Water relations of trees growing in Green Infrastructure (GI) storm water trenches

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OLD-GROWTH FOREST
Most of the original trees had been cut down by the beginning of the 20th century.

FORESTED LAND, 2006
Forests have since reclaimed abandoned farms and filled in around suburban development.

SOURCES: USGS, US Forestry Service
A Survey of the City of Philadelphia

and its Environs showing the several Works conducted by His Majesty's Troops under the Command of Sir William Howe, from their possession of that City 26th September 1777, comprehending likewise the Attack upon Fort Mifflin on 30th April, and until its Reduction.

30th November 1777

To the Hon. S. William Howe, K.B.

Ober-Generalfeld-Marshal and Commander in Chief of His Majesty's Forces, within His Majesty's Dominions in America.

Presented by His Majesty's Surveyor, John Cadwalder, Esq.

New York: Printed by John Smith, 1778.
A conjectural sketch of the whole city of Philadelphia about the year 1707. Dock Creek may plainly be seen, with its pond at Fourth and High Streets, and its dock and mouth in the left foreground; also the high river banks in which the first settlers dug their caves. About the left half of this picture shows what developed into the Independence Square Neighborhood. From a print at the Historical Society of Pennsylvania.
An 1840 bird's eye view of the Delaware River and Philadelphia, looking downstream from present-day Center City. Market Street is the large street.
Impervious surface!
The fate of precipitation

TYPES OF SEWERS IN PHILADELPHIA

60%

http://www.beachapedia.org/File:Cso-ss0-524.jpg

40%

http://www.beachapedia.org/File:Cso-ss0-524.jpg
• Serving more than three-quarters of the city's residents, the combined sewer system is in the oldest and densest parts of the city,
  – Center City, South Philadelphia, West Philadelphia, North Philadelphia, Bridesburg/Kensington/Richmond, East Mt. Airy and East Germantown, parts of near Northeast
• 164 combined sewer outfalls (CSOs) along the Delaware and Schuylkill rivers and the Cobbs, Tookany/Tacony-Frankford, and lower Pennypack creeks.
experiment 1
• Tree pit with stormwater trench
T-55, T-57, T-59: *Platanus x acerifolia* ‘Bloodgood’ (London plane)

T-56, T-58: *Acer rubrum* ‘Armstrong’ (red maple)
water relations of trees in GI tree trench systems

• Experiment 1: 5 trees/ 2 species in a single GI tree trench
  – Stomatal conductance
  – Leaf water potential
  – LAI

• Experiment 2: 25 trees of 13 different species/cultivars in multiple GI tree trenches and tree pits
  – Stomatal conductance
Experiment 1:
Water relations of *Acer rubra* 'Armstrong' and *Platanus × acerifolia* 'Bloodgood' trees in a GI tree trench system

1. Assess the rate of water movement out of tree trench systems via stomatal conductance
2. Evaluate plant moisture stress of different tree species
Stomatal conductance - $g_s$

leaf porometer model SC-1 (Decagon Devices, Pullman, WA).
Stomatal conductance - $g_s$

- $g_s$ is a function of:
  - Plant and stomatal characteristics (density, size, and degree of opening)
  - Environmental factors (solar radiation, wind speed/humidity/boundary layer, precipitation/water availability)
Steady-state porometer

The leaf porometer measures stomatal conductance by putting the conductance of a leaf in series with two known conductance elements, and comparing the humidity measurements between them.

Measures mmol/m²s (millimoles per meter squared per second)
Measurements of $g_s$

• From late May to early November ~daily measurements
• Taken during the period of peak irradiance, from 11:45 a.m. to 2:45 p.m.
• Three different leaves that were fully exposed to direct sunlight were sampled
Weekly stomatal conductance rates for *Acer rubra* 'Armstrong' and *Platanus x acerifolia* 'Bloodgood'

Average conductance dropped during mid-summer months for *A. rubrum* while *P. x acerifolia* showed more stability.
Total average stomatal conductance

A Kruskal-Wallis test (one-way ANOVA on ranks) was performed followed by a post hoc Dunn test. The test shows a significant difference between species but not within species with the exception of T-55.

T-55, a *P. x acerifolia*, shows significant difference from all other trees.

<table>
<thead>
<tr>
<th>Sample</th>
<th>T-55</th>
<th>T-56</th>
<th>T-57</th>
<th>T-58</th>
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<tbody>
<tr>
<td>T-55</td>
<td></td>
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<td>T-56</td>
<td>7.538204</td>
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<tr>
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<td>3.649419</td>
<td>-3.879578</td>
<td>0.0001*</td>
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<td>T-58</td>
<td>9.105290</td>
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<tr>
<td>T-59</td>
<td>2.492492</td>
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<td>-1.148662</td>
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</tr>
</tbody>
</table>

Results of Dunn’s Test (Benjamini-Hochberg method) *Indicates significant difference among samples. Upper number signifies Dunn’s pairwise z test statistic
Leaf water potential \( (Ψ)_{lf} \)

- Model 615 Pressure Chamber Instrument
- Pressure chamber or “pressure bomb”
  (PMS Instrument Company, Albany, OR)
Plant moisture stress (PMS), or plant water potential, indicates the demand for water within a plant.

A low pressure (e.g. 3 bar or 45 psi) is sufficient to force water to the cut surface of the sample, the plant is under relatively low moisture stress (high water potential) and probably has sufficient water for its growth process.

If 20 bar pressure is required to force water to the cut surface, the moisture stress is relatively high (low water potential).

http://www.pmsinstrument.com/resources/pms-meaning-and-importance
Weekly leaf water potential readings dropped drastically during mid-summer months for *Acer rubra* 'Armstrong' while *Platanus x acerifolia* 'Bloodgood' showed more stability during those months, despite having lower readings as well.
A Kruskal-Wallis test showed significant difference between ranked data ($P = 1.777e-05$)

The post-hoc Dunn’s test showed a significant difference in leaf water potential between species but not within species.

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<th>T-58</th>
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</tr>
</tbody>
</table>

Results of Dunn’s Test (Benjamini-Hochberg method)

*Indicates significant difference among samples. Upper number signifies Dunn’s pairwise z test statistic
Regression analyses of $\Psi_{lf}$ and leaf temperature
Experiment 1 conclusions

• In general, through the entire growing season, *P. × acerifolia* had greater stomatal conductance and lower susceptibility to water stress than *A. rubrum* ‘Armstrong’.
• These results suggest *P. × acerifolia* performs more successfully in these systems when compared to *A. rubrum*.
• These results are likely due to inherent differences in the species’ physiological traits that affect water relations and may be influenced by other environmental factors that influence plant health (disease and insect pressure)
Experiment 2

• 25 trees of 13 different species/cultivars in multiple GI tree trenches and tree pits
  – Stomatal conductance

1. Assess the rate of water movement out of tree trench systems via stomatal conductance

2. Evaluate plant moisture stress of different tree species
~15 species of trees being evaluated for stomatal conductance rates

Examples: *Quercus rubra*; *Quercus robur*; *Cercis canadensis*; *Kolreuteria paniculata*; *Quercus macrocarpa*; *Syringa reticulata*
Species respond differently in periods of high and low precipitation.

Several species exhibited resilience to water deficit through sustained or increased stomatal conductance in the dry period.
Direct comparisons of Green Infrastructure (GI) storm water trenches and traditional street pits (non GI) between individual trees of same species. Shared letters within species indicate statistical insignificance.

On average, *K. paniculata* and *P. sargentii* conduct more water in GI storm water trenches whereas *Q. robur* interestingly conducted more water in a traditional street pit.
Non-parametric pairwise multiple comparisons (Dunn’s test) of the average stomatal conductance of individual trees over the research duration.

Dunn’s test revealed the stomatal conductance of many trees significantly differed through the year (Figure 1)
Experiment 2 conclusions

• In assessing 25 different trees, the mean ranks of conductance data by species were significantly different, suggesting some species may be better suited for use in urban GI trench trees than others.

• Two potential benefits of these species are
  – 1) they have higher overall levels of conductance resulting in greater water movement out of the system via evapotranspiration following rain events, and
  – 2) they may be less susceptible to water stress during periods of low precipitation.

• Pairwise comparisons revealed that Koelreuteria paniculata and Prunus sargentii trees conducted significantly more water on average within storm water trenches compared to traditional, isolated tree pits, whereas Quercus macrocarpa and Q. robur showed the opposite tendency.
Acknowledgements

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