Why Tree Canopy Land Uses in Phase 6?

- Since 2003, it has been the policy of the Chesapeake Bay Program partners to increase urban tree canopy cover for water quality and other benefits
  - Reaffirmed and strengthened in the 2014 Chesapeake Bay Agreement Tree Canopy Outcome

- Urban tree canopy benefits are not directly accounted for in the CB Model land uses
  - Implication: Retaining tree canopy has no “value” in the TMDL framework, whereas Forest, Open Space, and other preferred land uses do

Tree Canopy LU/Loading Rate Review Timeline

- **February 11** – Webinar, comments due 2/22
- Brief workgroups and seek their approval of Tree Canopy Land Uses/Loading rates where needed
  - **March 2**: Forestry Workgroup
  - **March 2**: Land Use Workgroup
  - **March 3**: Watershed Technical Workgroup
  - **March 8**: Urban Stormwater Workgroup
  - **March 10**: Modeling Workgroup
  - **March 14**: Water Quality Goal Implementation Team
- **Goal to include Tree Canopy land uses/loading rates in April 1 beta calibration**
- Expert Panel report on Tree Canopy BMP for new plantings – partnership review starting in April

Relative Non-Point Source Pollution Loading Rates of Tree Canopy Land Uses

Justin Hynicka[1] and Marion Divers[2]

1 – Maryland Department of Natural Resources – Forest Service

2 – University of Pittsburgh – Department of Geology and Environmental Science

This analysis builds on work by the Tree Canopy EP

- Expands the scope of the previous Tree Canopy Expert Panel Technical Memo beyond canopy interception to include ecosystem level processes
- This analysis draws from an expanded literature review on urban tree planting and canopy (Karen Cappiella, Center for Watershed Protection)
- **Incorporates feedback from webinar on 02/11/16**
- Use plant parameter values that represent average conditions across a range of tree species and sizes

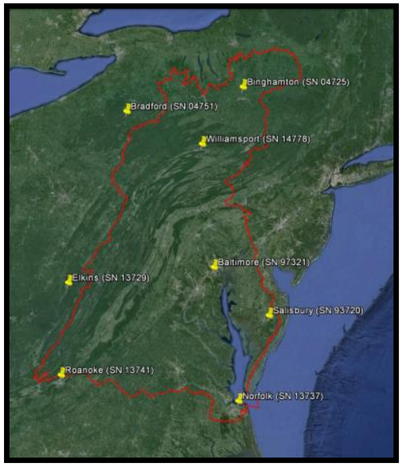
Why water balance, and what does it look like?

- Hydrologic processes govern the fate and transport of pollution to surface waters

- Water balance is a mathematical framework that accounts for all additions and losses of water from a drainage area

Tree canopy over turfgrass

NCDC Quality Controlled Daily Local Climatological Data (2005 to 2015)



Tree canopy over turfgrass

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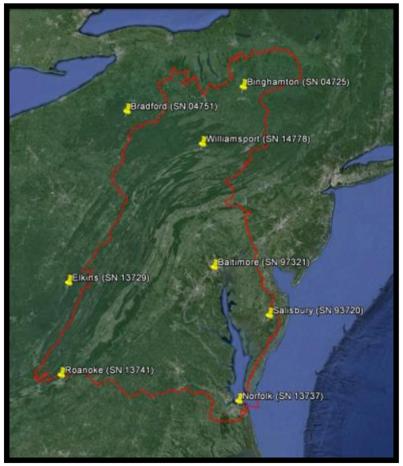
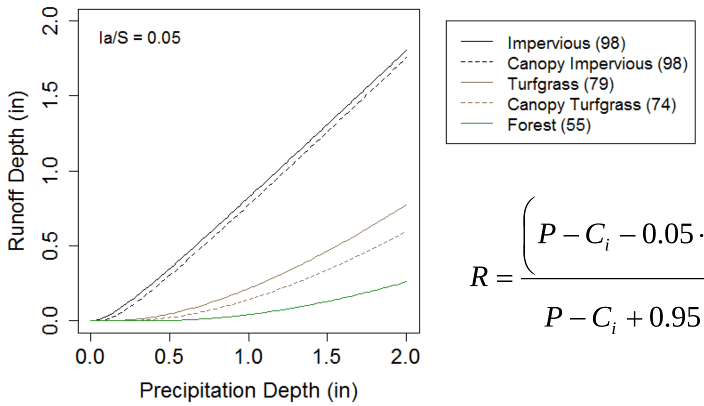


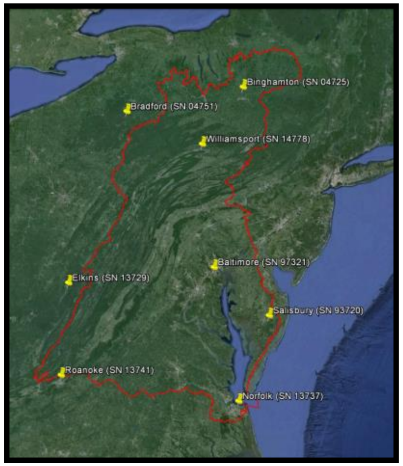
Calculate stormwater runoff using the SCS Curve Number Method



$$R = \frac{\left(P - C_i - 0.05 \cdot \left(\frac{1000}{CN} - 10\right)\right)^2}{P - C_i + 0.95 \cdot \left(\frac{1000}{CN} - 10\right)}$$

Tree canopy over turfgrass

NCDC Quality Controlled Daily Local Climatological Data (2005 to 2015)



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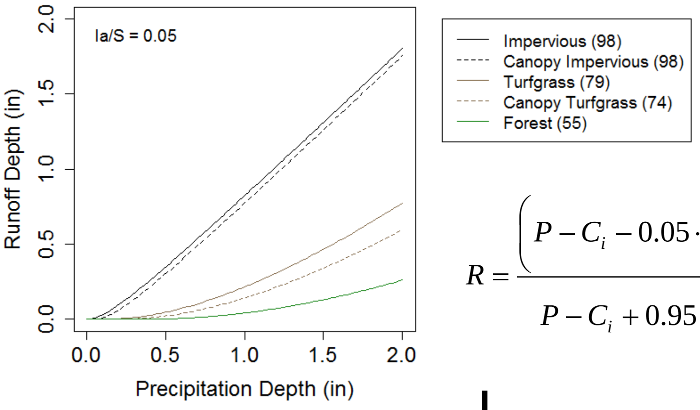

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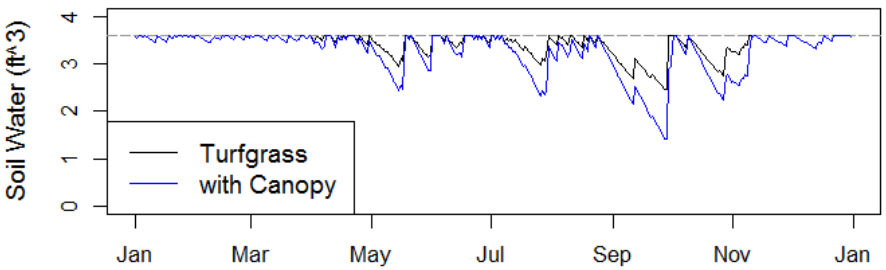
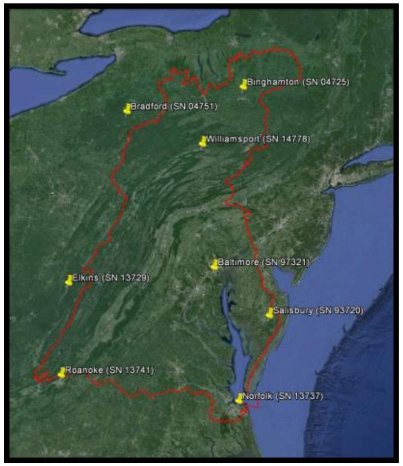
Calculate leaching by tracking changes in soil water due to infiltration and evapotranspiration

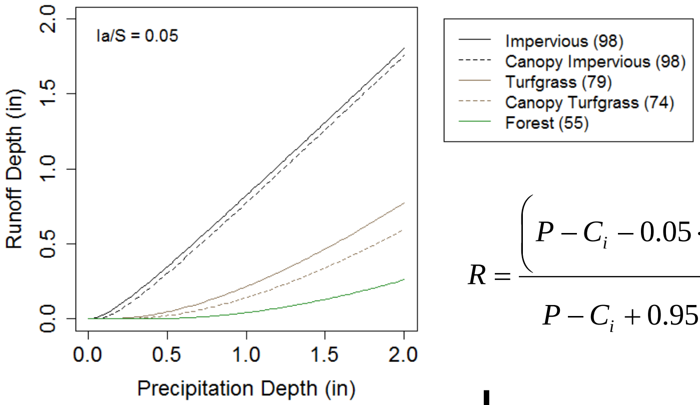


Tree canopy over turfgrass

NCDC Quality Controlled
Daily Local Climatological
Data (2005 to 2015)

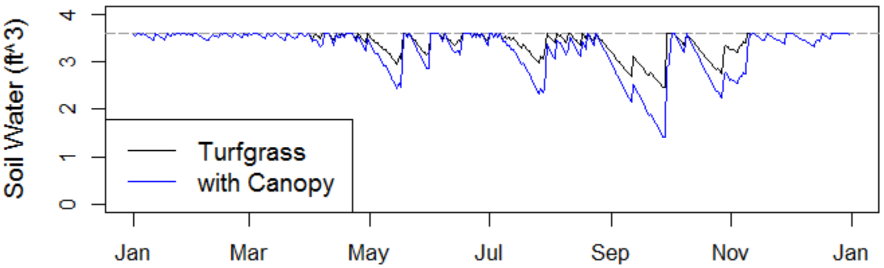


Calculate stormwater runoff using the
SCS Curve Number Method



$$R = \frac{\left(P - C_i - 0.05 \cdot \left(\frac{1000}{CN} - 10\right)\right)^2}{P - C_i + 0.95 \cdot \left(\frac{1000}{CN} - 10\right)}$$

Calculate leaching by tracking changes in soil water
due to infiltration and evapotranspiration



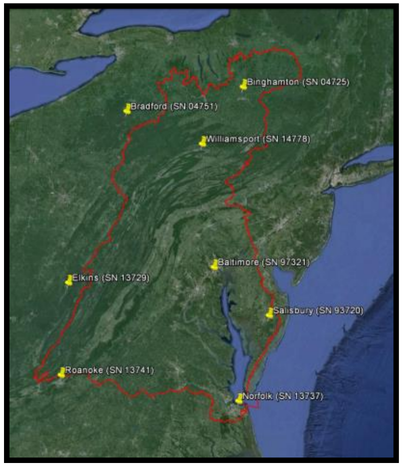
Calculate relative reduction
in water yield

$$\frac{J_{gc}}{J_g} = \left(1 - \frac{\sum R_{gc} + \sum L_{gc}}{\sum R_g + \sum L_g}\right) \times 100$$

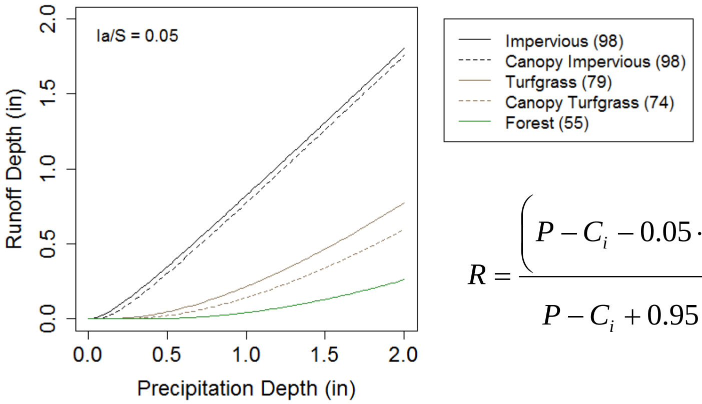
Tree canopy over impervious surfaces

Tree canopy over impervious surfaces

NCDC Quality Controlled Daily Local Climatological Data (2005 to 2015)



Calculate stormwater runoff (R) using the SCS Curve Number Method



$$R = \frac{\left(P - C_i - 0.05 \cdot \left(\frac{1000}{CN} - 10\right)\right)^2}{P - C_i + 0.95 \cdot \left(\frac{1000}{CN} - 10\right)}$$

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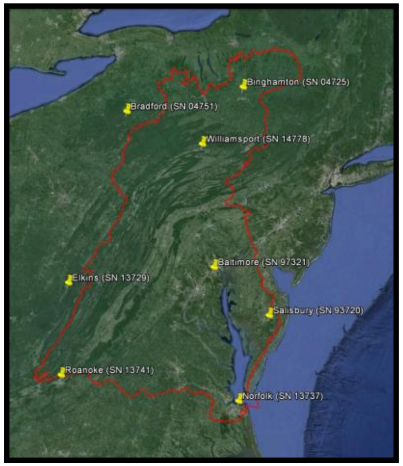
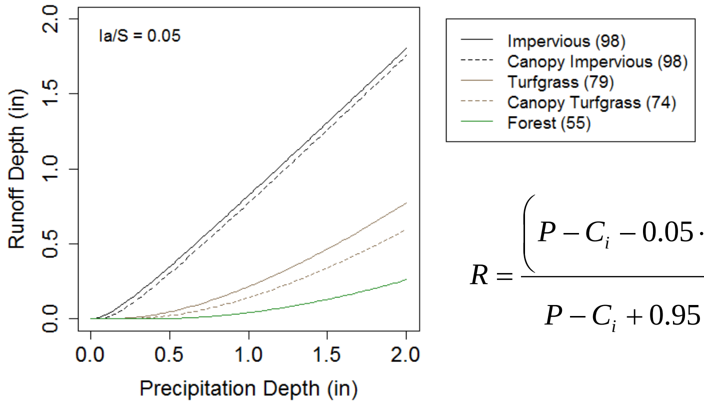


→ Calculate stormwater runoff (R) using the SCS Curve Number Method



$$R = \frac{\left(P - C_i - 0.05 \cdot \left(\frac{1000}{CN} - 10\right)\right)^2}{P - C_i + 0.95 \cdot \left(\frac{1000}{CN} - 10\right)}$$

Calculate change in throughflow (T) due to evapotranspiration

← Calculate relative reduction in water yield

$$\frac{J_{ic}}{J_i} = \left(1 - \frac{\sum R_{ic} + \sum T_{ic}}{\sum R_i + \sum T_i}\right) \times 100$$

Updated results: relative reductions in water yield

Land Use	Precip. (in)	Runoff Red. (%)	Leaching Red. (%)	Throughflow Red. (%)	Total (%)
Canopy over Turfgrass	39.9	29.0	22.5	NA	23.8
Canopy over Impervious	39.9	7.0	NA	22.3	14.9

Updated results: relative reductions in water yield

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Hydrologic processes govern the fate and transport of pollution

- Absolute loading rates for TC land uses are limited by the low availability of concentration data

$$J_{gc} = \overline{X}_1 \cdot \sum R_{gc} + \overline{X}_2 \cdot \sum L_{gc}$$

Hydrologic processes govern the fate and transport of pollution

- Absolute loading rates for TC land uses are limited by the low availability of concentration data

$$\frac{J_{gc}}{J_g} = \frac{\overline{X}_1 \cdot \sum R_{gc} + \overline{X}_2 \cdot \sum L_{gc}}{\overline{X}_3 \cdot \sum R_g + \overline{X}_4 \cdot \sum L_g}$$

- For a long-term practice in complex watersheds modeling is the best approach to estimate relative reductions in pollutant loads

- If trees reduce edge of field pollution loads then where does the mitigated pollution go?

Trees promote pollution storage and removal in pervious areas

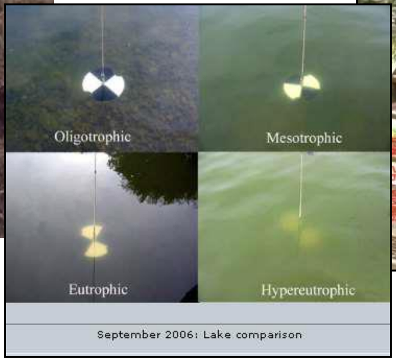
- N and P are essential nutrients that are taken up through roots and stored in plant tissues
- Trees increase infiltration rates that leads to greater filtration/capture of nutrients and sediments (Bartens 2008, Busman 2002, Day 2010, Leguedois 2008)
- Increased soil moisture and soil organic matter from trees enhances the conditions required for denitrification (Day 2010, Gift 2010, Huyler 2014, Lovett 2002, Takahashi 2008, Zhu 2004)

Impervious surfaces limit EOF water quality benefits of trees

- New N and P inputs of have little chance to enter the nutrient cycle

- Our estimate of throughflow is poorly constrained, and a large portion of pollution taken up by trees with canopy over impervious is later deposited on that impervious surface.

- Relative reductions in N & P loads (7%) were based solely on downstream benefits of reduced runoff (Asadian 2009, Nowak 2007, Wang 2008)



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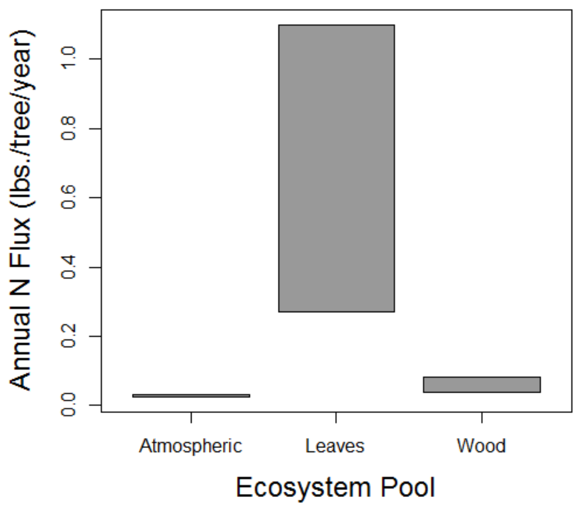
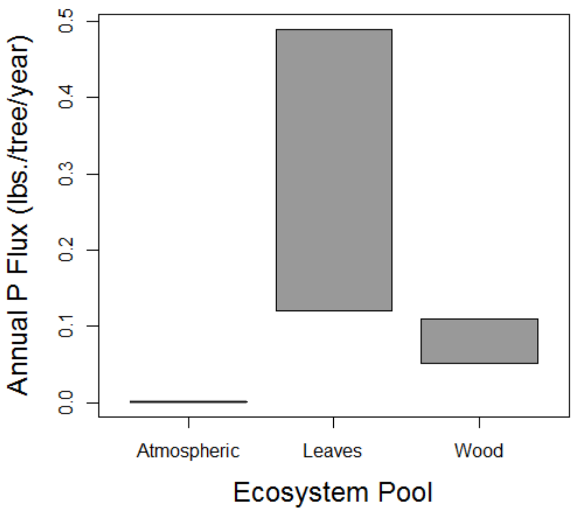
- New N and P inputs of have little chance to enter the nutrient cycle
- Our estimate of throughflow is poorly constrained, and a large portion of pollution taken up by trees with canopy over impervious is later deposited on that impervious surface.
- Relative reductions in N & P loads (7%) were based solely on downstream benefits of reduced runoff (Asadian 2009, Nowak 2007, Wang 2008)
- **However, N and P in wood is a long term store of water quality pollution**

Estimated N and P stores annually in wood





- Proportion of annual N and P stored in wood ~ 5 and 14 %, respectively
- Assumed uptake efficiency based on the proportion of time that deciduous trees transpire water 7/12 months x 1/2 hours/day = 0.29
- References: Abelho 2001, Chapin 2011, Martin 1998, McGroddy 2004, NADP, Nowak 2002, Olsen 1963, Petterson 1984, Rastetter 1991, and Smullen 1982

Final relative reduction in pollution loads for TC land uses

Land Use	Total N Reduction (%)	Total P Reduction (%)	Sediment Reduction (%)
Canopy over Turfgrass	23.8	23.8	4.5
Canopy over Impervious	7.0 + 1.5	7.0 + 4.0	7.0

Final relative reduction in pollution loads for TC land uses

Land Use	Total N Reduction (%)	Total P Reduction (%)	Sediment Reduction (%)
Canopy over Turfgrass	23.8	23.8	4.5
Canopy over Impervious	8.5	11.0	7.0

Relative reduction from 2/11/16 webinar

Land Use	Pollution Reduction (%)
Canopy over Turfgrass	26.0
Canopy over Impervious	7.1

Final relative reduction in pollution loads for TC land uses

Land Use	Total N Reduction (%)	Total P Reduction (%)	Sediment Reduction (%)
Canopy over Turfgrass	23.8	23.8	4.5
Canopy over Impervious	8.5	11.0	7.0

Supplemental Slides

Runoff calculated using the SCS Curve Number Method

- Developed by the USDA Soil Conservation Service (TR-55, 1986)

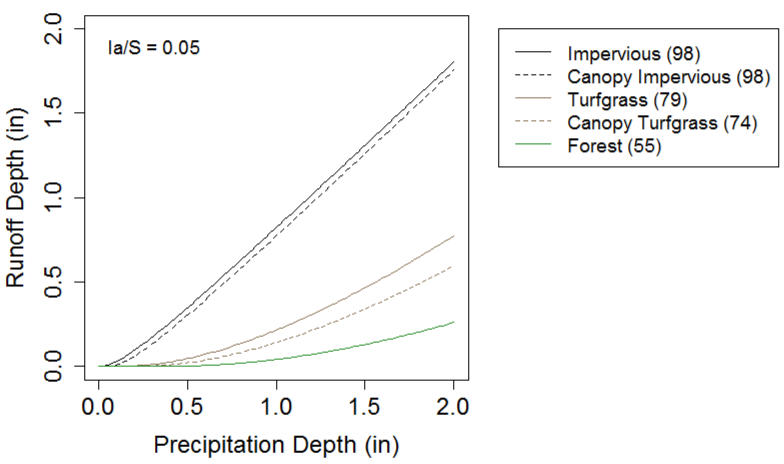
- Added a term to account for tree canopy interception (C_i), which isolates the effects of tree canopy from the water retaining properties of the underlying land use.

- C_i ranges from 0.02 to 0.11 inches of precipitation per storm for deciduous tree species, and 0.02 to 0.18 in. per storm for coniferous trees (Breuer et al. 2003).

- We used a fixed C_i value of 0.05 in. in our calculations during the growing season (April through October).

- **C_i set to zero in the winter.**

$$R = \frac{(P - C_i - I_a)^2}{(P - C_i - I_a) + S}$$



Modified CN assumptions to better reflect runoff at small scales

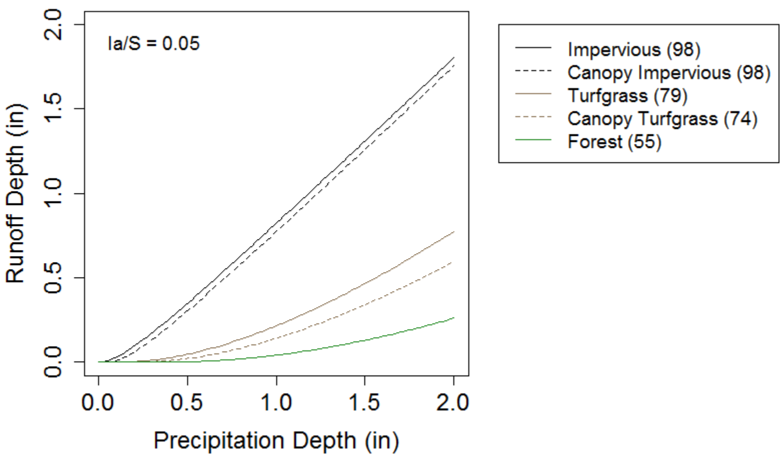
- Observations at that the watershed scale during CN method development revealed that $I_a/S \sim 0.2$ (Garen and Moore 2005)

- More recent work has revealed that this simplification underestimates runoff of small storm events especially at smaller scales (Woodward et al. 2003)

- $I_a/S \sim 0.05$ is more appropriate for evaluating the role of tree canopy in runoff calculations (Woodward et al. 2003)

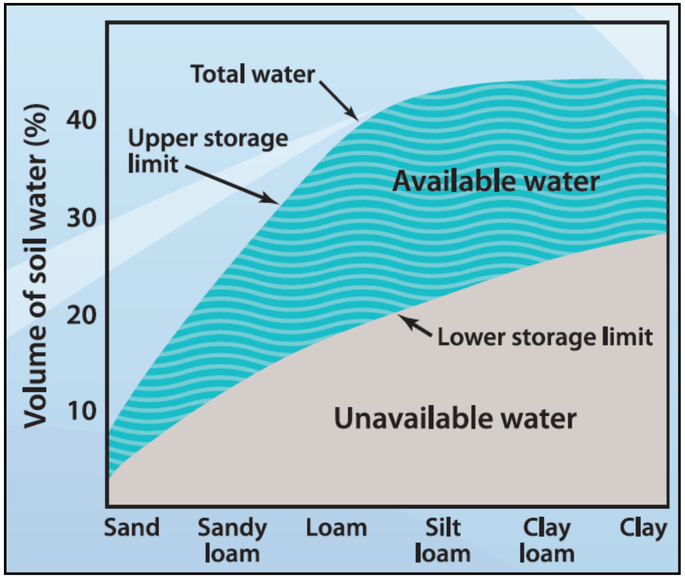
- In addition, soils from hydrologic soil group C (rather than D) are likely more representative conditions in the urban environment.

$$R = \frac{(P - C_i - I_a)^2}{(P - C_i - I_a) + S}$$



Leaching calculated by tracking changes in soil water volume

- Leaching is water that infiltrates in excess of the soil water holding capacity, which varies by soil type and over time due to plant evapotranspiration (ET).
- Calculations based on silt clay loam soils with a maximum water holding capacity of 2.0 inches per foot of soil (Brady and Weil 1996)



(http://soilquality.org.au/factsheets/water-availability)

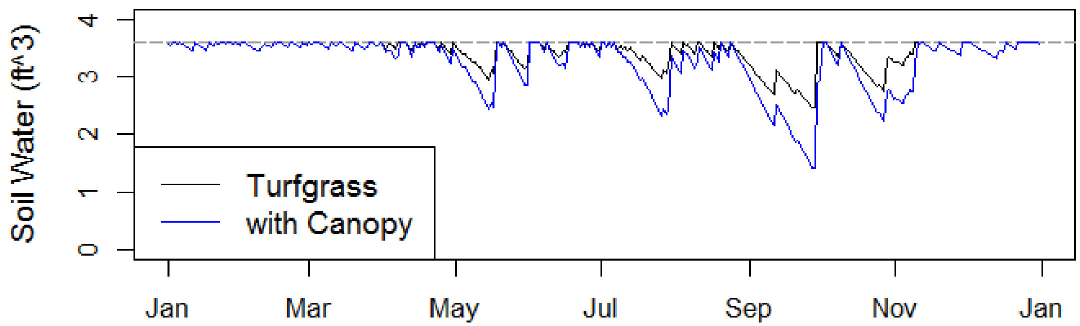
Leaching calculated by tracking changes in soil water volume

- Leaching is water that infiltrates in excess of the soil water holding capacity, which varies by soil type and over time due to plant evapotranspiration (ET).

- Average annual ET is similar between grasses, natural forests, and urban trees ranging from ~15 to 24 in yr^{-1} (Ford 2011, Penmen 1948, Wullschleger 2001, Wullschleger 2000, Wilson 2001, and Peters 2010)

- ET during growing was set at 0.05 and 0.08 inches per day for turfgrass and canopy over turfgrass, respectively

- **During the dormant season these land uses are equivalent**



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Throughflow provides a source of water and nutrients to trees

- Average daily throughflow was estimated using the volume of water leached annually from a square meter of turfgrass and redistributing it evenly over the course of a year.

- ET of trees during growing season set to 0.05 inches per day (Ford 2011, Wullschleger 2001, Wullschleger 2000, Wilson 2001, and Peters 2010)