Defining Stormwater Attenuation on a Green Roof

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What is a Green Roof?

- **Definition**
- **Types of Green Roof**

**Extensive Green Roof**

**Intensive Green Roof**

Extensive Green Roof on Slope

Gateway Technical College - Racine, WI

Extensive Green Roof
Typical Extensive Green Roof

Vegetative
Media
Drainage
Waterproof
Advantages of Green Roof

- Attenuate stormwater
- Air cleaning
- Improving water quality
- Mitigating urban heat-island effects
- Protection and life extension of the roof membrane
- Energy conservation
- Sound insulation
Stormwater Attenuation

- Stormwater attenuation is one of the biggest concerns particularly in the big cities.
- Many of the Best Management Practices (BMP) that have been developed to attenuate stormwater are either expensive or applicable.
- Green roofs have been shown to reduce the amount of stormwater runoff.
- Effect of ET on attenuation stormwater.
Evapotranspiration, ET

- Evaporation and plant Transpiration
  - Original Penman
  - Penman-Monteith
  - Wright-Penman
  - FAO Penman
  - Jensen-Haise
  - Blaney-Criddle
Goals, Objectives, and Hypotheses

Overall Goal:

- Measure evaporation and transpiration rates under controlled environmental conditions.
- Find the best ET model to describe CAM plants ET rates.
- Find CAM plant crop coefficient.
Objectives

- Measure ET
- Measure evaporation
- Measure the available environmental parameters
- Measure plant transpiration
- Repeat measuring ET and evaporation for several climatic conditions ranges
  - Winter (plant dormancy)
  - Fall/Spring
  - Early summer
  - Hot summer
- Compare observed ET to predicted ET
- Identify Kc
Hypotheses

- Evapotranspiration from an extensive green roof is different from the evapotranspiration from a similar roof system without plants, under a range of climate conditions.

- Green roof ET rates can be effectively modeled with at least one of the following ET models, original Penman, Penman-Monteith, Wright-Penman, FAO Penman, Blaney-Criddle, or Jensen-Haise.
Methodology

**Phase I:** Construct simulated green roof boxes and media boxes

**Phase II:** Installation and calibration the climatic measurement instruments
Wet-Dry Bulb
Light meter
Thermocouple and Infrared Thermocouple
Phase III: Collecting the data
- Collect water loss in planted and unplanted under different conditions
- Collect climatic data

Phase IV: Data analysis
- Compare evapotranspiration and evaporation rates
- Apply selected ET models with collected climate data
- Compare the estimated ET rates with measured ET rates
Results and Discussions
### Winter Condition

- **Average Daily Water Loss**
  - Planted: 0.79 mm/d
  - Unplanted: 0.59 mm/d

- **Total Water Loss**
  - Planted: 17.25 mm
  - Unplanted: 12.76 mm

**Variable**

- Planted
- Unplanted

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<table>
<thead>
<tr>
<th>Time (day)</th>
<th>Y-Data</th>
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<tbody>
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<td>2015-10-05</td>
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<tr>
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</tr>
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</table>

**P = 0.003**
Modeling Results

### Scatterplot of Penman-Monte, Wright Penma, FAO Penman, ... vs observed

<table>
<thead>
<tr>
<th>Model</th>
<th>Regression Results</th>
<th>Correlation</th>
<th>R-Square</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penman-Monteith</td>
<td>Penman-Monteith = 0.462 + 1.35 observed</td>
<td>0.899</td>
<td>80.9%</td>
<td>0.0001</td>
</tr>
<tr>
<td>FAO Penman</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Original Penman</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blaney-Criddle</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Jensen-Haise</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wright-Penman</td>
<td>Wright Penman = 0.546 + 0.136 observed</td>
<td>0.68</td>
<td>46.7%</td>
<td>0.002</td>
</tr>
</tbody>
</table>

### Regression Results

- **Penman-Monteith**
  - Equation: $y = 0.462 + 1.35x$
  - Correlation: 0.899
  - R-Square: 80.9%
  - P-value: 0.0001

- **FAO Penman**
  - Equation: $y = 0.576 + 0.505x$
  - Correlation: 0.817
  - R-Square: 66.7%
  - P-value: 0.0001

- **Original Penman**
  - Equation: $y = 1.09 + 0.449x$
  - Correlation: 0.88
  - R-Square: 77.4%
  - P-value: 0.0001

- **Blaney-Criddle**
  - Equation: $y = 1.65 + 0.351x$
  - Correlation: 0.54
  - R-Square: 29.3%
  - P-value: 0.0001

- **Jensen-Haise**
  - Equation: $y = 1.06 + 0.131x$
  - Correlation: 0.68
  - R-Square: 46.7%
  - P-value: 0.002

- **Wright Penman**
  - Equation: $y = 0.546 + 0.136x$
  - Correlation: 0.68
  - R-Square: 46.7%
  - P-value: 0.002
Fall/ Spring Condition

Average Unplanted
Average Planted
Variable

Average Water Loss Fall-Spring

P=0.026
Total water loss planted 16.83
Total water loss unplanted 13.03
Average water loss rate planted, Actual 0.68 mm/d, Maximum 0.97 mm/d
Average water loss rate unplanted, 0.48 mm/d, Maximum 0.57%
## Modeling Result

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<tr>
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</thead>
<tbody>
<tr>
<td>Penman-Monteith</td>
<td>Penman-Monteith = 1.41 + 4.14 observed</td>
<td>0.902</td>
<td>81.4%</td>
<td>0.0001</td>
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<tr>
<td>FAO Penman</td>
<td></td>
<td>0.001</td>
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<tr>
<td>Original Penman</td>
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<td>0.001</td>
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<tr>
<td>Blaney-Criddle</td>
<td></td>
<td>0.073</td>
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<tr>
<td>Jensen-Haise</td>
<td></td>
<td>0.0001</td>
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<td></td>
</tr>
<tr>
<td>Wright-Penman</td>
<td>Wright Penman = 2.07 + 0.634 observed</td>
<td>0.009</td>
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</tr>
</tbody>
</table>

**ET10 days after watering**
Early Summer

Scatterplot of Planted water loss, Unplanted water loss vs time (day)

P = 0.026
Total water loss planted 15.64
Average water loss rate planted, Actual 0.66 mm/d, Maximum 1.74 mm/d
Total water loss unplanted 13.06
Average water loss rate unplanted, Actual 0.46 mm/d, Maximum 1.00 mm/d
## Modeling Result

### Model Comparison 6-day after watering

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Penman-Monteith</td>
<td>Penman-Monteith = 0.964 + 0.853 observed</td>
<td>0.956</td>
<td>91.3%</td>
<td>0.003</td>
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<tr>
<td>FAO Penman</td>
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<td></td>
<td>0.017</td>
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<tr>
<td>Original Penman</td>
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<td>0.026</td>
</tr>
<tr>
<td>Blaney-Criddle</td>
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<td>0.067</td>
</tr>
<tr>
<td>Jensen-Haise</td>
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<td>0.063</td>
</tr>
<tr>
<td>Wright Penman</td>
<td>Wright Penman = 1.40 + 0.331 observed</td>
<td>0.877</td>
<td>76.8%</td>
<td>0.022</td>
</tr>
</tbody>
</table>
Hot Summer

Scatterplot of unplanted average daily vs time (day) and planted average daily variable.

P = 0.0001

Total water loss planted: 20.89 mm
Total water loss unplanted: 16.8 mm
Average water loss rate planted: Actual 0.89 mm/d, Maximum 3.023 mm/d
Average water loss rate unplanted: 0.69 mm/d, Maximum 2.08 mm/d
## Modeling Result

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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Penman-Monteith</td>
<td>Wright Penman = 3.81 + 0.106 observed</td>
<td>0.388</td>
<td>37.4%</td>
<td>0.388</td>
</tr>
<tr>
<td>FAO Penman</td>
<td>Jensen-Haise = 12.7 - 0.762 observed</td>
<td>0.612</td>
<td>37.4%</td>
<td>0.388</td>
</tr>
<tr>
<td>Original Penman</td>
<td>Original Penman = 1.12 + 0.446 observed</td>
<td>0.988</td>
<td>97.6%</td>
<td>0.012</td>
</tr>
<tr>
<td>Blaney-Criddle</td>
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<tr>
<td>Jensen-Haise</td>
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</tr>
<tr>
<td>Wright-Penman</td>
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Conclusions

- Green roofs have an overall average water loss (actual ET) of 0.76 mm/d.

- Regular roofs have an overall average water loss of 0.56 mm/d.

- Actual ET rate from a green roof is approximately 35% more than water loss by evaporation from a soil-covered roof.
Cont.

- Maximum ET rate of a green roof is on average about 1.68 mm/d.
- Maximum ET rate from a soil-covered is about 1.06 mm/d.
- Maximum ET from green roof is approximately 58% higher than medium roof ET rate.
- Penman-Monteith is the best model to predict ET rates from extensive green.
Acknowledgement

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- Dr. David J. Beattie
- EPA
Questions?