Knowledge for Life

Digging into the data: unraveling the influence of urban trees on stormwater quantity and quality

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Project collaborators Tom Jacobs (Mid-America Regional Council) & Lisa Treese (KC Water Services); WRF Project Advisory Committee

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Objective 1. Peer into the data to gain insight to the following questions:

- Q1: To what extent to urban tree systems regulate stormwater runoff quantity?
- Q2: To what extent do urban tree systems regulate stormwater runoff quality?
- Q3: At what spatial scales are these functions relevant?

Objective 2. Collect feedback from you

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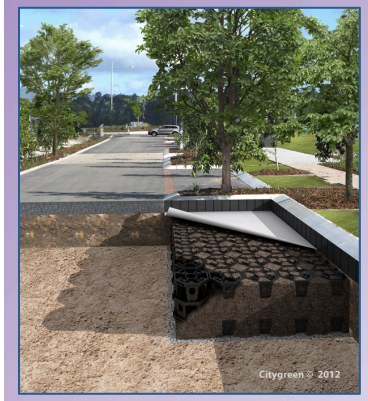
Poll: Which of these urban tree systems (**a., b., c. and/or d.**) do you think of with respect to stormwater management?

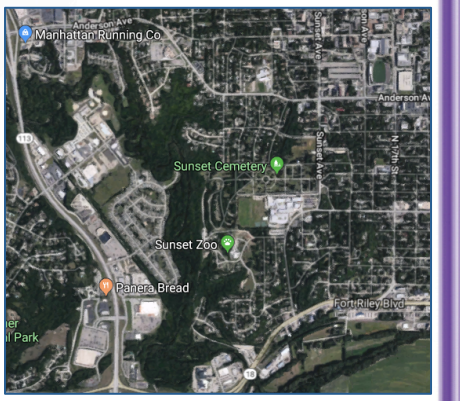
a



b

c

d



highly managed/ "engineered"
(higher energetic inputs)

"natural"
(low energetic inputs)

Tree-mediated, stormwater regulating processes

Precipitation partitioning
- Precipitation depth
- Precipitation intensity
- Wind speed & direction
- Tree traits (phenology; leaf, stem & branch orientation, LAI/canopy architecture, bark roughness)

Infiltration
- Soil type
- Soil compaction factors
- Tree species and rooting structure
- Time

Transpiration
- Evaporative demand (temperature, wind, relative humidity, vapor pressure deficit)
- Soil water availability
- Tree species

Nutrient capture & cycling
- Atmospheric deposition rates
- Annual precipitation
- Infiltration
- Soil type
- Tree litter traits & decomposition environment
- Surface/subsurface nutrient inputs

Poll: With respect to role of trees as stormwater management infrastructure, which of these processes (PP, In, Tr, NCC) do you consider most useful to understand?

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Studies to understand the linkage between process, outcome, and all those forcing variables

Process	Predicted variables	Potential explanatory variables included in analysis	Analysis time scale (n = number of studies)
Rainfall partitioning	Throughfall Rainfall capture[1]	*Climatic*: rainfall depth, intensity[2], Koppen climate *Tree*: evergreen-ness, bark roughness, DBH, LAI, Height	Rainfall event (n=10) Annual (n = 16)
Transpiration	Sapflow rate Whole tree transpiration	*Climatic*: Solar radiation, vapor pressure deficit, rainfall depth, Koppen climate *Tree*: evergreen-ness, xylem anatomy DBH, LAI	Daily transpiration (n= 4) Average seasonal (n = 8)
Water quality	Throughfall nutrient washoff	*Tree system:* precipitation nutrient content; annual precipitation	Annual (n = 14)
	Litter nutrient mass release	*Leaf litter characteristics:* initial N and P content; N:P ratio; C:N ratio, lignin content	Annual (n = 8)
	Below root zone nutrient leaching	*Climatic*: annual precipitation *Tree*: leachate volume	Annual (n = 4)

Digging into those data with meta-analysis

Precipitation partitioning
- Precipitation depth
- Precipitation intensity
- Wind speed & direction
- Tree traits (phenology; leaf, stem & branch orientation, LAI/canopy architecture, bark roughness)

Transpiration
- Evaporative demand (temperature, wind, relative humidity, vapor pressure deficit)
- Soil water availability
- Tree species

Nutrient capture & cycling
- Atmospheric deposition rates
- Annual precipitation
- Infiltration
- Soil type
- Tree litter traits & decomposition environment
- Surface/subsurface nutrient inputs

Caveats for every remaining slide: representative of experimental datasets included in analysis (conditions, measured variables, etc.)

Statistical analysis (regression)

Predictive equations:

Rainfall capture = *f*(x, y, z)

Throughfall = *f*(a, b, c)

Transpiration = *f*(n, o, p)

Goals:

- Identify most influential variables
- "Simple" data-driven tool

Throughfall vs. "Rainfall Capture"

Annual precipitation partitioning
- Annual precipitation depth
- Tree traits (evergreen/deciduous, bark roughness, LAI, DBH, climate zone)

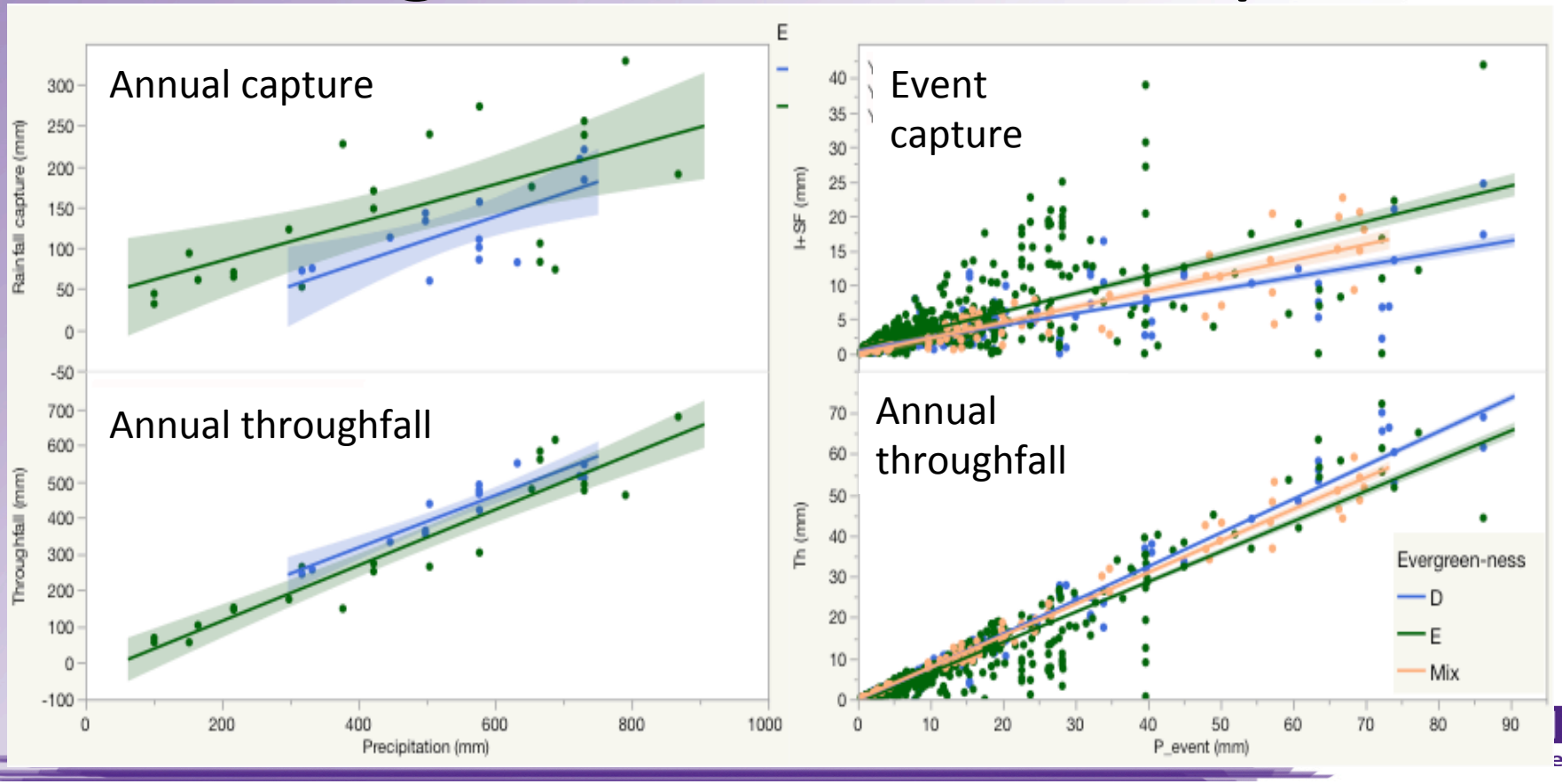
Event precipitation partitioning
- Event precipitation depth
- Event precipitation intensity
- Tree traits (evergreen/deciduous, bark roughness, LAI, DBH, climate zone)

Statistical analysis (linear regression)

On an annual or event basis, **evergreen-ness** and **precip depth** were most significant factors
- Positive but insignificant correlation w/ LAI & bark roughness
- Higher event capture in hotter, drier climates

Rainfall capture = *f*(evergreen/deciduous, P depth, canopy area)
Throughfall = *f*(evergreen/deciduous, P depth, canopy area)

Throughfall vs. Rainfall Capture



Throughfall vs. Rainfall Capture

Tree type	Predictive equation: *average annual* rainfall capture and throughfall	
Evergreen	Rainfall capture (mm): $= 0.23P_{gr} + 37.9$	$R^2 = 0.43$ (n=21)
	Throughfall (mm) $= 0.77P_{gr} - 38.16$	$R^2 = 0.89$ (n=21)
Deciduous	Rainfall capture (mm): $0.28P_{gr} - 31.5$	$R^2 = 0.52$ (n=14)
	Throughfall (mm) $= 0.72P_{gr} + 30.2$	$R^2 = 0.88$ (n=14)
Equation terms: Rainfall capture and throughfall are in mm/unit evergreen or deciduous canopy area on an annual basis; P_{gr} is gross annual precipitation depth (mm); these equations not recommended for precipitation depths less than 150 mm.		
Tree type	**Predictive equation: rainfall *event* capture and throughfall**	
Evergreen	Rainfall capture (mm): $= 0.26P_{gr} + 0.86$	$R^2 = 0.47$ (n=717)
	Throughfall (mm) $= 0.74P_{gr} - 0.86$	$R^2 = 0.88$ (n=717)
Deciduous	Rainfall capture (mm): $0.17P_{gr} + 0.56$	$R^2 = 0.66$ (n=431)
	Throughfall (mm) $= 0.82P_{gr} - 0.56$	$R^2 = 0.98$ (n=431)
Equation terms: Rainfall capture and throughfall are in mm/unit evergreen or deciduous canopy area on a storm event basis; P_{gr} is gross precipitation for a given storm event; DBH is tree diameter at breast height (cm). Minimum recommended event precipitation depth is 1 mm		

Poll: in your context, which time scale is most useful to predict? (a) Annual, (e) Event or both?

- Annual precip: 1,000 mm (40 inches)
- Water quality storm: 25 mm (1 inch)

Annual **evergreen** rainfall capture: = (0.23*1,000 mm) + 37.9 mm = 268 mm (10.5 inches)

Annual **deciduous** rainfall capture: = (0.28*1,000 mm) – 31.5 mm = 250 mm (9.8 inches)

Event **evergreen** rainfall capture: = (0.26*25.4 mm) + 0.86 mm = 7.4 mm (0.3 inches, 29%)

Event **deciduous** rainfall capture: = (0.17*25.4 mm) – 0.56 mm = 4.8 mm (0.2 inches, 19%)

Transpiration

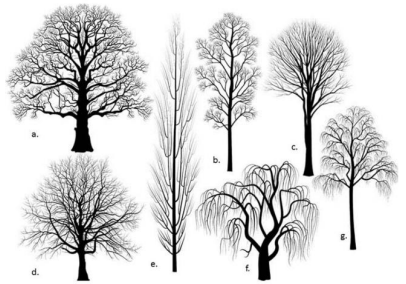
Annual Transpiration

- *Simplification*: only non-limiting water conditions considered
- Physical variables (annual average temperature, solar radiation, vapor pressure deficit)
- Tree traits (wood type, DBH, LAI)

Daily Transpiration

- *Simplification*: only non-limiting water conditions considered
- Physical variables (daily temp, solar radiation, vapor pressure deficit)
- Tree traits (wood type, DBH, LAI)
- zone)

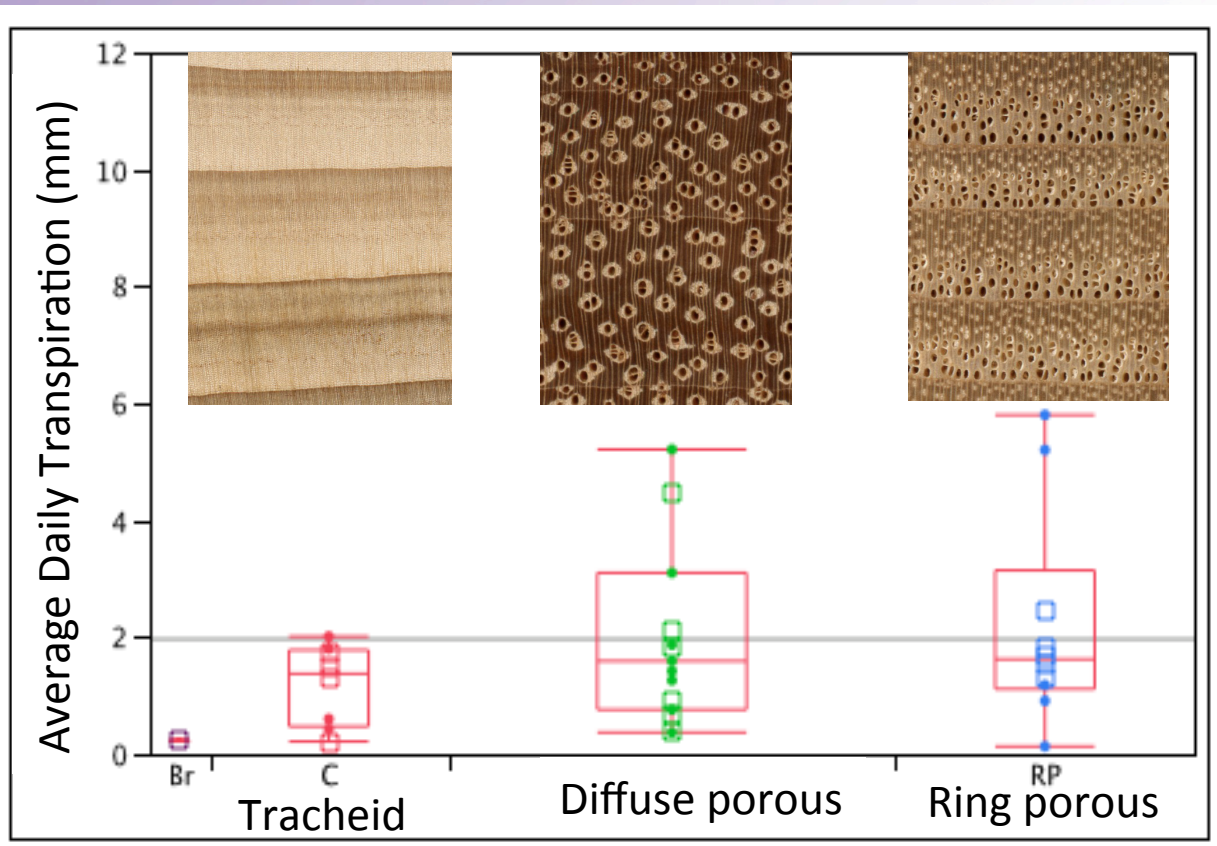
Statistical analysis
(multiple linear regression)



Positive correlation w/ LAI, but not enough data to support statistically

Annual T = *f*(wood type, Temp, solar radiation, vapor pressure deficit)
Daily T = *f*(wood type, solar radiation, vapor pressure deficit)

Transpiration



Different wood types respond differently to climatic drivers

Wood anatomy figures from *wood-database.com*

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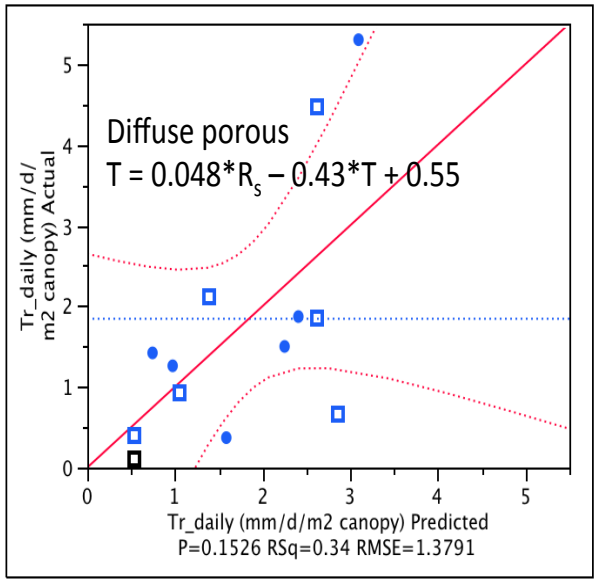
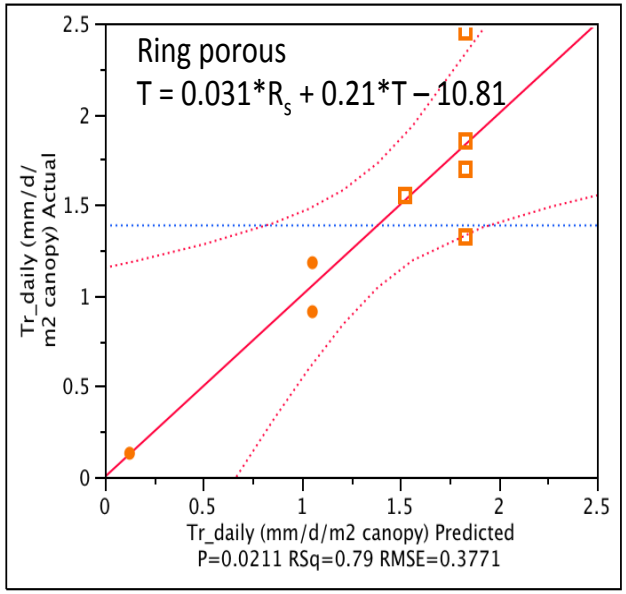
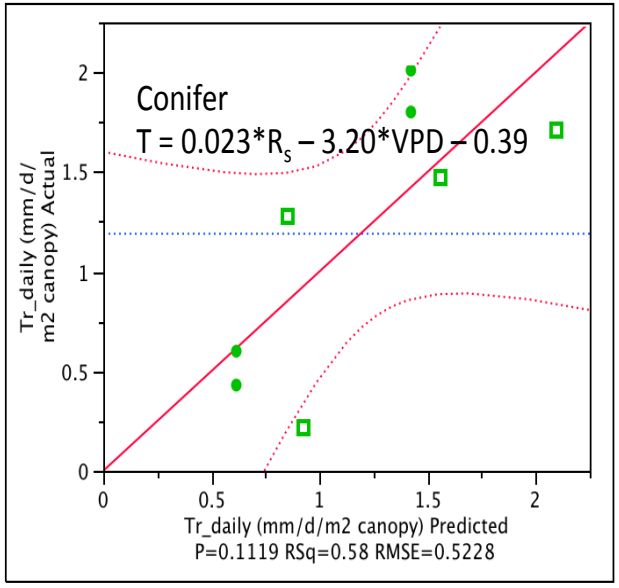
Annual Transpiration



$R^2 = 0.34$



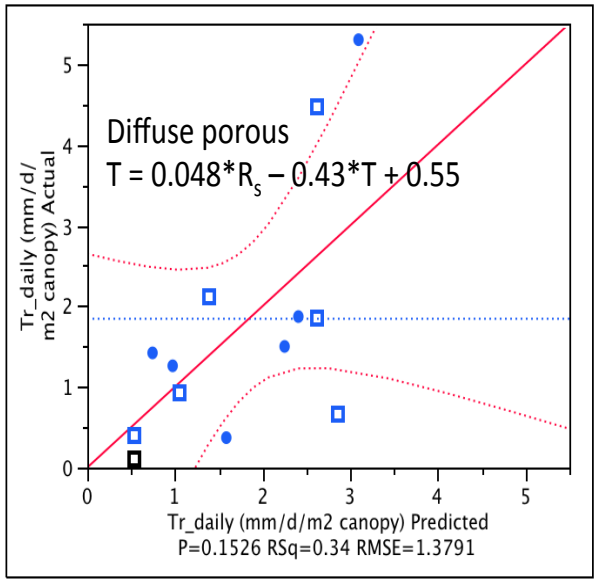
$R^2 = 0.79$

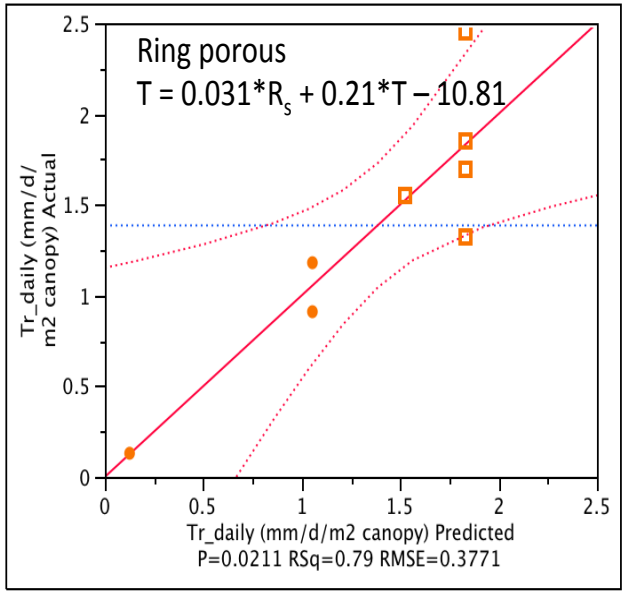


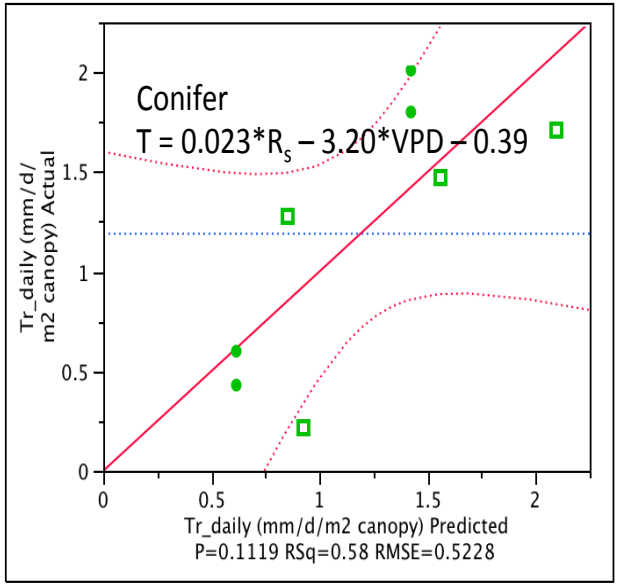
$R^2 = 0.58$

Open squares: Mediterranean/Semi-arid; Closed: continental/humid

Event Transpiration





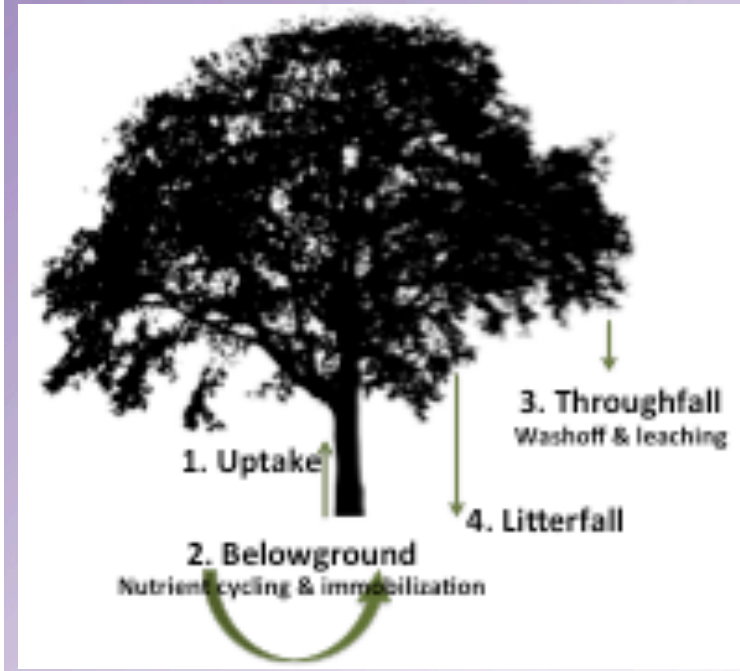


Transpiration: opportunity to "squeeze the soil sponge" in between runoff events

Equation type	Predictive equation: *daily tree water use Tr*	Equation fit[a]
Average daily water use (averaged over growing season; mm d^{-1})	Diffuse porous: $Tr = 0.048*R_s - 0.43*T + 0.55$	$R^2 = 0.58$ (n = 12)
	Ring porous: $Tr = 0.031*R_s + 0.21*T - 10.81$	$R^2 = 0.79$ (n = 8)
	Conifer: $Tr = 0.023*R_s - 3.20*VPD - 0.39$	$R^2 = 0.58$ (n = 8)
Daily water use (mm d^{-1})	Diffuse porous: $Tr = 0.001*R_s + 0.45*VPD$	$R^2 = 0.28$ (n = 235)
	Ring porous: $Tr = 0.004*R_s - 0.07*VPD + 0.38$	$R^2 = 0.39$ (n = 349)
	Conifer: $Tr = 0.56*VPD$	$R^2 = 0.30$ (n = 536)

Equation terms: Transpiration (Tr) is in mm/day/m^2 canopy area; R_s is average daily solar radiation in W/m^2; VPD is average daily vapor pressure deficit in kPa; T is temperature in degrees Celsius; Equations most appropriate for solar radiation values ranging from 40 W/m^2 to 350 W/m^2 and VPD up to 3 kPa.

Water quality



Water quality process	Reference system	Data collected to characterize process
Throughfall washoff & leaching	Bulk precipitation	Measured throughfall nutrient concentrations and loads
Litter decomposition	NA	Nutrient mass loss rates from urban tree litter
Biological uptake, belowground processes	Managed turfgrass	Leachate nutrient concentrations and loads measured below urban tree root zones (used as proxy for net nutrient retention in root zone); International Stormwater BMP database nutrient load retention in bioretention with trees, herbaceous or no vegetation

Descriptive statistics

Insight

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Insight 1: Trees capture atmospheric pollutants and transfer to root zone via throughfall & stemflow

Nutrient (mg/L)	**Median Precip**	**Median Throughfall**
Nitrate	0.43 (n = 28)	1.08 (n = 29)
Ammonium	0.43 (n = 28)	0.68 (n = 28)
Total dissolved N	1.0 (n = 8)	2.95 (n = 9)
Soluble reactive P	0.14 (n = 5)	0.29 (n = 5)
Total dissolved P	0.45 (n = 9)	0.53 (n = 9)

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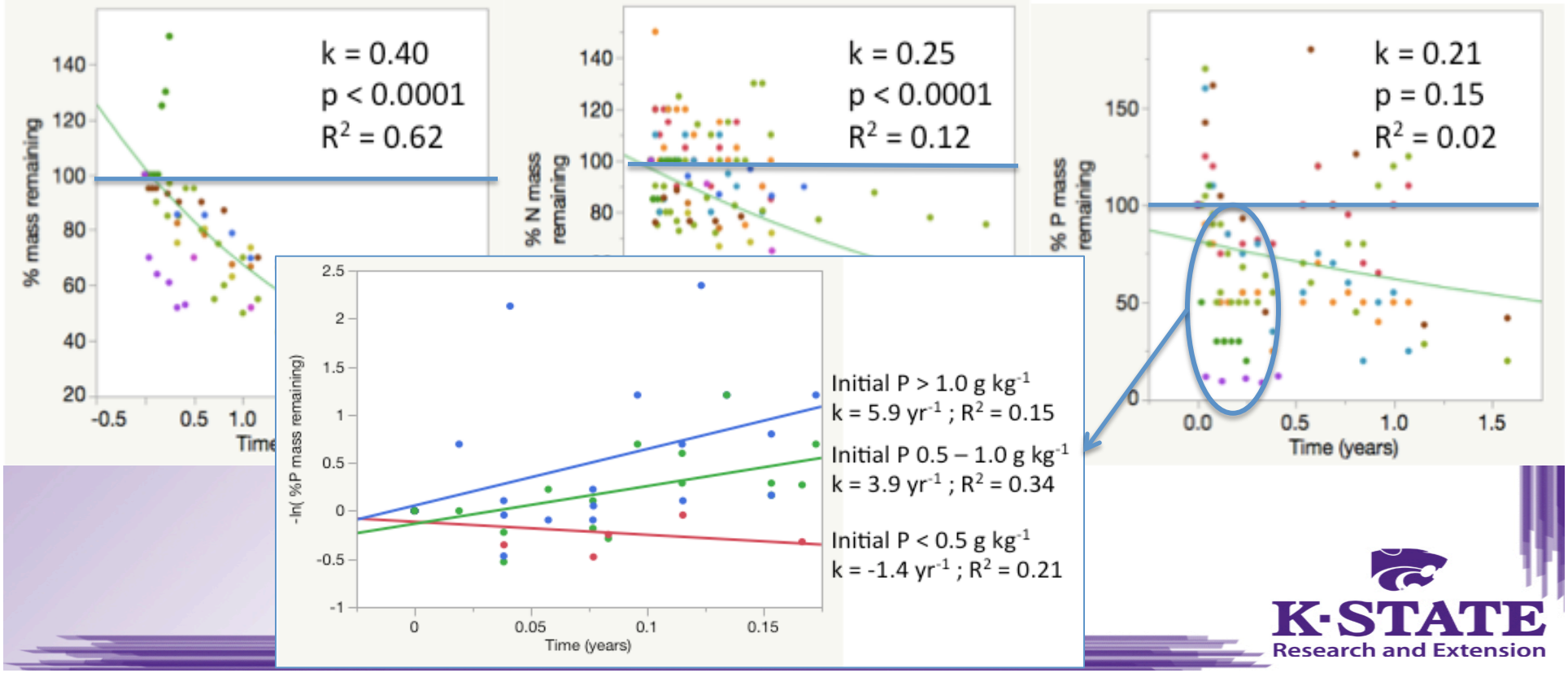
Insight 2: Tree litter tends to leach P over short time frames; N dynamics complicated



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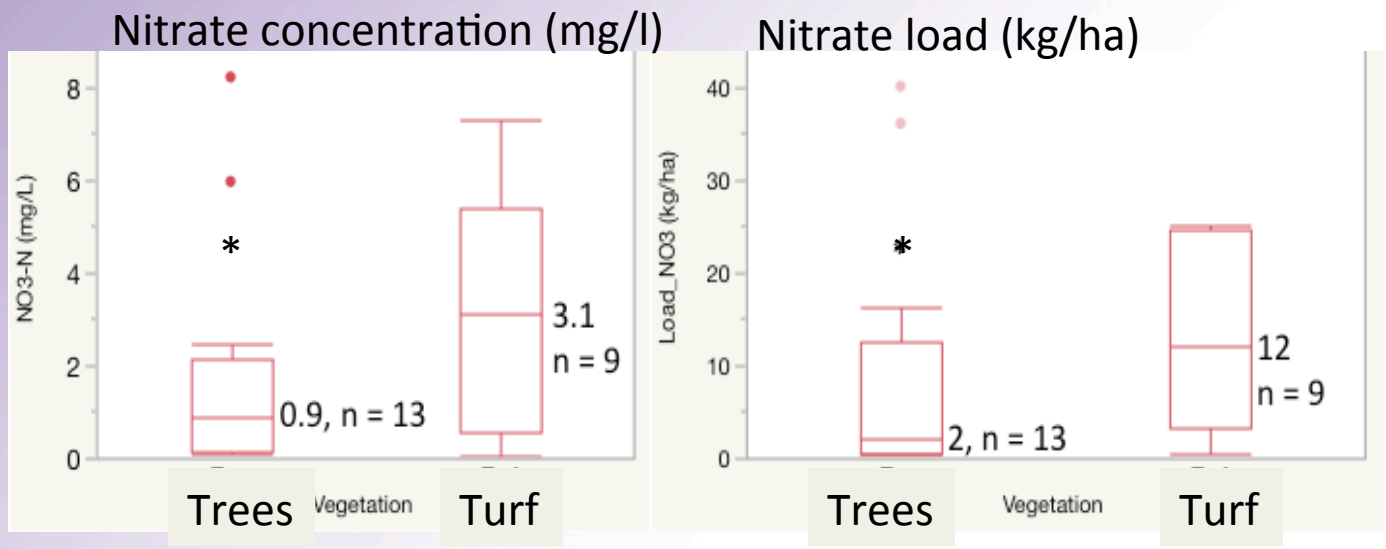
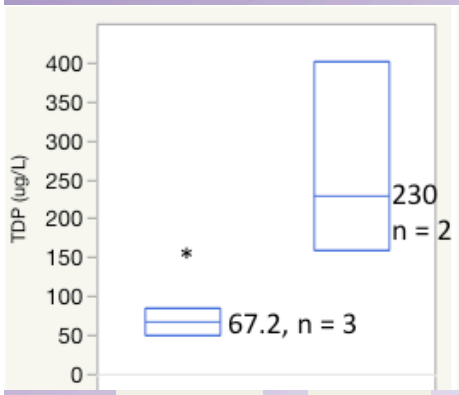
Insight 3: Trees *appear* to control subsurface nutrient losses better than turfgrass

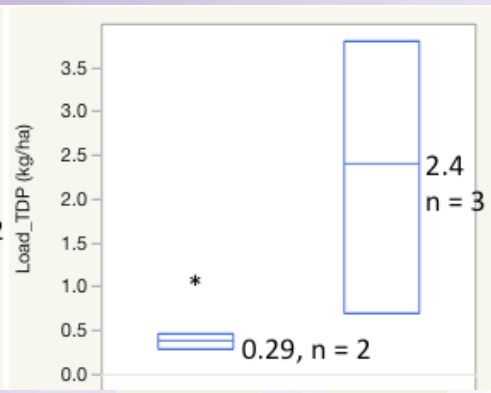


Insight 3: Trees *appear* to control subsurface nutrient losses better than turfgrass

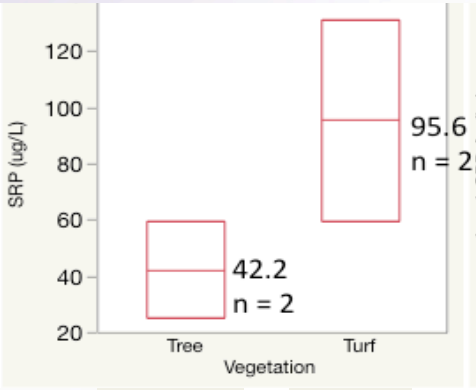
TDP concentration (ug/l)



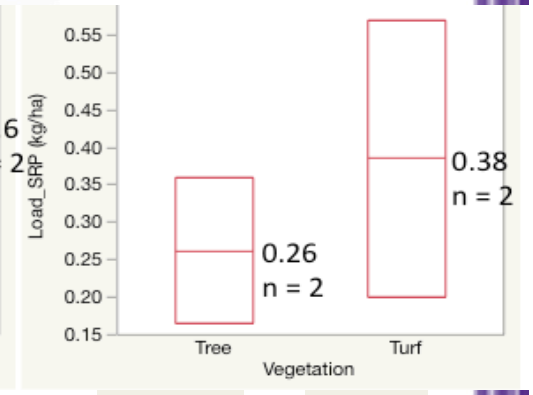
TDP load (kg/ha)



SRP concentration (ug/l)



SRP load (kg/ha)



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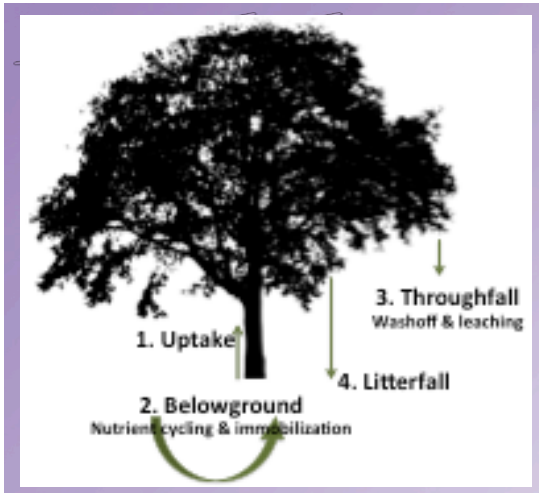
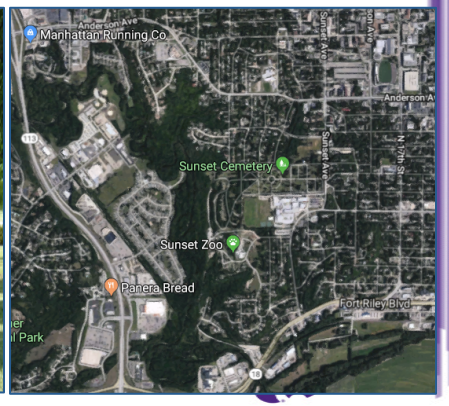


Insight 4: Ultimate effect on stormwater quality probably depends on landscape context; litter management important in case of street trees



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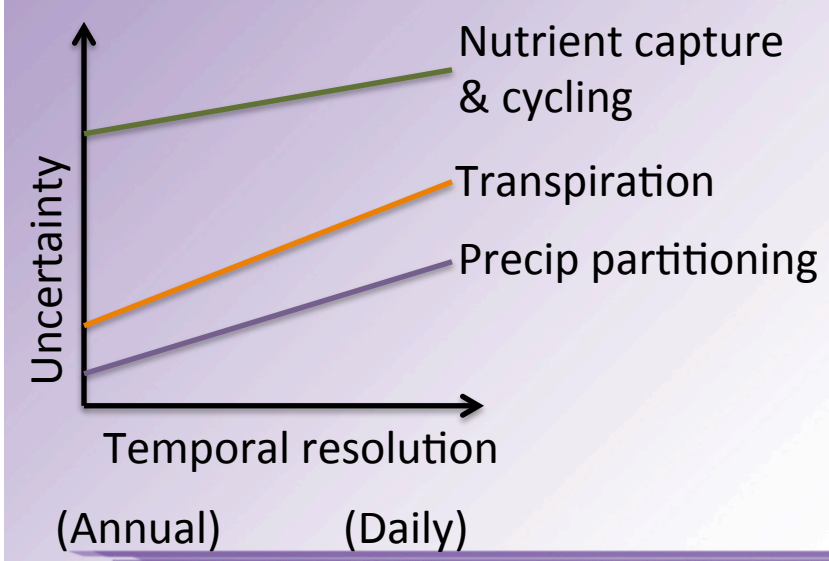
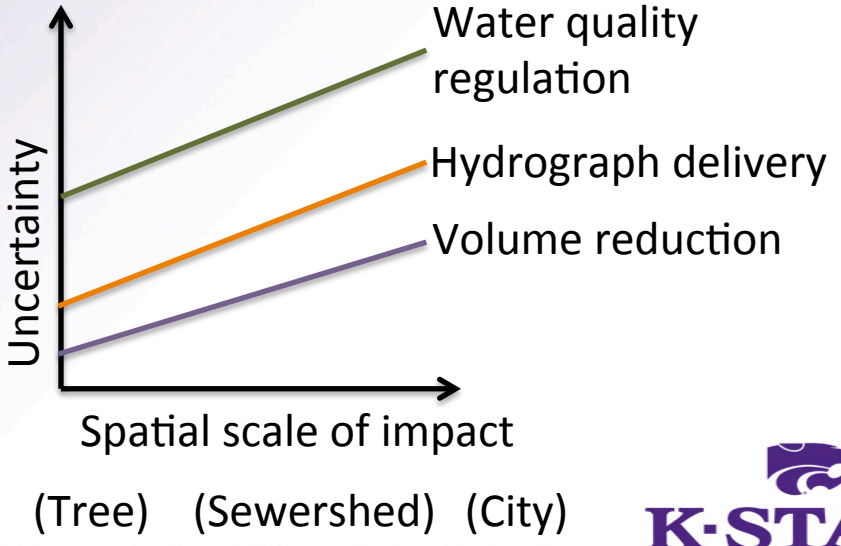
Summary: What we know…and what we'd like to know more about

Poll: What would you like to know more about?

Processes



Stormwater regulating services



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Take home points

- Key outcomes of this study
  - "simple" predictive equations for rainfall capture (or throughfall) and transpiration
  - Foundation for future work to continue to improve quantification method
- Follow WRF for upcoming release of project report, products and webinar

Questions? tlcmoore@ksu.edu

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Bonus slides

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Poll: in your context, which time scale is most useful to predict? (a) Annual, (e) Event or both?

- Average daily VPD
- Average daily solar radiation

17.5617.56 17.56

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