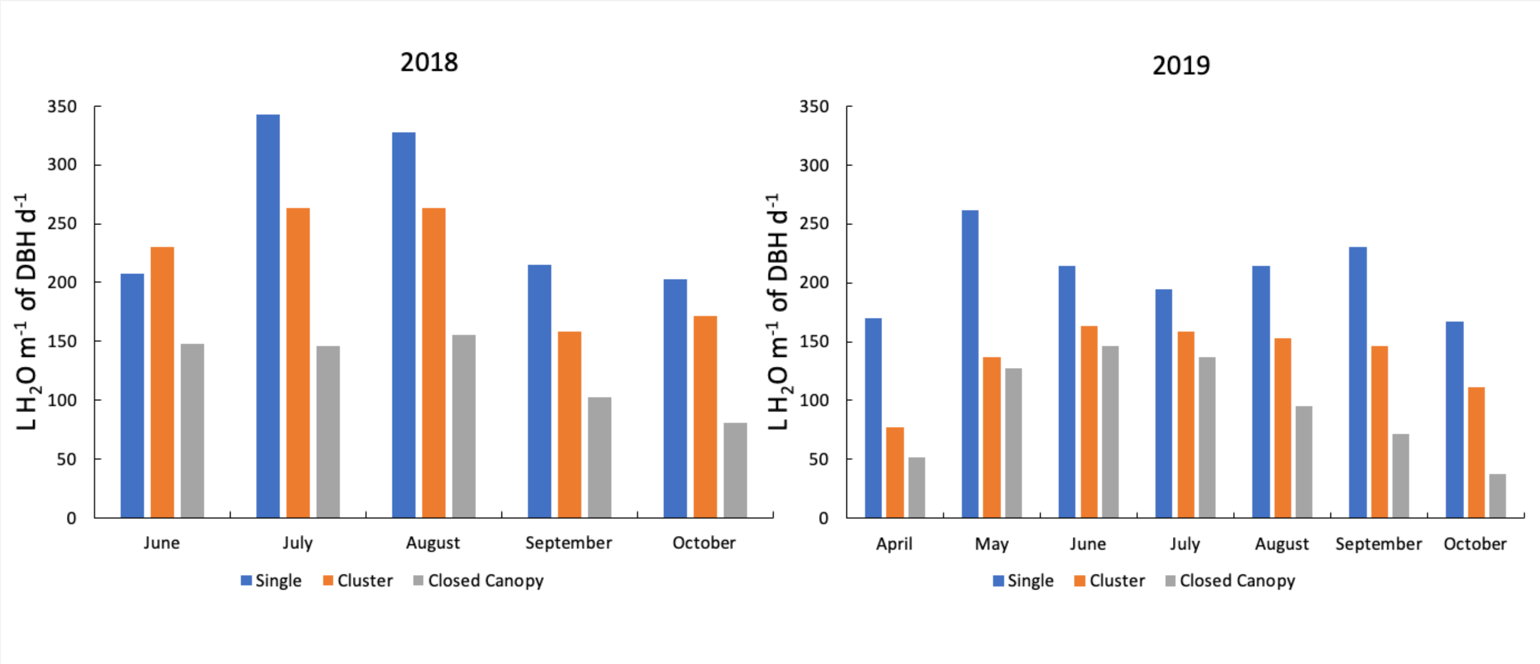
SPECIES	CLOSED CANOPY	CLUSTER OF TREES OVER TURFGRASS	SINGLE TREE OVER TURFGRASS
Tree Species 1: Red maple, Acer rubrum	X	X	X
Tree Species 2: Tulip poplar, Liriodendron tulipifera	X		
Tree Species 3: Sweet Gum, Liquidambar styraciflua	X	X	

RESULTS ON A PER-DBH UNIT



SINGLE TREES HAVE HIGHER TRANSPIRATION IN ALMOST EVERY MONTH OF THE STUDY



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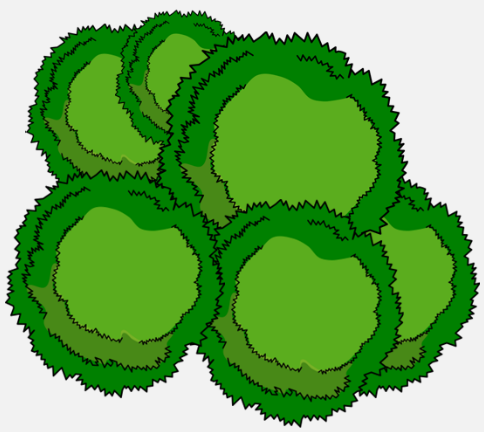
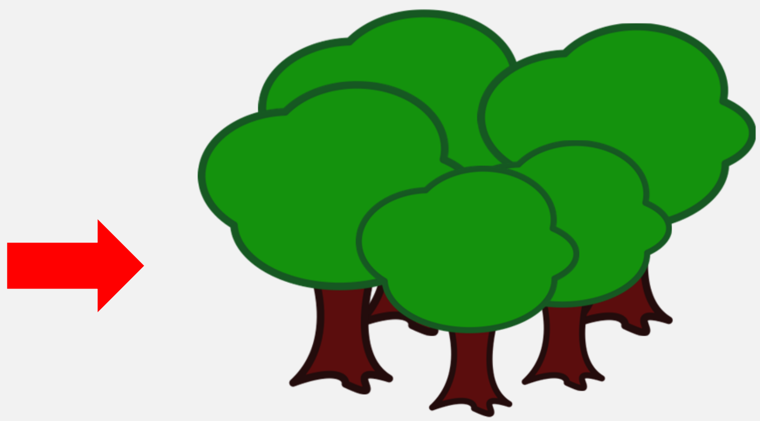
WHY DO INDIVIDUAL TREES HAVE THE HIGHEST PER-TREE TRANSPIRATION RATES?

- Tree Density (Per-Tree or Per-DBH has different results than Per-Area)
- Exposure to Wind and Sun
- Greater Leaf Area for Single Trees





Birds Eye View of Tree Canopy

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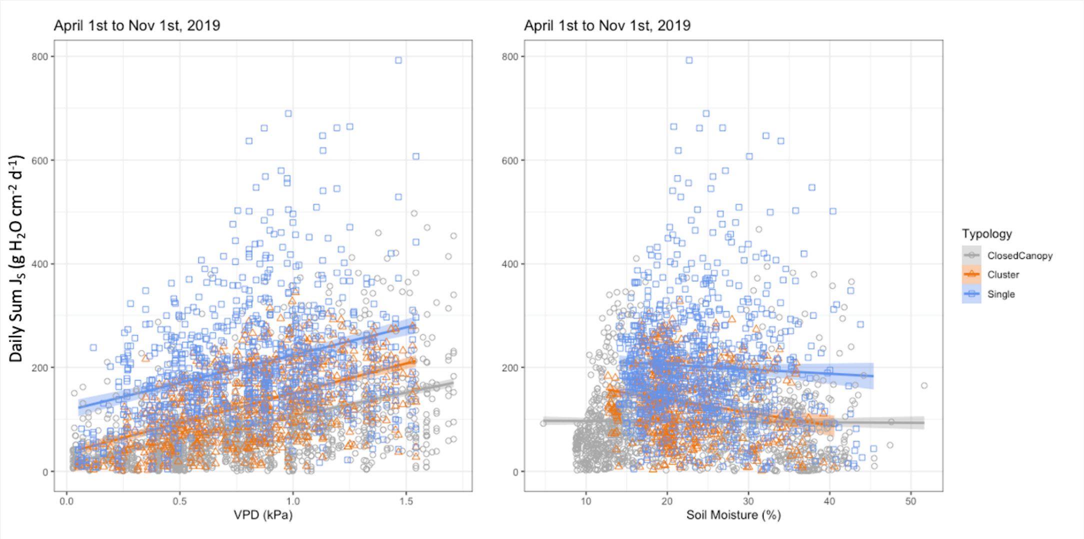
WHAT DRIVERS INFLUENCE TRANSPIRATION?

- Vapor Pressure Deficit
  - Temperature
  - Relative Humidity
  - Wind Speed
- Soil Moisture
  - Measured in first 12”



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WHY ISN'T THERE A STRONGER RELATIONSHIP BETWEEN SOIL MOISTURE AND TRANSPIRATION?

- Soil moisture is measured in the first 12"; tree roots may be drawing from deeper beneath the soil.
- There is likely a timing/ interaction issue
  - Higher transpiration is possible when moisture content is high, but
  - Transpiration reduces soil moisture

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POTENTIAL FUTURE RESEARCH: TRANSPIRATION

- Detailed site assessment to determine a per-DBH transpiration rate on a per-acre rather than per-tree basis.
- Allows for a more direct measure of transpiration volume between different tree planting settings.
- Use data from this study to develop a time-series model relating soil moisture to transpiration

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STORMWATER RUNOFF HYPOTHESES

- Trees in a closed canopy setting will reduce runoff volume more than single trees.
- Trees in the cluster setting will have an intermediate performance.

WATER BALANCE

- Estimate Interception from Rain Gage Data
- Estimate Infiltration from:
  - Soil Moisture Meters
  - "Throughfall" (rainfall measured beneath the canopy)
  - Green-Ampt Equation
- Runoff = Throughfall-Infiltration

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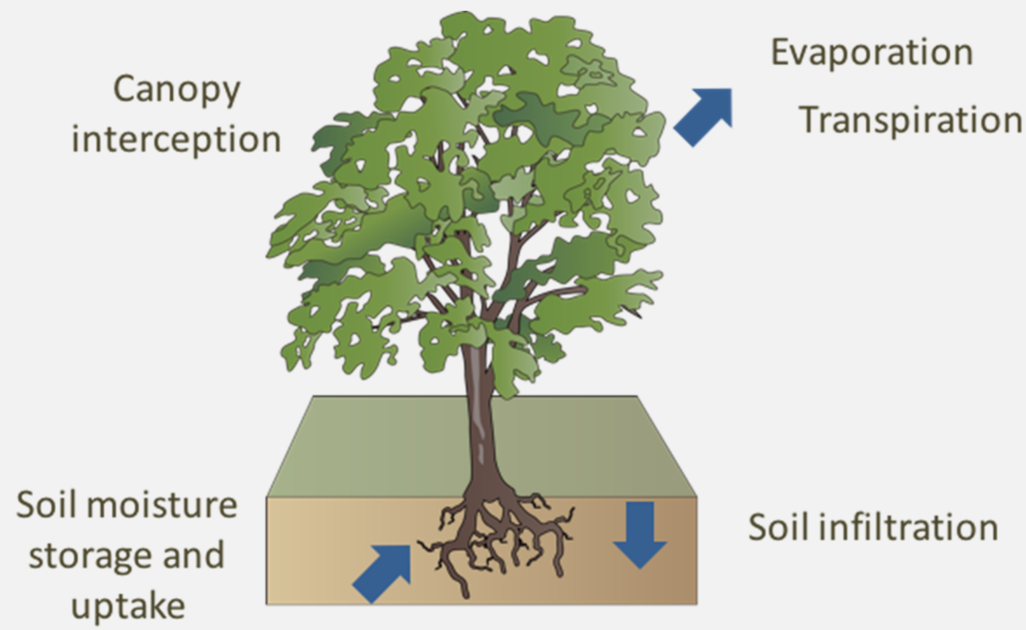

INTERCEPTION

FACTORS THAT INFLUENCE

- Storm Depth and Intensity
- Tree Canopy "Leaf Area Index"
- Canopy Complexity

CALCULATION

Interception = Rainfall (Measured outside the canopy)-Throughfall (Measured Under the Canopy)

Calculated for individual storms

Eliminated some outlier values

Computed annual (all seasons) and growing-season values

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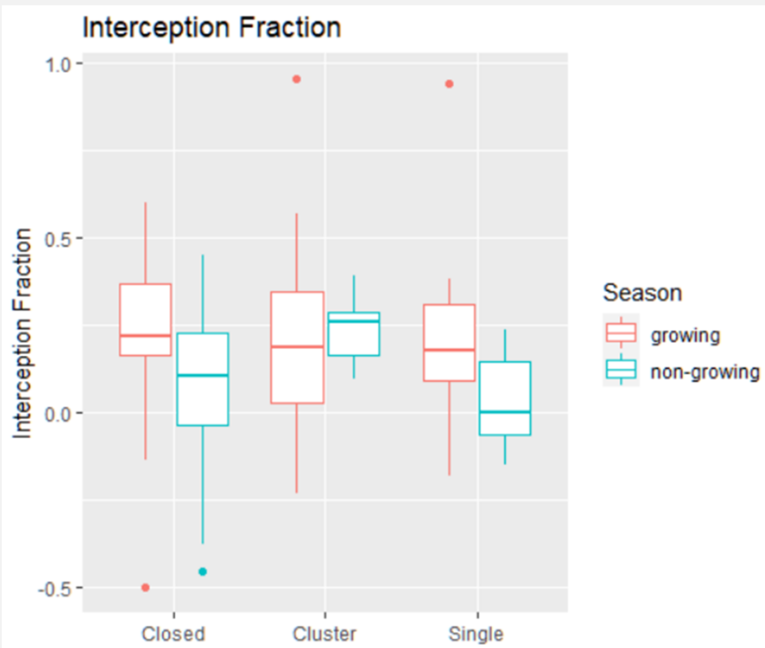
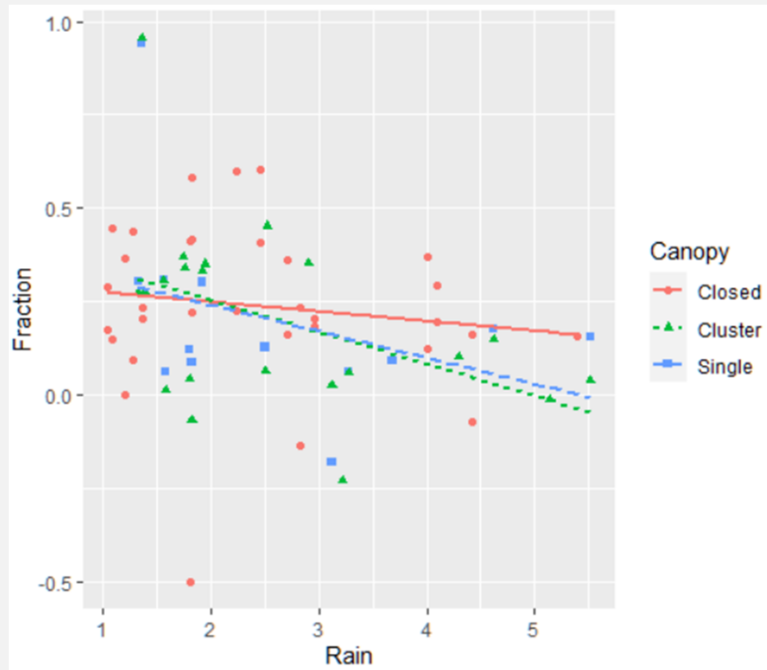
INTERCEPTION RESULTS
(FRACTION OF RAINFALL DEPTH)





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FACTORS INFLUENCING RUNOFF DEPTH

- Soil
  - Density
  - Moisture
  - Organic Matter
- Runoff Depth/Intensity
- Tree Canopy
- Understory

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SOIL CONDITIONS AT EACH SITE

- Soil types were mostly similar.
- The "Northwest" site at the Maryland School for the Blind (closed canopy) had high organic matter, and was also often saturated
- Single Tree setting had the lowest organic matter.
- The cluster setting had the highest bulk density (a measure of soil compaction)
- Bulk density is similar to undisturbed soils (not compacted)

	Soil Type	Bulk Density (g/cc)	Organic Matter (%)
Closed - (NW)	Loam-Clay Loam	1.31	4.6
Closed - (SE)	Loam	1.22	2.6
Single	Loam	1.22	2.0
Cluster	Loam	1.33	2.7

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MEASUREMENTS NEEDED TO QUANTIFY RUNOFF DEPTHS

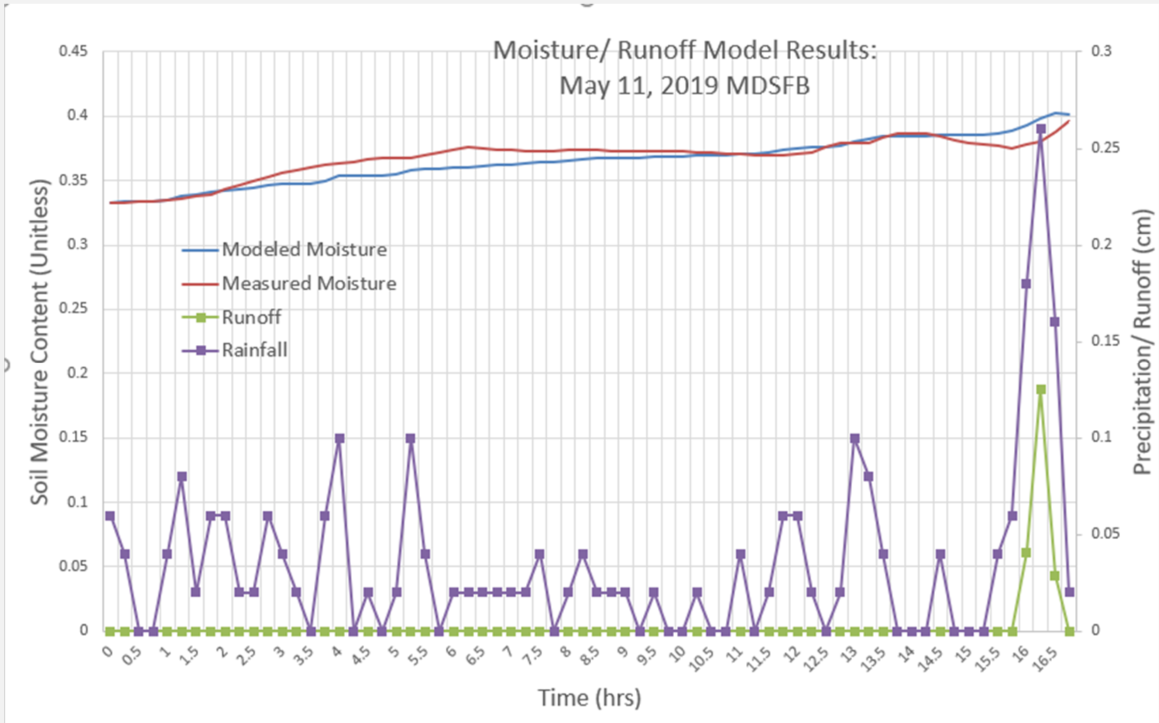
Rainfall

- Under Canopy
- Open

Soil Moisture

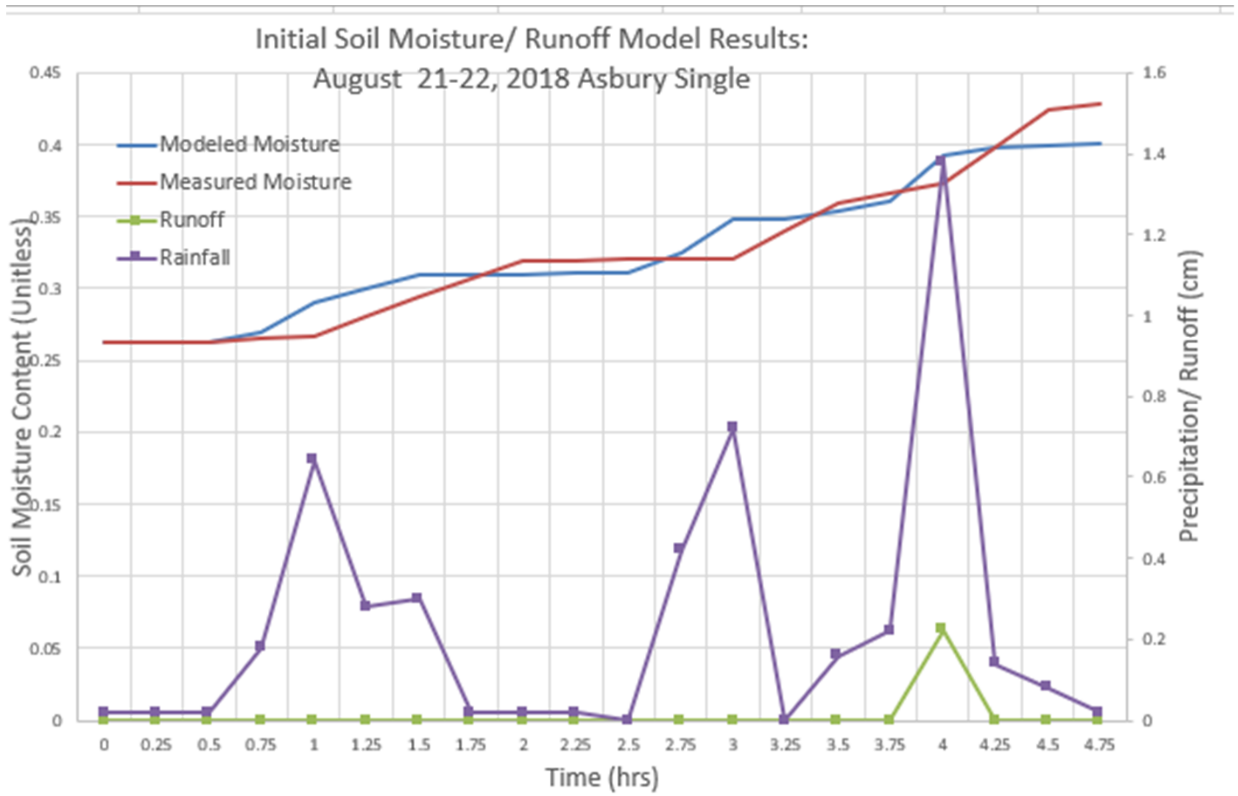
- Continuous
- Measured in First 12" of Soil

Runoff Computed Using the Green-Ampt Infiltration Model



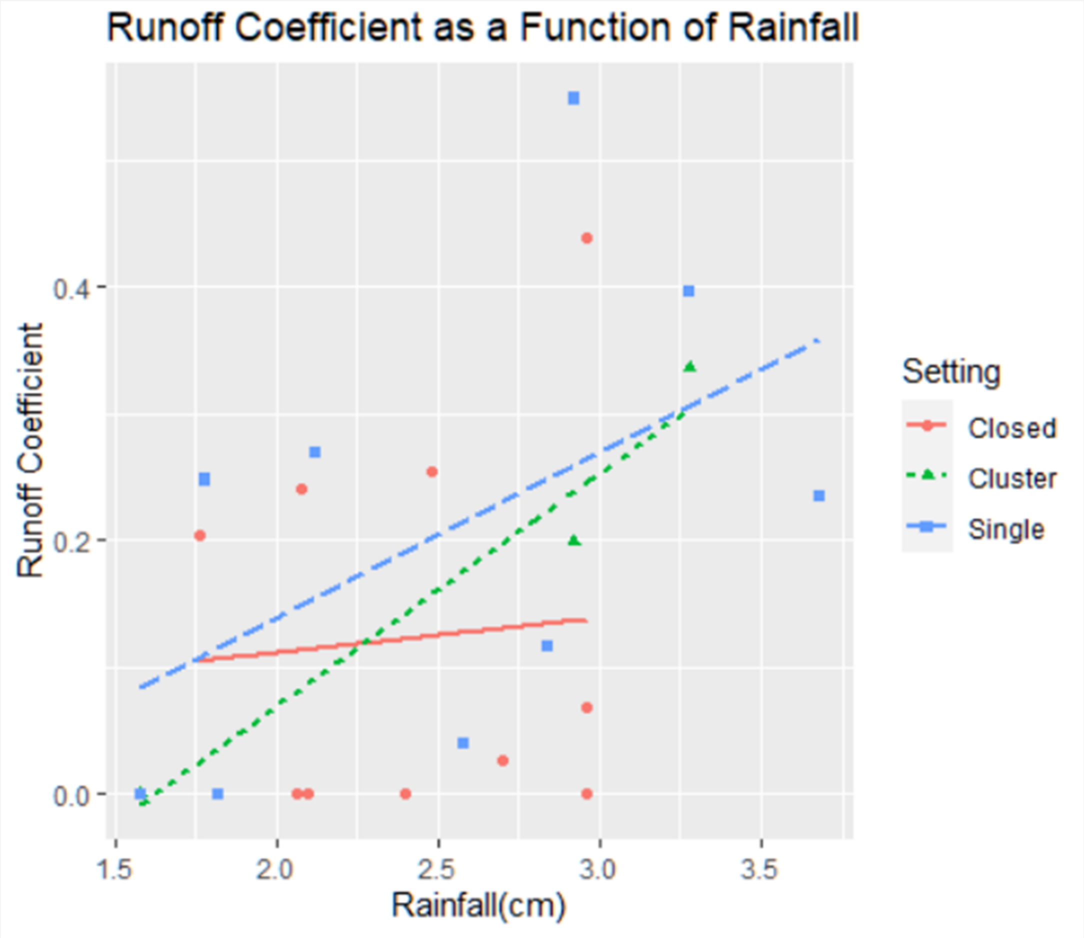
Runoff *when rainfall intensity exceeds infiltration rate*

Calibrate to reproduce monitored soil moisture


Initial Soil Moisture/ Runoff Model Results:
August 21-22, 2018 Asbury Single
Modeled Moisture
Measured Moisture
Runoff
Rainfall
Soil Moisture Content (Unitless)
Precipitation/ Runoff (cm)
Time (hrs)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0 0.25 0.5 0.75 1 1.25 1.5 1.75 2 2.25 2.5 2.75 3 3.25 3.5 3.75 4 4.25 4.5 4.75

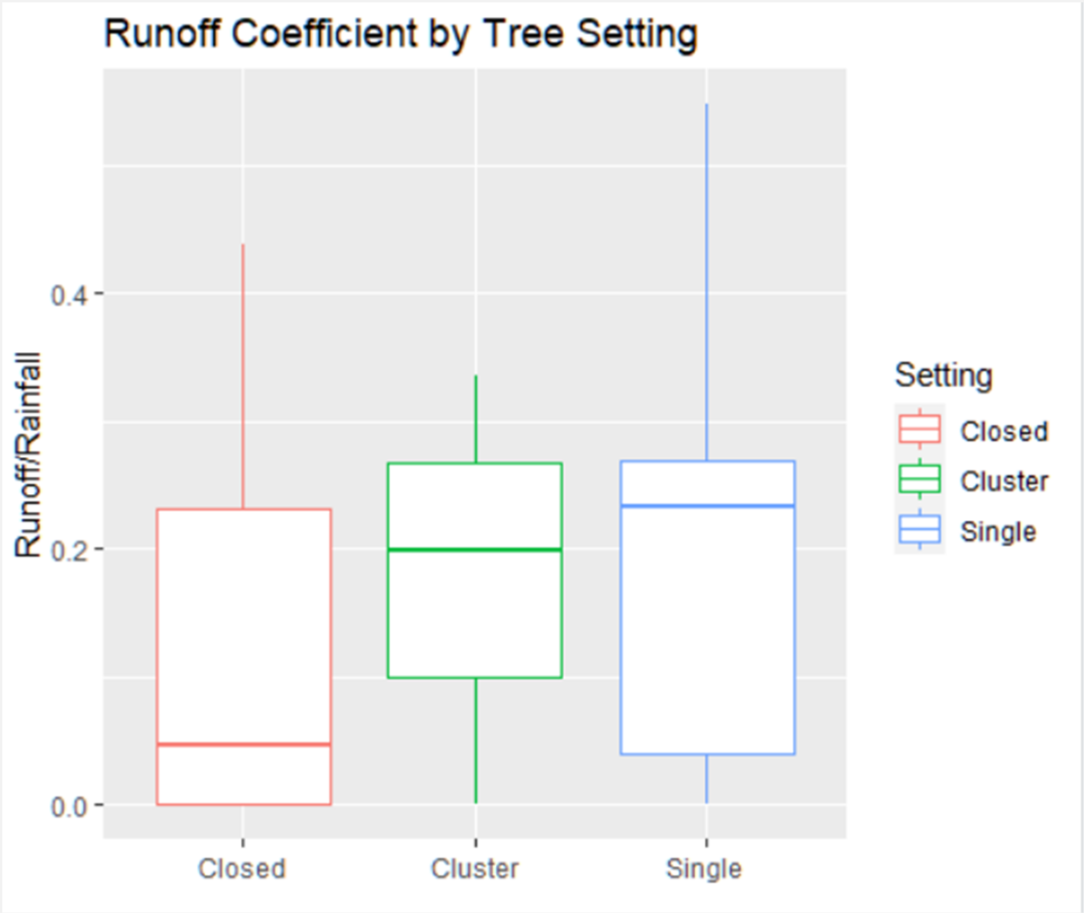
RUNOFF COEFFICIENT

- Highly variable
- Storm durations/ pre-event moisture highly variable.
- Some potential measurement error.
- This is not a paired analysis (few points overlapped at Asbury; MDSFB only has one setting/ typology)



RUNOFF VOLUME: SETTING COMPARISON

- Compares runoff coefficient for storms between 1 and 4 cm
- Includes the effects of interception and impacts on soil
- Typical runoff coefficient for grass is 0.2, but highly variable from site to site.
- Only 3 storms in this analysis for the Cluster site.



RUNOFF VOLUME: TOTAL OVER OBSERVED STORMS

- Cluster setting had too few storms to make a meaningful comparison.
- The Closed setting achieves about 17% reduction through interception, compared with 12% for Single
- About 15% of throughfall converted to runoff for closed, compared with 26% for Single

CANOPY	N	RAINFALL SUM(CM)	THROUHFALL SUM(CM)	RUNOFF SUM(CM)
CLOSED	10	24.5	20.4	3.06
CLUSTER	3	7.80	6.10	1.68
SINGLE	9	22.6	20.1	5.20

FUTURE RESEARCH/ ANALYSIS FOR RUNOFF COMPARISONS

- Add soil moisture meters in turf areas.
- More years of data.
  - Capture a wider array of storm events.
  - Develop a relationship that incorporates pre-event moisture.
  - Better able to capture seasonal differences
- More sites
  - Site/storm conditions are confounded with canopy/setting
- Movement of water through deeper soil layers
  - Wells?
  - Deep pits to evaluate soil restrictive layers/perched groundwater
- Stemflow
  - Measure at the same sites?

THINGS WE STILL DON'T UNDERSTAND

Scale

- We evaluated transpiration from individual trees, but transpiration might be taking water from a wider spatial area
- Interactions between trees in the forest setting

Deep root systems

- What is a reasonable depth to assume transpiration is taking water from?
- Is it a simple water balance, or do deep roots access deep groundwater?

Role of the Understory

- Transpiration/ runoff reduction

AN ECOHYDROLOGICAL TYPOLOGY

Trees will perform differently in terms of stormwater mitigation based on their immediate surroundings. We used ecohydrological landscape characteristics to develop a typology, grouping trees with others that have similar ecohydrological benefits..

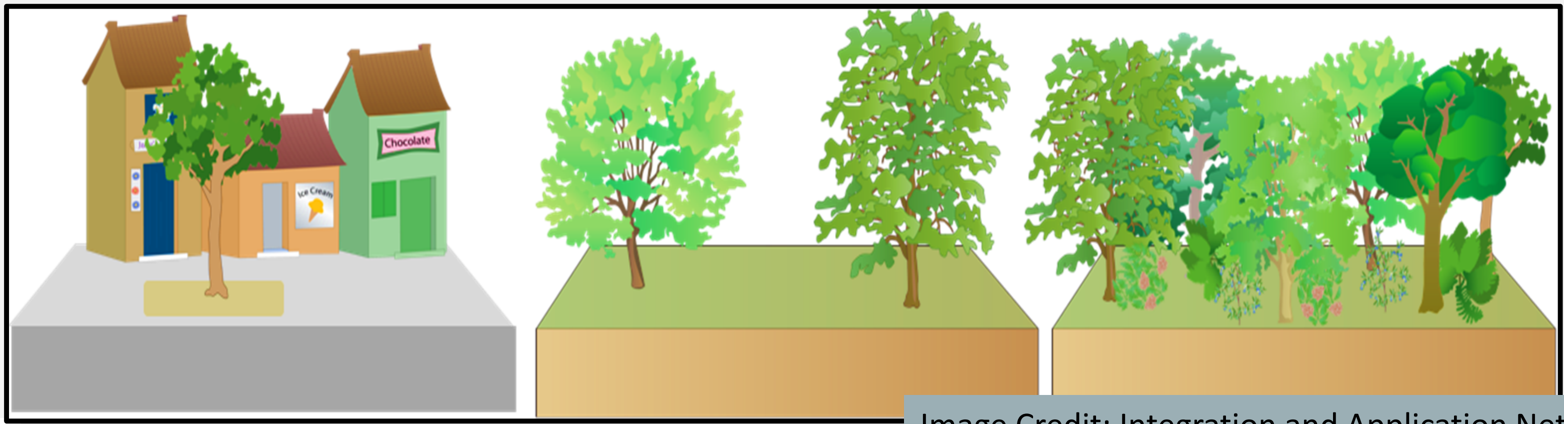


Image Credit: Integration and Application Network, UMD Center for Environmental Science

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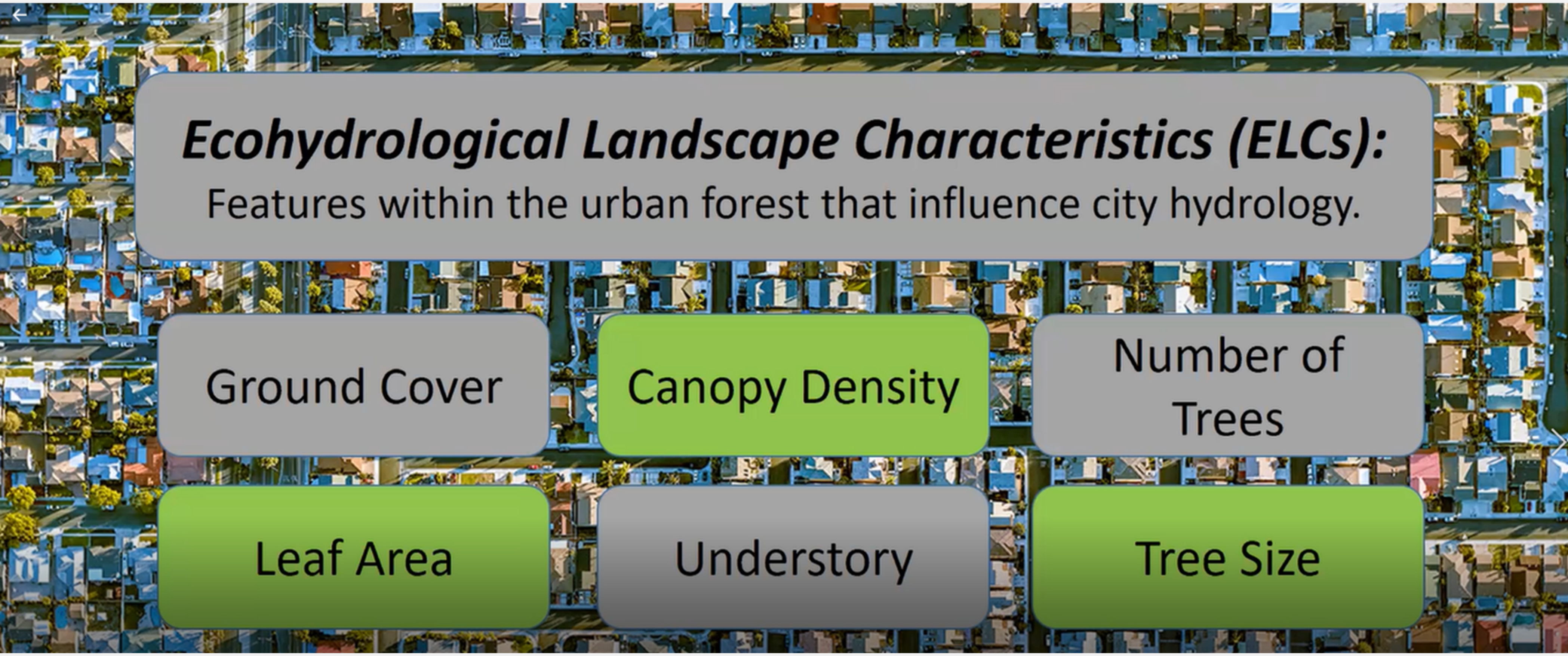

Ecohydrological Landscape Characteristics (ELCs):
Features within the urban forest that influence city hydrology.
Ground Cover
Canopy Density
Number of Trees
Leaf Area
Understory
Tree Size

METHOD POTENTIALLY ALLOWS PLANNERS TO UNDERSTAND DIFFERENCES AMONG TREE CANOPY TYPES

- Buildings are grayed
- Black is ground level under and near canopy
- The dark to light grey indicate canopy height

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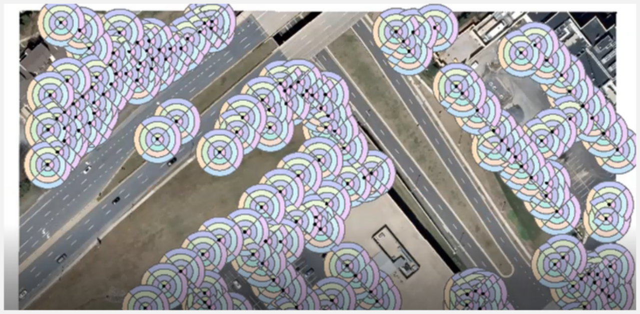
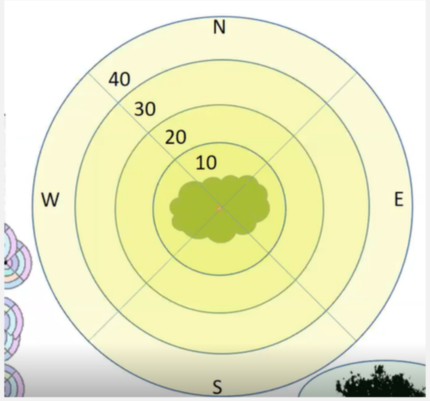
Source: Esri, Maxar, GeoEye, Earthstar Geographics,
CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the
GIS User Community, Esri, HERE, Garmin, (c)
OpenStreetMap contributors, and the GIS user community





METHOD TAKES INTO ACCOUNT THE TREE AND ITS SURROUNDINGS

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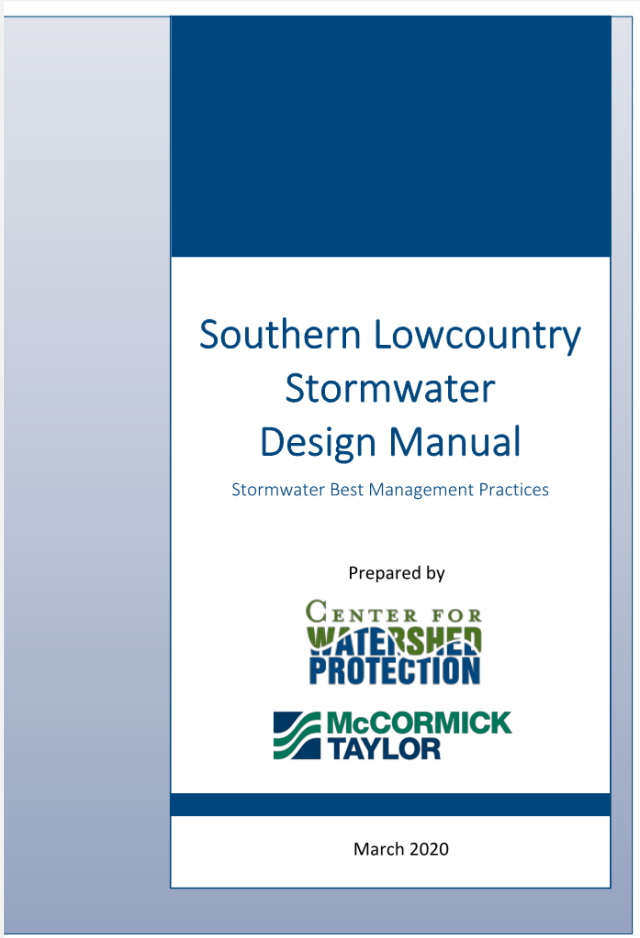
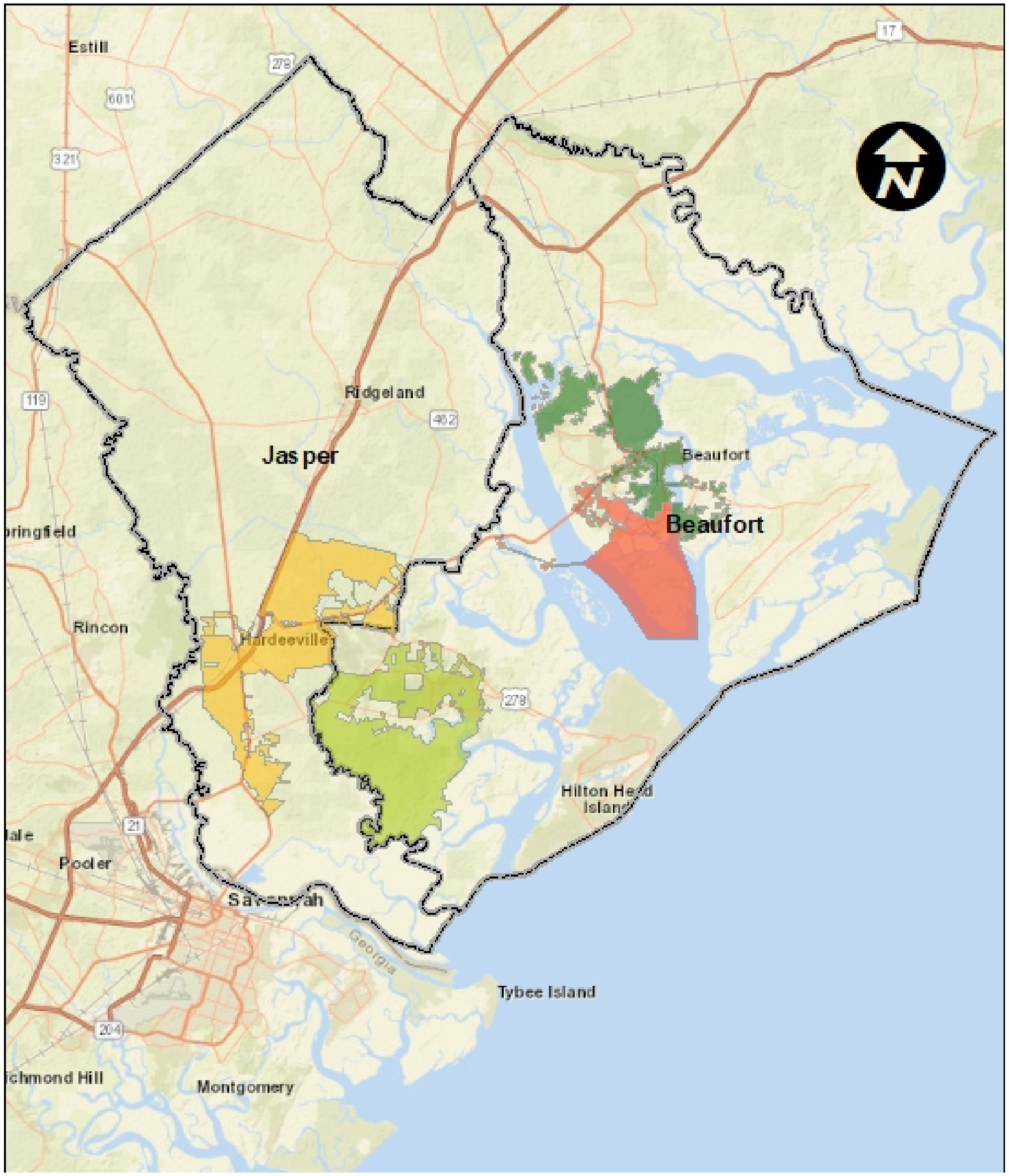
STORMWATER TREE CREDITS IN SOLOCO

- Project of Beaufort County in 2019-2020
  - Significant similarities to the Virginia Stormwater Management Manual, the DC SWM and other states
- A regional effort of the South Carolina Southern Low Country
  - Intergovernmental agreements shared cost of preparation





- Southern Low Country of South Carolina

LID PRACTICES TO MEET 85TH AND 95TH PERCENTILE STORMS

Table 3.3. Pollutant Removal Efficiencies of Structural BMPs.

BMP	Water Quality Credits			
	Runoff Reduction	TSS % Removal	Total N % Removal	Bacteria % Removal
Bioretention - No Underdrain	100%[1]	100%[1]	100%[6]	100%[6]
Bioretention – Internal Water Storage	75%[1]	85%[1]	85%[4]	80%[5]
Bioretention - Standard	60%[2]	85%[1]	75%[4]	80%[5]
Permeable Pavement - Enhanced	100%[1]	100%[1]	100%[6]	100%[6]
Permeable Pavement - Standard	30%[2]	80%[1]	45%[4]	30%[6]
Infiltration	100%[1]	100%[1]	100%[6]	100%[6]
Green Roof	100%[3]	100%[6]	100%[6]	100%[6]
Green Roof - Irrigated	50%[3]	50%[6]	50%[6]	50%[6]
Rainwater Harvesting	100%[3]	100%[6]	100%[6]	100%[6]
Impervious Surface Disconnection	40%[2]	80%[1]	40%[4]	40%[6]
Grass Channel	10%[2]	50%[1]	25%[4]	30%[5]
Grass Channel - Amended Soils	20%[2]	50%[1]	35%[4]	30%[5]
Dry Swale	60%[2]	85%	70%[4]	80%[5]
Wet Swale	0%[1]	80%[1]	25%[4]	60%[5]
Regenerative Stormwater Conveyance	0%[1]	80%[1]	40%[6]	80%[6]
Filtering Systems	0%[3]	80%[1]	30%[4]	80%[6]
Storage Practices	0%[3]	60%[1]	10%[4]	60%[5]
Stormwater Ponds	0%[1]	80%[1]	30%[4]	60%[5]
Stormwater Wetlands	0%[1]	80%[1]	25%[4]	60%[5]
Tree Planting and Preservation	see section 4.12			
Proprietary Practices	see section 4.13			
Conservation Areas	see section 4.14			

PRESERVE EXISTING TREES

- Inventory existing trees
- Identify trees to preserve
- Protect trees and soil during construction
- Protect trees after construction

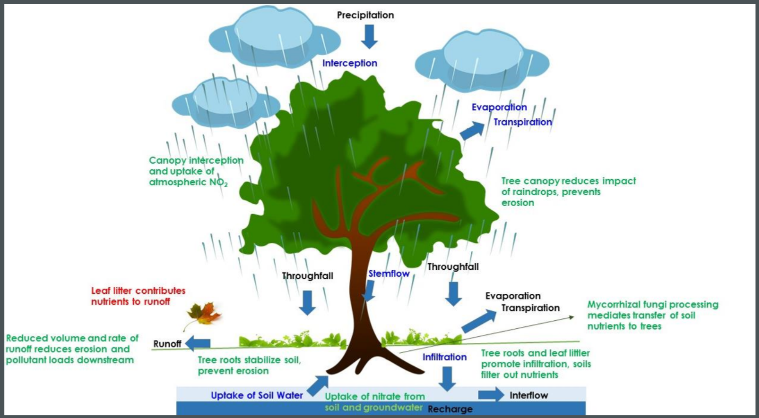
PLANTING TREES

- Trees planted with minimum caliper 1.5"
- Minimum rootable soil volumes
- Small and large tree quantities
- Soil volume requirement
- Assumed volume reduction
- Used in runoff reduction spreadsheet tool

STORMWATER TREE CREDITS IN SOLOCO

Table 4.59. T-1 Preserved and Planted Tree Retention

Tree Type	Retention Credit
Planted Tree – Small	5 cf per tree
Planted Tree – Large	10 cf per tree
Preserved Tree – Small	10 cf per tree
Preserved Tree – Large	20 cf per tree
Preserved Tree – Special	30 cf per tree



STORMWATER TREE CREDITS IN SOLOCO

BMPs

	Contributing Drainage Area				Storage Volume Provided by BMP (cubic feet)	Downstream BMP	Water Quality Credits				Retention (cf)					TSS Removal Achieved	Total N Removal Achieved	Bacteria Removal Achieved
	Forest Cover Draining to BMP	Turf Cover Draining to BMP	Impervious Cover Draining to BMP	BMP Surface Area														
	Area (square feet)	Area (square feet)	Area (square feet)	Area (square feet)			Runoff Reduction	TSS % Removal	Total N % Removal	Bacteria % Removal	Volume from Direct Drainage	Volume from Upstream Practices	Total Volume Captured by BMP	Volume Credited	Remaining Volume			
Bioretention - No Underdrain							100%	100%	100%	100%	0	0	0	0	0	0	0	0
Bioretention - IWS							75%	85%	85%	80%	0	0	0	0	0	0	0	0
Bioretention - Standard							60%	85%	75%	80%	0	0	0	0	0	0	0	0
Permeable Pavement - Enhanced							100%	100%	100%	100%	0	0	0	0	0	0	0	0
Permeable Pavement - Standard							30%	80%	45%	30%	0	0	0	0	0	0	0	0
Infiltration							100%	100%	100%	100%	0	0	0	0	0	0	0	0
Green Roof							100%	100%	100%	100%	0	0	0	0	0	0	0	0
Rainwater Harvesting							100%	100%	100%	100%	0	0	0	0	0	0	0	0
Impervious Surface Disconnection							40%	80%	40%	40%	0	0	0	0	0	0	0	0
Grass Channel							10%	50%	25%	30%	0	0	0	0	0	0	0	0
Grass Channel - Amended Soils							20%	50%	35%	30%	0	0	0	0	0	0	0	0
Dry Swale							60%	85%	70%	80%	0	0	0	0	0	0	0	0
Wet Swale							0%	80%	25%	60%	0	0	0	0	0	0	0	0
RSC							0%	80%	40%	80%	0	0	0	0	0	0	0	0
Filtering Systems							0%	80%	30%	80%	0	0	0	0	0	0	0	0
Storage Practices							0%	60%	10%	60%	0	0	0	0	0	0	0	0
Stormwater Ponds							0%	80%	30%	60%	0	0	0	0	0	0	0	0
Stormwater Wetlands							0%	80%	25%	60%	0	0	0	0	0	0	0	0
Proprietary Practice											0	0	0	0	0	0	0	0
					Input Number of Trees													
Planted Tree - Small							5 cf/tree	N/A	N/A	N/A	N/A	N/A	N/A	0	N/A	0	0	0
Planted Tree - Large							10 cf/tree	N/A	N/A	N/A	N/A	N/A	N/A	0	N/A	0	0	0
Preserved Tree - Small							10 cf/tree	N/A	N/A	N/A	N/A	N/A	N/A	0	N/A	0	0	0
Preserved Tree - Large							20 cf/tree	N/A	N/A	N/A	N/A	N/A	N/A	0	N/A	0	0	0
Preserved Tree - Special							30 cf/tree	N/A	N/A	N/A	N/A	N/A	N/A	0	N/A	0	0	0
Totals	0.00	0.00	0.00	0.00	0.00													

Site Data | BMPs | Detention | Lookup Tables

Ready Accessibility: Investigate

RUNOFF REDUCTION VOLUME

- Stormwater retention volume SWRv
- Volume reduction assists with SWRv
- Small and large tree quantities
- Soil volume requirement
- Assumed volume reduction
- Used in runoff reduction spreadsheet tool

SOLOCO IMPLEMENTATION

- Beaufort County Effective 1Q 2021
- Town of Bluffton Ordinance September 2021
- City of Hardeeville currently in Council Workshops
- Jasper County – TBD
- City of Beaufort – TBD
- Town of Port Royal - TBD

CENTER FOR WATERSHED PROTECTION

QUESTIONS

Making Urban Trees Count Resources

Center for Watershed Protection https://www.cwp.org/making-urban-trees-count/

https://www.chesapeakebay.net/documents/Urban_Tree_Canopy_EP_Report_WQGIT_approved_final.pdf

Transpiration rates of red maple (Acer rubrum L.) difer between management contexts in urban forests of Maryland, USA
Sarah Ponte, Nancy F. Sonti, Tuana H. Phillips & Mitchell A. Pavao-Zuckerman https://doi.org/10.1038/s41598-021-01804-3

Southern Low Country Stormwater Design Manual
https://www.beaufortcountysc.gov/stormwater/documents/Manuals--Plans-page/SoLoCo-Design-Manual-and-Appendices.pdf

CENTER FOR WATERSHED PROTECTION

THANK YOU

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