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

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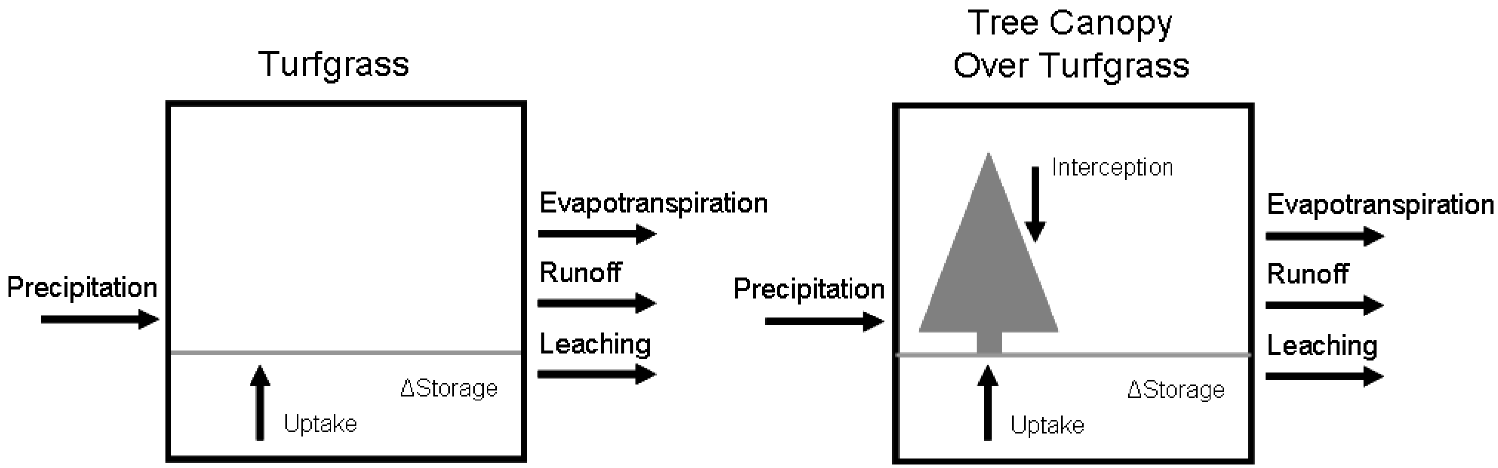
Why water balance, and what does it look like?

- Regardless of the source, nutrients and sediment are transported by water to streams, rivers, estuaries, and beyond.



Runoff calculated using the SCS Curve Number Method

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

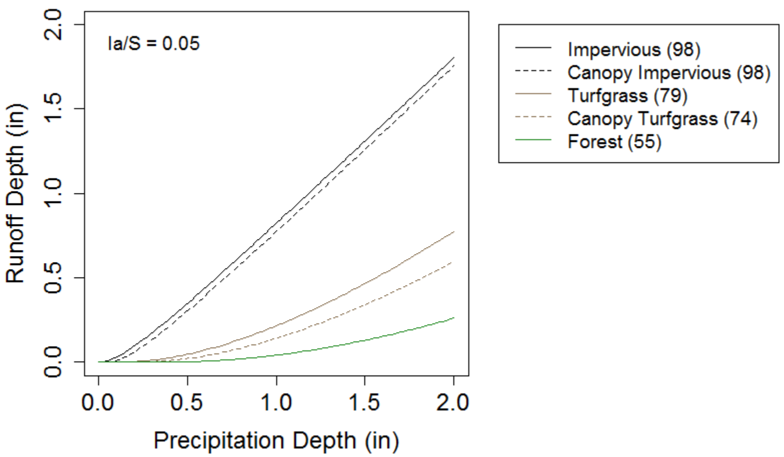
- Added a term to account for tree canopy interception (C_i), which isolates the effects of tree canopy from the water retaining properties of the underlying land use.

- 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

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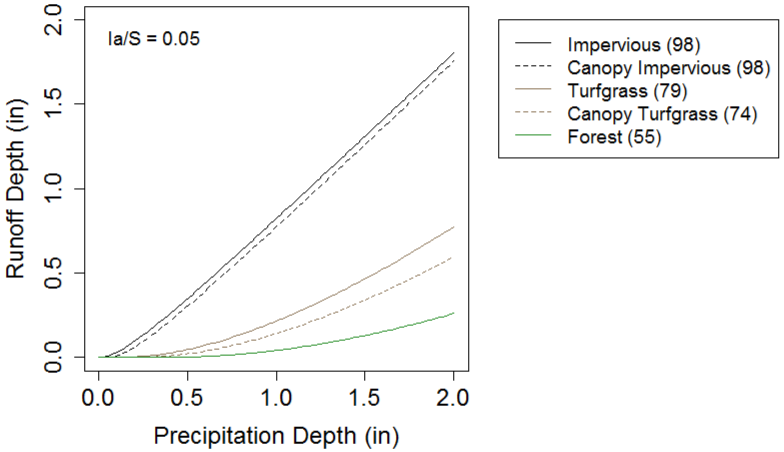

Modified CN assumptions to better reflect runoff at small scales

- 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.

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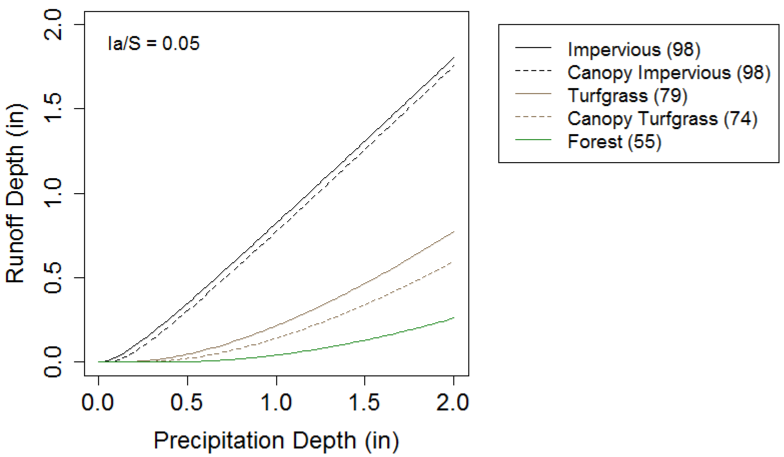
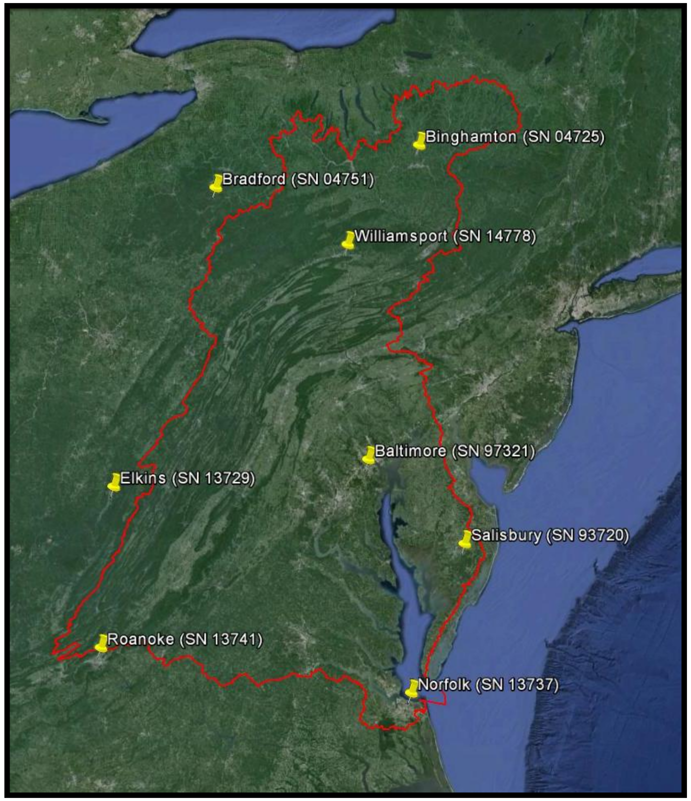
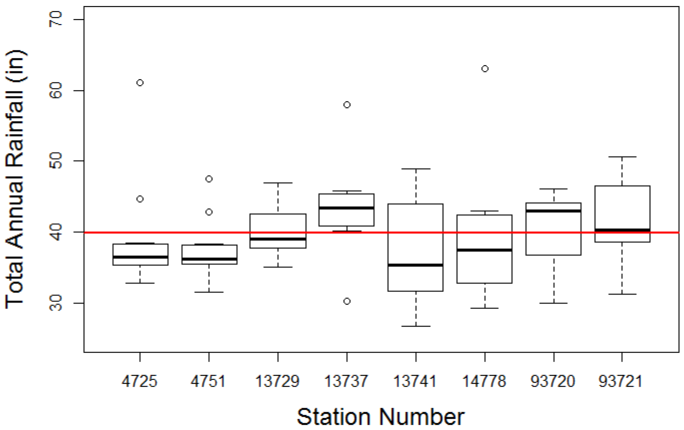


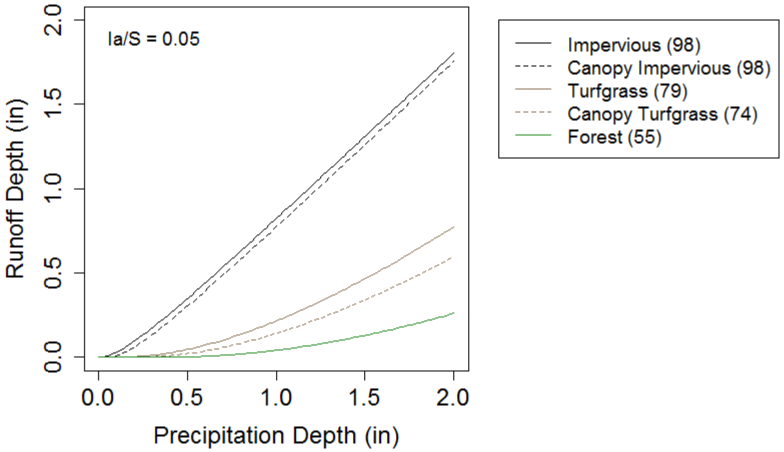
We used daily weather data (2005 to 2015) from eight locations



Chesapeake Bay Watershed Boundary

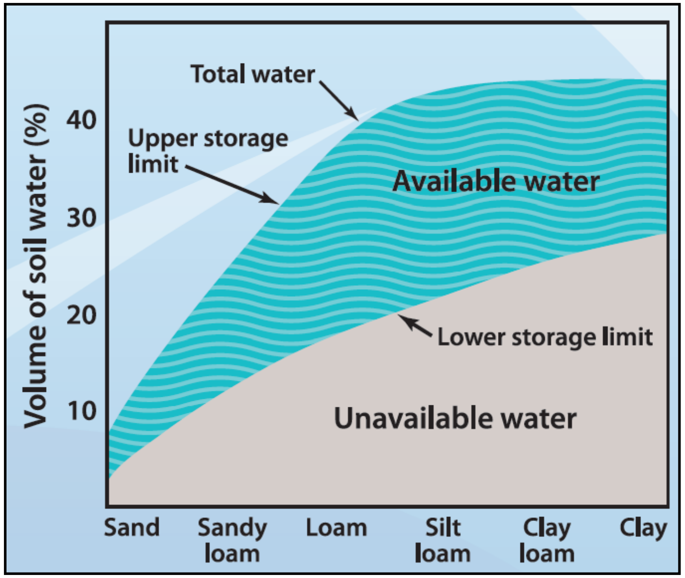


(NCDC Quality Controlled Local Climatological Data)



Leaching calculated by tracking changes in soil water volume

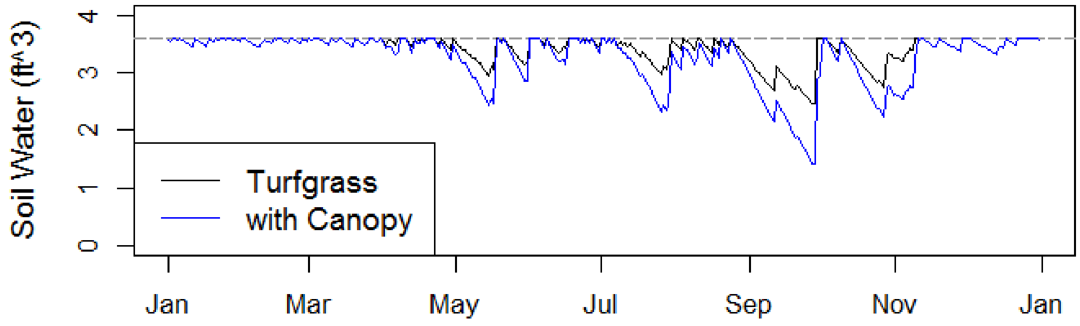
- Leaching is water that infiltrates in excess of the soil water holding capacity, which varies by soil type and over time due to plant evapotranspiration (ET).
- Calculations based on silt clay loam soils with a maximum water holding capacity of 2.0 inches per foot of soil (Brady and Weil 1996)



(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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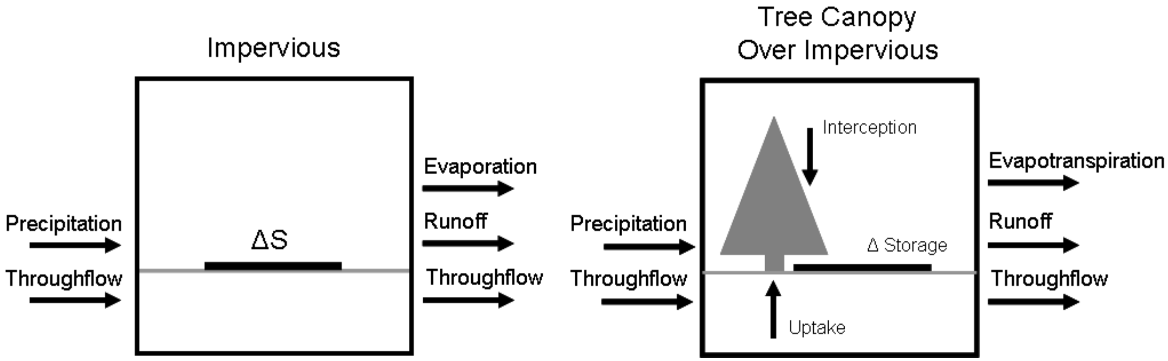
Throughflow provides a source of water and nutrients to trees

- 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)



Updated water yield results

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

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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

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

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

- For a long-term practice in complex watersheds modeling is the best approach to estimate relative loading rates among land classes

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

Trees promote pollution storage and removal in pervious areas

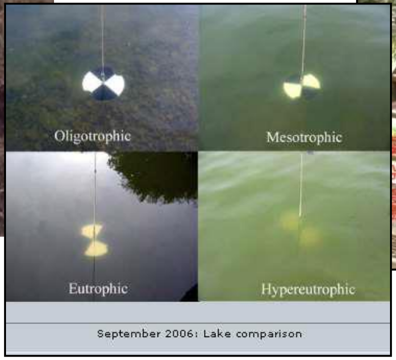
- N and P are essential nutrients that are taken up through roots and stored in plant tissues
- Trees increase infiltration rates that leads to greater filtration/capture of nutrients and sediments (Bartens 2008, Busman 2002, Day 2010, Leguedois 2008)
- Increased soil moisture and soil organic matter 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 returned to that surface.

- Recommended relative loading rate of 7.1% for N, P, and sediment was based solely on downstream benefits of reduced runoff (Asadian 2009, Nowak 2007, Wang 2008)



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- Our estimate of throughflow is poorly constrained, and a large portion of pollution taken up by trees with canopy over impervious is later returned to that surface.
- Recommended relative loading rate of 7% for N, P, and sediment was 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**

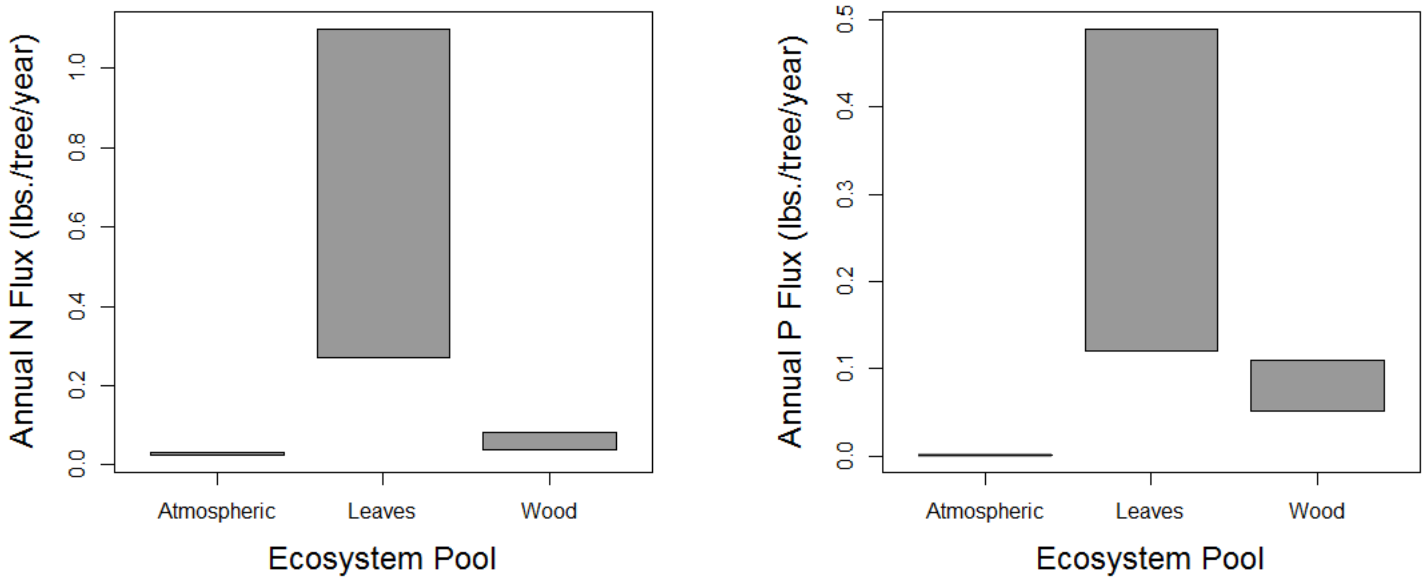
Estimating N and P stored in woody biomass

- We used estimates of annual wood production (Nowak and Crane 2002), annual leaf litter production (Abelho 2001, Chapin 2011, Martin 1998, and Olsen 1963), and annual fluxes of N and P deposition (NADP, and Smullen 1982)

- Combined fluxes with nutrient concentration data (Martin 1998, McGroddy 2004, Petterson 1984, Rastetter 1991)

- **What proportion of N and P stored in wood relative to total nutrient uptake (wood + leaf production) and new inputs of atmospheric deposition?**

Estimating N and P stored in woody biomass



- Proportion of annual N and P stored in wood ~ 5 and 14 %, respectively
- We still need to make an assumption about uptake efficiency to make results comparable to water yield results.
- Assumed uptake efficiency based on the proportion of time that deciduous trees transpire water 7/12 months x 1/2 hours/day = 0.29

Final estimated relative loading rates 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 estimated relative loading rates 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 loading rates from 2/15/16 webinar

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

TN Relative Loading Rate TC over Imp Taken From Roads (90%) & Buildings (10%)

Land Use	Original	Adjusted
Tree Canopy over Turfgrass	-	0.37
Turf Grass	0.48	0.50
Tree Canopy over Impervious	-	0.93
Roads	1.00	1.02
Buildings and Other	0.79	0.81
Construction	1.19	1.19

TP Relative Loading Rate
TC over Imp Taken From
Roads (90%) & Buildings (10%)

Land Use	Original	Adjusted
Tree Canopy over Turfgrass	-	0.77
Turf Grass	1.00	1.04
Tree Canopy over Impervious	-	0.95
Roads	1.00	1.04
Buildings and Other	0.79	0.83
Construction	3.89	3.89

Final estimated relative loading rates 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