Comparing Lysimeter ET Measurements to Entire Green Roof Performance

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Background

Green roofs are often times under-credited for stormwater volume reduction. However, research has shown that volume reduction due to evapotranspiration (ET) can account for a significant portion of the water balance. Villanova's Green Roof was constructed in the summer of 2006 atop the Center for Engineering Education and Research, and has been continuously monitored since 2009. Past research has focused on quantifying potential ET from an undrained weighing lysimeter on the roof. With the installation and calibration of outflow-measuring instrumentation, future investigations will focus on comparing the ET measurements of the lysimeter to the performance of the entire green roof with a drainage system. Using preliminary data for over 6 months, including data from more than 10 storms of varying size, analysis has shown very similar water balances for both the green roof and the lysimeter.

Villanova's green roof is an extensive green roof with approximately 575 ft^2 of total drainage area. The roof's profile consists of primarily sedums planted in approximately 3-4 inches of growing media over a 1 inch thick drainage board separated by a geotextile. The system is designed to hold 1.85 inches of rain assuming complete saturation, however the capture of a 1 inch storm is more realistic.

Instrumentation

The site is equipped with a weather station to measure meteorological variables including precipitation, wind speed, air temperature, relative humidity, and solar radiation (Figure 1). Within the growing media, there are two temperature probes for monitoring the insulation effect the green roof has. There is a second rain gauge as well as an additional temperature probe on a nearby grey roof for comparison studies.

Evapotranspiration measurements are taken using a weighing lysimeter located on the green roof. The 18 inch square lysimeter has the same profile as the entire roof, however it does not have an underdrain and is slightly elevated above the rest of the roof. (Figure 1)

Figure 1: The instrumentation used including the weather station on the left and the weighing lysimeter on the right.

Overflow from the entire green roof is measured using a combination of a tipping bucket for low flows and a Thelmar weir for flows greater than 0.04 GPM. (Figure 2)

Figure 2: The instrumentation used for measuring overflow from the green roof. Pictured on the left is a tipping bucket mechanism for low flows. On the right is the Thelmar Weir used for measuring higher flows.

Previous Research: Lysimeter Measurements

Previous research has focused on measuring ET using data from the weighing lysimeter. This has been done by using a water balance in which

$$ET_{lys} = P - Q_r - \Delta\theta z_s$$

where P=precipitation (mm), Q_r=surface runoff and overflow (mm), $\Delta\theta$=average moisture content change of the soil (m^3/m^3), and z_s= depth of the soil (mm). (Wadzuk et al. 2013)

In this specific case ET can be calculated using the following equation

$$ET_{lys} = W_0 - W_{24} + P - Q_r$$

in which W_0 is the weight at midnight at the beginning of the day, W_{24} is the weight at midnight at the end of the day, P is precipitation, and Q_r is overflow (estimated from weights exceeding the maximum yearly weight).

Over the 5 years of data collected, there has been a wide range of climate conditions. 2009 was a wetter year, while 2010 and 2011 experienced long periods of droughts. 2012 had a fairly even distribution of rainfall and 2013 had a dryer than usual spring but a typical summer and fall. Although total precipitation for these years varied from around 800 mm to nearly 1400 mm, it is interesting to note that the percentage of the water budget attributed to ET seemed to remain fairly constant between 70 and 90 percent (Table 1).

	2009	2010	2011	2012	2013
Rainfall (mm)	1153	817	1351	814	900
ET (mm)	783	718	982	688	652
Percent ET	68%	88%	73%	85%	72%

Table 1: Summary of calculated ET for April through November for 2009 though 2013

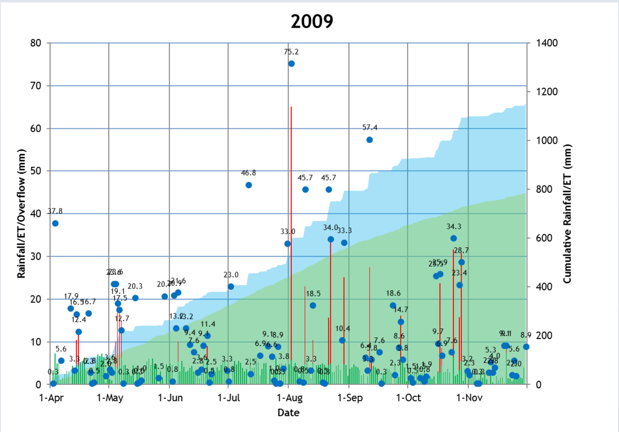

Figure 3: Cumulative rainfall and ET for 2009: This was a relatively wetter and cooler year.

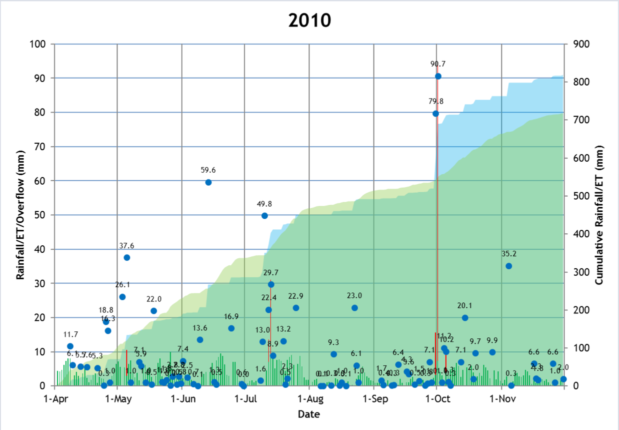

Figure 4: Cumulative rainfall and ET for 2010: There was a significant drought during August and September.

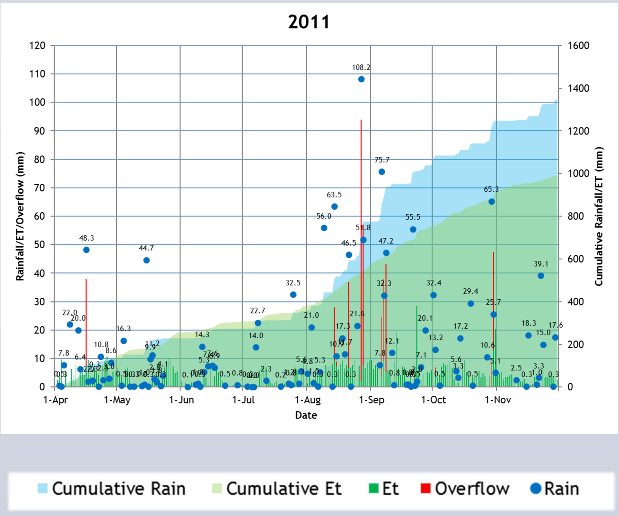

Figure 5: Cumulative rainfall and ET for 2011. There was a drought in June and July of this year. Hurricane Irene occurred in the end of August.

Current Research: Entire Roof Performance

Recent work has focused on studying the performance of the entire green roof and correlating it to the data obtained from the weighing lysimeter. In the case of the weighing lysimeter, ET was calculated by measuring the change in weight of the sample. A loss of weight was attributed entirely to ET since there was no underdrain, and a gain in weight was attributed to precipitation. When looking at the entire roof, it would be nearly impossible to measure the change in weight of the entire area so another way to close the mass balance was needed. A simple mass balance equation $Q_{in} = Q_{out} + \Delta_{Storage}$, was used where Q_{in} is precipitation; Q_{out} is overflow or drainage; and $\Delta_{Storage}$ is entirely ET since infiltration is impossible. Using precipitation data as well as outflow data from the tipping bucket and Thelmar Weir, ET for the entire roof was calculated over a period of 6 months. For June through September 2013, lysimeter data showed 71% ET and entire roof drainage measurements showed 30% overflow. When October and November data was added, lysimeter data showed 60% ET rates and overflow measurements showed 43% overflow. This preliminary data seems to indicate that although the lysimeter does not have an underdrain, it fairly accurately represents the actual roof's performance. (Table 2)

Time Period	Rainfall (mm)	ET Lysimeter	Overflow	Percent Difference
June-September 2013	560	71%	30%	1%
June-November 2013	733	60%	43%	3%

Table 2: Summary of the long term comparison of lysimeter ET measurements to the performance of the entire roof.

For a single storm based comparison, a rain event of just over 1.25 in on August 28th 2013 was chosen for analysis. This is an ideal storm for comparison since there was no rain recorded for 9 days prior and only one small event for 7 days afterwards. This dry period helps to minimize any effect stored water may have had on ET and overflow measurements. In terms of the entire green roof, rainfall contributed 493.5 gallons of water to the system, overflow measurements showed just over 39 gallons of drainage, and lysimeter data extrapolated over the entire green roof estimated just over 431 gallons of water was lost to ET. When comparing lysimeter ET to precipitation and overflow data, there is less than 5% of unaccounted for water. (Figure 6)

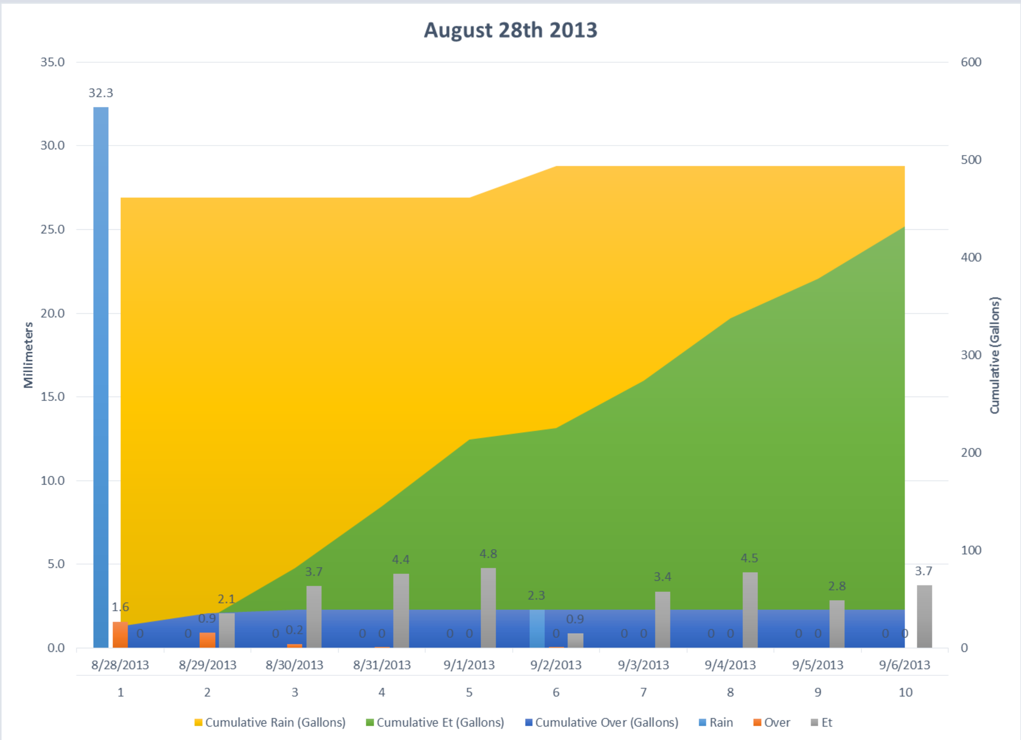

Figure 6: The correlation between lysimeter ET measurements and the performance of the whole green roof. Notice how the final cumulative ET and the final cumulative overflow nearly account for all of the cumulative rainfall.

Other Areas of Interest

In addition to recording air temperature, temperature probes were installed within the soil media as well as on a traditional grey roof. A plot of these temperatures for the August 28th storm was created (Figure 7). As is expected, the higher the temperature, the more ET there was. This graph also highlights the insulating effect the green roof has. This effect can lead to a significant savings in heating and cooling expenses as well as help to reduce the heat island effect seen in traditional development.

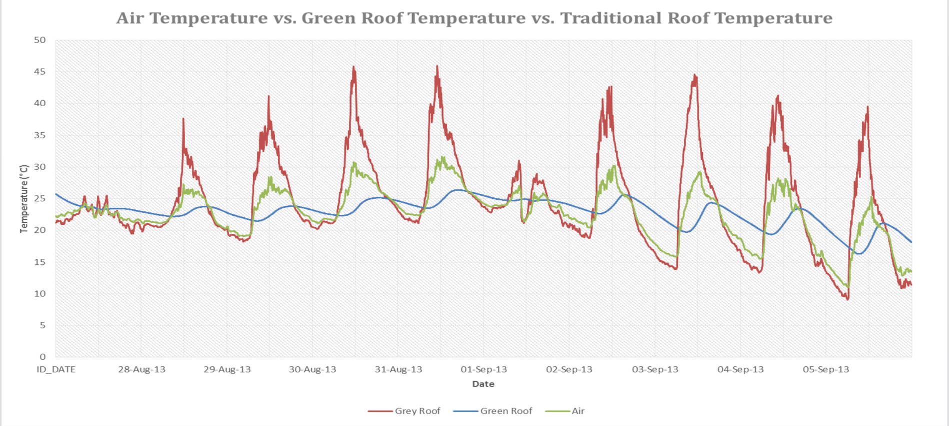

Figure 7: Temperature data from within the green roof compared to ambient air temperature and grey roof temperature.

Moving Forward

The ultimate goal of this project is to develop a model for designers to use when designing green roofs to better account for evapotranspiration in stormwater calculations.

Municipalities want something that is simple to implement and use. However, there is an inherent tradeoff between simplicity and accuracy. Traditional models used for agriculture typically do not accurately represent ET on small scale sites such as green roofs, however as the number of variables needed for each model decreases, so does its relative accuracy. Currently many municipalities use TR-55 modeling for green roofs but is this appropriate for such a small scale site?

Lastly, it will be important to look into how certain design variables affect ET including media thickness and porosity, types of drainage boards, location of the roof in relation to other structures, and how the total area may influence its performance.

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References

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