Examination of Evapotranspiration from Bioretention Planters

Etude de l'évapotranspiration des "jardinières de pluie"

Elizabeth Fassman-Beck, Ph.D.[1], M. ASCE, Michael Borst[2], Kiera Nissen[1]

1. Stevens Institute of Technology, efassman@stevens.edu
2. US EPA Office of Research and Development, borst.mike@epa.gov

RÉSUMÉ

Quartes jardinières de pluie ont été installées à Stevens Institute of Technology afin d'effectuer un suivi hydrologique. Les données d'humidité du sol récoltées de Mars à Septembre 2018 ont été analysées pour déterminer l'évapotranspiration. L'évapotranspiration est un processus crucial pour assurer la réduction des ruissellements par les systèmes reposant sur des infrastructures « vertes » ayant une faible capacité globale de stockage, telles que les toitures végétalisées et jardinières de pluie. Cette étude a examiné trente périodes sèches pendant le printemps et l'été 2018. Des taux d'évapotranspiration plus élevés ont été observés pendant les mois présentant les plus grosses précipitations, sauf en juillet. Deux types de media (un suivant les spécifications pour les jardins de pluie du New Jersey Department of Environmental Protection et un media à base de pumice) présentaient des taux d'évapotranspiration journaliers moyens différents. Le media à base de pumice avait des taux d'évapotranspiration plus élevés. Les données terrain ont montré des taux d'évapotranspiration bien plus élevés que ceux prédits par les méthodes de Thornthwaite ou Blaney-Criddle. Ce nouveau système continuera à être suivi afin de détecter les changements de comportement.

ABSTRACT

At Stevens Institute of Technology, four bioretention planters are set up for hydrologic monitoring. Soil moisture data from March through September 2018 were examined to determine evapotranspiration. Evapotranspiration is a critical process to ensure the continual runoff mitigation function of green infrastructure systems with low overall storage capacity, such as green roofs and planters. This study examined thirty dry periods over the spring and summer of 2018. Higher evapotranspiration rates were observed in months with higher rainfall, except for July. Two different media types (New Jersey Department of Environmental Protection rain garden specifications and a pumice-based media) demonstrated a difference between the average daily evapotranspiration rate. The pumice-based media had a higher evapotranspiration rate. The field data showed much higher evapotranspiration rates than were predicted using the Thornthwaite or Blaney-Criddle methods. This new system will continue to be monitored for changes in these trends.

KEYWORDS

Bioretention, Combined Sewer Overflow, Evapotranspiration, Green Infrastructure, Urban Hydrology

1 INTRODUCTION

The fundamental objective of green infrastructure is to mimic the pre-development hydrologic cycle. This objective is accomplished primarily by infiltration and evapotranspiration. A bioretention planter is one form GI technology that manages stormwater runoff, primarily but not exclusively, from rooftops. Flow-through planters typically have an above ground installation without direct contact with the underlying soil so there are no volumetric exfiltration losses (Figure 1). Bioretention planters delay and attenuate peak flows with some overall volume losses through inter-event evapotranspiration (ET).

ET is the driving factor “empty” stored water back into the atmosphere. It is a critical process to ensure the continual mitigation function of GI systems will low overall storage capacity, such as green roofs and planters. Compared to the underlying assumptions of ET models such as Penman-Monteith, Thornthwaite, or Blaney-Criddle methods, GI is characterized by small scale applications limited water availability. As such, ET from GI systems is hypothesized to differ substantially from ET predicted by these well-known methods. There has been much work on the study of ET for green roofs (Berretta et al. 2014; DiGiovanni et al. 2012; Voyde et al. 2010). Soil lysimeters have been used to measure ET from bioretention cells (Denich and Bradford 2010; Hickman et al. 2010; Wadzuk et al. 2015) and soil moisture sensors have been used to measure ET from green roofs (Rezai 2005; Voyde 2011). This study is the first known work to quantify and evaluate the ET from bioretention planters.

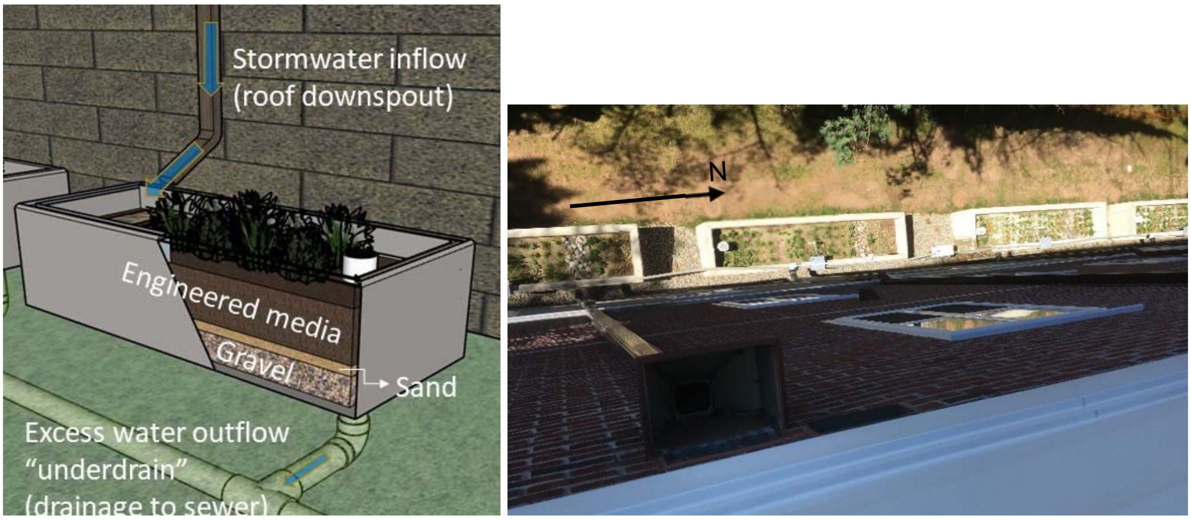

Fig. 1. Typical above-ground bioretention planter configuration (left); test site at Stevens Institute of Technology (right).

2 METHODS

As part of the environmental stewardship program at Stevens Institute of Technology (Hoboken, New Jersey, USA), the university designed and installed four planters to receive the rooftop runoff from the newly constructed North Building on campus (Figure 1, right). The rooftop runoff flows through scuppers and down 10.2 cm by 12.7 cm rectangular metal downspouts. PVC pipes (3.8 cm) connected to the downspouts carry runoff to the inlet each planter. The rooftop area is roughly rectangular with an estimated area of 443.8 m^2.

Planters are numbered 1 to 4 from north to south (right to left in Figure 1, right). Each planter is 2.1 m long, 1.2 m. wide, 1.4 m. tall (exterior dimension). Sidewalls and bottoms are 15.2-cm thick rebar-reinforced concrete. Pumice based media (88% v/v pumice sand with 12% v/v compost) was placed in planters 1 and 2 while planters 3 and 4 have a rain garden media blend that meets New Jersey Department of Environmental Protection (NJDEP) specifications (91% sand, 2% clay, with 4% organics, pH of 5.9 and hydraulic conductivity of 16.8 cm/hr. at installation). The NJDEP rain garden media is primarily quarried lake sand, which has different mineralogy and water holding characteristics than the pumice-based media. The 55.9 cm deep media layer is underlain by 7.6 cm sand. A geotextile separates the sand from a 15.2 cm thick layer of pea gravel. Between the media surface and emergency overflow bypass, there is a 43.2 cm ponding zone +freeboard.

Each planter has six water content reflectometers (WCRs) which measure volumetric water content

(VWC). In this study, All WCRs are installed with tines pointing toward the water source (inlet). The 24 WCRs are hardwired to a Campbell Scientific data logger programmed to measure and record output parameters at 10-min intervals.

The 10-min data were averaged over dry twenty-four-hour periods to calculate the average volumetric soil moisture content for the day. The start of a dry period was defined as midnight after all rain has ceased. If it rained overnight, the dry period started the following night. There were some dry periods over the summer months with increasing soil moisture with no detectable rainfall, this is believed to be an anomaly from excessive overnight humidity or dew. These dates were excluded from the analysis.

VWC coupled was multiplied by growing media depth (55.9 cm) to determine depth of actual water loss. The ET of the planter is determined as the difference between the average volumetric soil moisture content from the previous day and the current day (Fassman and Stokes 2011). Soil lysimeters have been used to measure ET from bioretention cells (Denich and Bradford 2010) and soil moisture sensors have been used to measure ET from green roofs (Voyde 2011).

The system was established in the summer of 2017. This study evaluated 30 dry periods from March 2018 through Sept. 2018, representing the first full spring and summer after construction.

3 RESULTS AND DISCUSSION

In general, ET is greatly affected by microclimate and available water content. From the planters, Table 1 shows that the average monthly ET seems to correlate with total rainfall, except for July. The highest rate in September also had the lowest average length of dry period with the highest rainfall, making sense that frequent rainfall replenishes soil moisture to maintain a higher ET rate. July and September have similar climate characteristics but have different average ET. July, with a higher average temperature and lower average humidity should in theory have a lower ET rate than September with similar average soil moisture content, but this is not the case. More investigation is needed to determine if July 2018 is an outlier or if other factors that must be considered.

The average daily ET over the thirty dry periods over the time period was 0.83 cm/day. There was a difference between the pumice-based and NJDEP specified media, 0.86 cm/day vs. 0.79 cm/day respectively (Figure 2, right).

Table 1: Average Monthly Statistics

Month	Soil Moisture (% v/v)	ET (cm/day)	Rainfall (mm)	Number of Dry Periods	Dry Period Duration (days)	Daily Temperature (°C)	Relative Humidity (%)
March	18.2	0.624	115.0	3	4.67	4.4	60
April	17.2	1.005	147.2	6	2.83	9.4	59
May	17.6	0.872	70.6	5	4	19.4	66
June	16	0.526	65.6	4	3.75	22.0	63
July	18.1	0.747	158.0	5	2.2	25.5	66
Aug.	19	1.382	155.6	3	2	25.5	72
Sept.	18.6	1.103	157.3	4	2	21.7	77

The Thornthwaite method and Blaney-Criddle method are temperature-based methods for estimating monthly ET. It is often assumed that actual ET is less than methods that estimate potential ET, and that water availability can limit ET (Zhao, et.al 2013). Thornthwaite and Blaney-Criddle are methods to estimate potential ET that are based on sufficient moisture and consistent cover which is often not the case in urban environments. Figure 2, left shows that the ET for the bioretention planters is much higher than the ET estimates from either method.

Figure 2 demonstrates the relationship between ET and soil moisture for the month of April. The average soil moisture ranged from 14.1% to 19.8% and the ET ranged from 0.09 cm/day to 5.3 cm/day. The small change in soil moisture accounts for a large spike in ET rates. This is a relationship that is unaccounted for in any ET estimations.

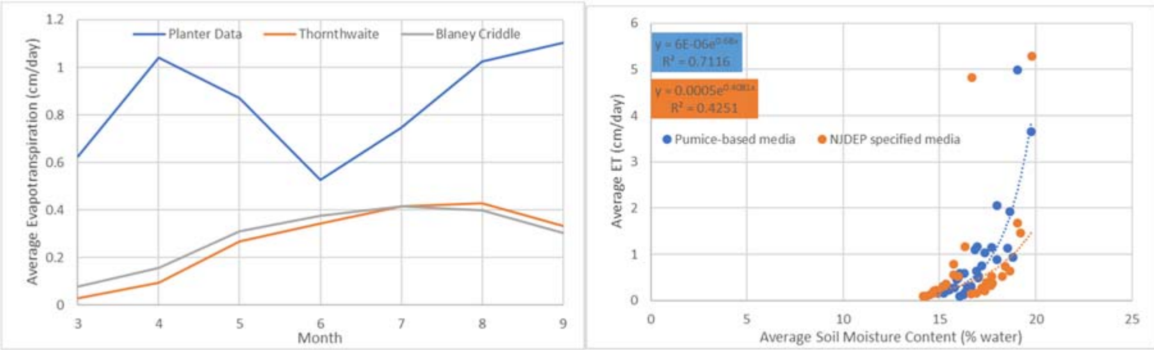

Figure 2. Monthly Potential ET verses Actual ET (left), ET by media for April 2018 (right)

4 CONCLUSION

Drying out a bioretention planter is an essential part of the process to manage stormwater runoff. ET prepares the bioretention planter to catch the next storm. By quantifying ET, it becomes possible to estimate available capture capacity for the next storm and contributes to continuous simulations for predicting long-term performance.

The ET rate of bioretention planters still has much more to explore. This study provides a look at a new system and the ET rate over spring and summer of 2018. The average ET varied from 0.526 cm/day in June to 1.382 cm/day in August. This wide range can be explained in part by available moisture, but further examination is ongoing to determine long term behavior. There is a difference in average ET between the two media types examined in this study. Continued monitoring will determine if this difference is meaningful with regard to long-term stormwater mitigation capacity. This study shows that ET is higher than estimated by temperature-based models throughout spring and summer in this urban environment.

LIST OF REFERENCES

Berretta, C., Poë, S., & Stovin, V. (2014). Moisture content behaviour in extensive green roofs during dry periods: The influence of vegetation and substrate characteristics. *Journal of Hydrology, 511*, 374-386.

Dench, C., & Bradford, A. (2010). Estimation of evapotranspiration from bioretention areas using weighing lysimeters. *Journal of Hydrologic Engineering*, 15(6), 522-530.

DiGiovanni, K., Montalto, F., Gaffin, S., & Rosenzweig, C. (2012). Applicability of classical predictive equations for the estimation of evapotranspiration from urban green spaces: Green roof results. *Journal of Hydrologic Engineering, 18(1),* 99-107.

Fassman, E.A., Stokes, K. (2011) Media Moisture Content to Determine Evapotranspiration from Swales and Bioretention Cells, EWRI World Environmental and Water Resources Congress, Palm Springs, CA, 22-26 May 2011. DOI: 10.1061/41173(414)79

Hickman, J., Schneider, D., Wadzuk, B. M., & Traver, R. G. (2010). Determination of Evapotranspiration in SCM's Using a Weighing Lysimeter: An Experimental Approach. In *World Environmental and Water Resources Congress 2010: Challenges of Change* (pp. 3990-3999).

Rezai, F. (2005). "Evapotranspiration rates from extensive green roof species," Pennsylvania State University, University Park.

Voyde, E., Fassman, E., Simcock, R., & Wells, J. (2010). Quantifying evapotranspiration rates for New Zealand green roofs. *Journal of hydrologic engineering*, *15*(6), 395-403.

Voyde, E. (2011). *Quantifying the complete hydrologic budget for an extensive living roof* (Doctoral dissertation, ResearchSpace@ Auckland).

Wadzuk, B. Hickman, J., Traver, R. (2015). Understanding the Role of Evapotranspiration in Bioretention: Mesocosm Study. *Journal of Sustainable Water in the Built Environment* 1(2).

Zhao, L., Xia, J., Xu, C. Y., Wang, Z., Sobkowiak, L., & Long, C. (2013). Evapotranspiration estimation methods in hydrological models*. Journal of Geographical Sciences, 23(2)*, 359-369.