Mini-project report

The role of evapotranspiration in green roof runoff retention performance

Emma Ireland – dtp11eji@shef.ac.uk

8th February 2012

ASSIGNMENT COVER SHEET 2010/2011/2012

A completed copy of this sheet MUST be attached to coursework contributing towards theme 2 assessment.

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Mini-Project Mark Sheet

Student: Emma Ireland **Grade:** fail/satisfactory/good/very-good/excellent

Supervisor: Virginia Stovin

Feedback:

	Excellent	**Good**	**Average**	**Poor**	**Very Poor**	**Not Done**	**Not applicable**
Introduction to the problem / subject							
Statement of aims							
Experimental description							
Presentation of results / findings							
Quality and depth of discussion / interpretation							
Relevance of conclusions							
Quality of English							
Use of reference material							
Evidence of external reading							
Quality of presentation							
Use of figures							

Comments:

1.0 Introduction

Traditional urban water management has focussed on using hard engineering and infrastructure techniques to remove large volumes of stormwater as fast as possible from densely populated and built up areas (White, 2002, cited in Nagase and Dunnett, 2012). However, modern ideals followed by many town planners, urban hydrologists and civil engineers revolve around the concepts of sustainable urban drainage systems (SuDS) (van Roon, 2007; Libralato *et al.*, 2012). These design philosophies are based on the concept of closed loop system management, with resources and wastes cycled at local scales (Elliott and Trowsdale, 2007; Morison and Brown, 2011). In this concept, stormwater becomes a resource rather than a waste product. In respect to urban areas built based around traditional stormwater management, the whole system is often unrealistic to convert to modern management, and consequently elements of adaptive stormwater management can be utilised as a complimentary management technique (Scholz, 2004).

One of the most frequently used elements are green roofs (Carter and Jackson, 2007). This is due to their applicability to both new developments and retrofitting. Green roofs also form the first stage of the urban stormwater management chain, and therefore have an impact through the whole system. Despite the multiple advances in green roof research, stormwater management remains one of the key functions and most researched areas. This is influenced by the significant energy and consequent emissions function of traditional stormwater management, as in 2009 1.7 $MtCO_2e$ was generated from the wastewater sector alone (Department of Energy and Climate Change, 2012). The requirement for a more effective stormwater management approach is therefore a priority in reducing the environmental impacts of the utilities sector. In this context, studies such as that by Hilten *et al.* (2008) who found extended stormwater detention for large storms and complete retention for storms of 2cm for a 10cm roof depth implies that the stormwater currently processed together with wastewater could be significantly reduced. Voyde *et al.* (2010) also found a cumulative retention efficiency of 66% in a trial in New Zealand, whilst Stovin *et al.* (2012) found 50.2% on a roof in the UK.

Effective and accurate models for estimations of runoff and therefore green roof performance in an urban setting in the context of stormwater management under different weather conditions will require a high degree of detailed input data sets. However, for a model to be used in different situations, such data is unlikely to be available. This consequently implies that a more generic and basic approach needs to be taken using the key influential factors upon green roof performance. This would therefore provide a useful tool for assessing the effectiveness of a generic green roof in any climate. Many studies have identified the key parameters that have the greatest impact upon green roof performance, including Voyde *et al.* (2010) and Tabares-Velasco and Srebric (2011) who found it to be rainfall (/substrate moisture), and Tabares-Velasco and Srebric (2012) who found it to be solar energy (linked to temperature).

1.1 Aims

Therefore the aim of this study was to develop a water flux modelling tool utilising the parameters found to be most significant from the literature. This would allow a generalist method of predicting the effectiveness of a generic green roof for application to different areas using the three inputs of average daily rainfall, average monthly temperatures and average daylight hours each month.

2.0 Methods

2.1 Data set

To analyse the effectiveness of such a basic modelling tool, rainfall and runoff data from a green roof test bed at Sheffield Green Roof Centre was used to compare the estimated and observed runoff levels for 2007. To apply the model to different scenarios, data from public sources was used. However, daily sunlight levels have been kept at a constant figure to match to calculations using the same Sheffield green roof test bed data set (Kasmin *et al.*, 2010; Stovin, 2010; Stovin *et al.*, 2012) due to no accurate source being publicly available for the other locations.

3.0 Model development

The water flux model is therefore based upon the following data analysis chain:

- Potential evapotranspiration calculated by the Thornthwaite equation as a function of average monthly temperatures and average monthly daily sunlight hours, with an additional precaution for average minus temperatures and therefore minus evapotranspiration values.
- Conversion of monthly evapotranspiration values to daily amounts as a function of days/month.
- Substrate moisture as a function of initial start moisture, daily rainfall and evapotranspiration level.
- Expected runoff volume as a function of substrate moisture and maximum substrate moisture.

4.0 Results

4.1 Effectiveness

To analyse the effectiveness of the modelling approach used in the water flux model, initial calculations were made for daily estimated runoff for 2007 in Sheffield, UK. This was therefore then comparable with the runoff data from the green roof test bed (Figure 1). The model follows the observed runoff relatively accurately (Figure 1), with the greatest inaccuracies seen in April, July, August, September and October.

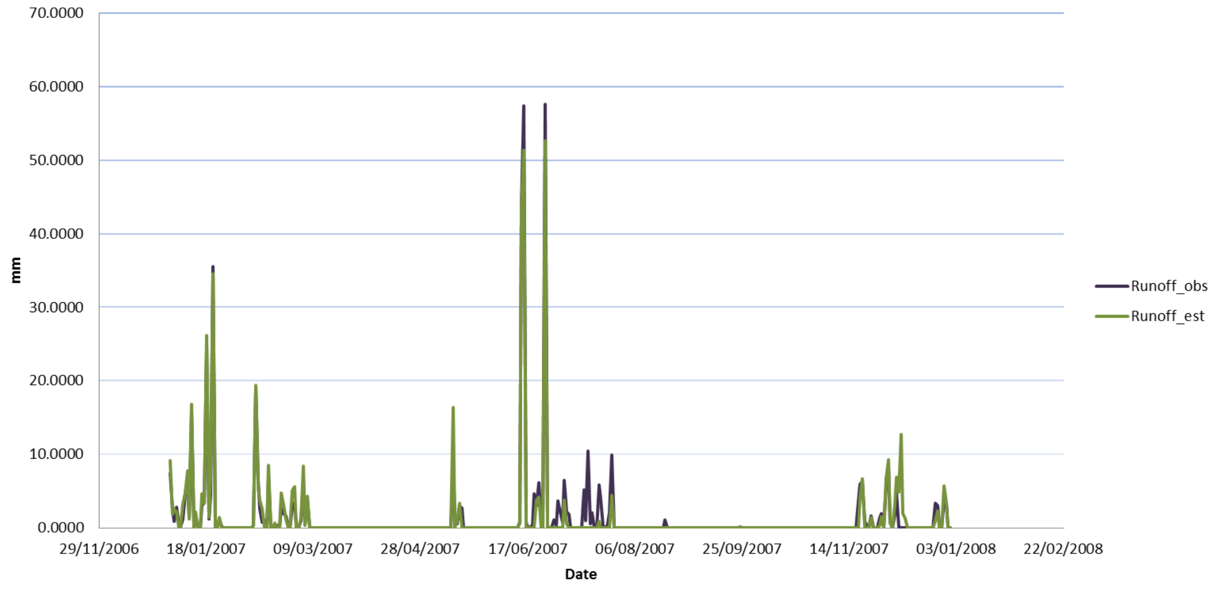

Figure 1. 2007 Sheffield green roof runoff observed and estimated.

4.2 Sensitivity

Inaccuracies in the models' predicted runoff appear to be linked to temperature and antecedent dry weather period (ADWP), although the model misestimates the runoff by ±5mm six times (Figure 2).

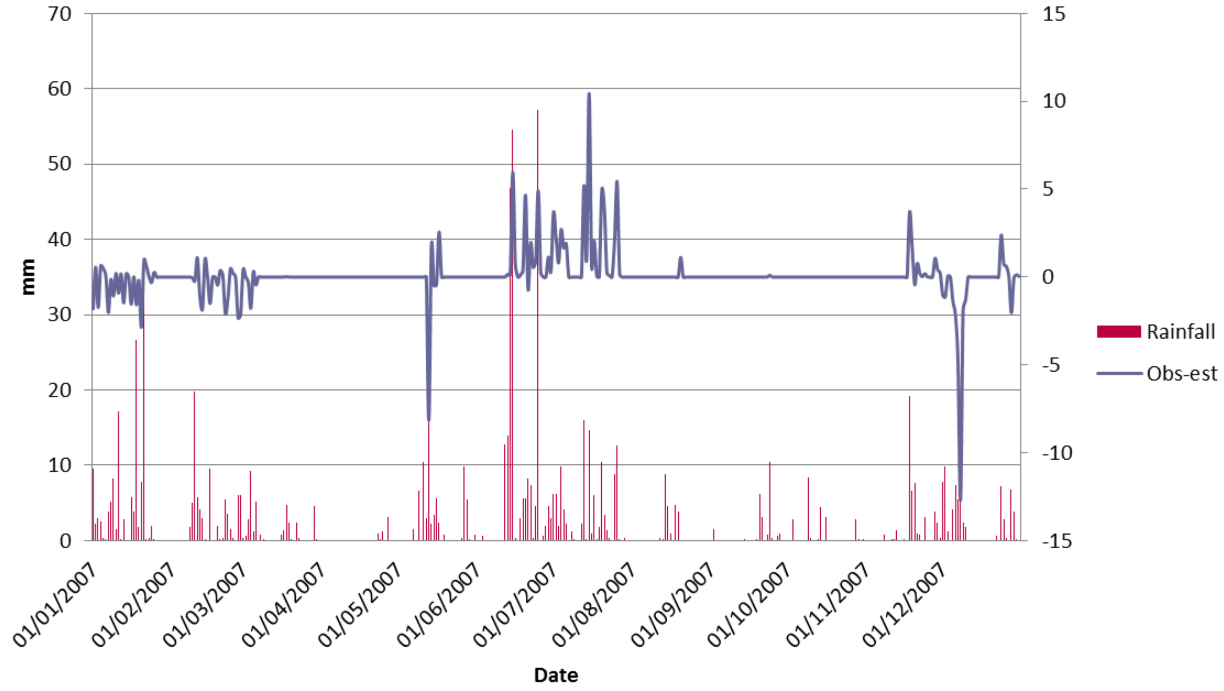

Figure 2. Sheffield 2007 rainfall compared to inaccuracy in model runoff prediction. Both daily total rainfall and daily total inaccuracy are displayed as mm.

4.3 Application to different climates

The model can also be applied at a daily scale for different climate patterns (Figure 3) and demonstrates sensitivity to the input data.

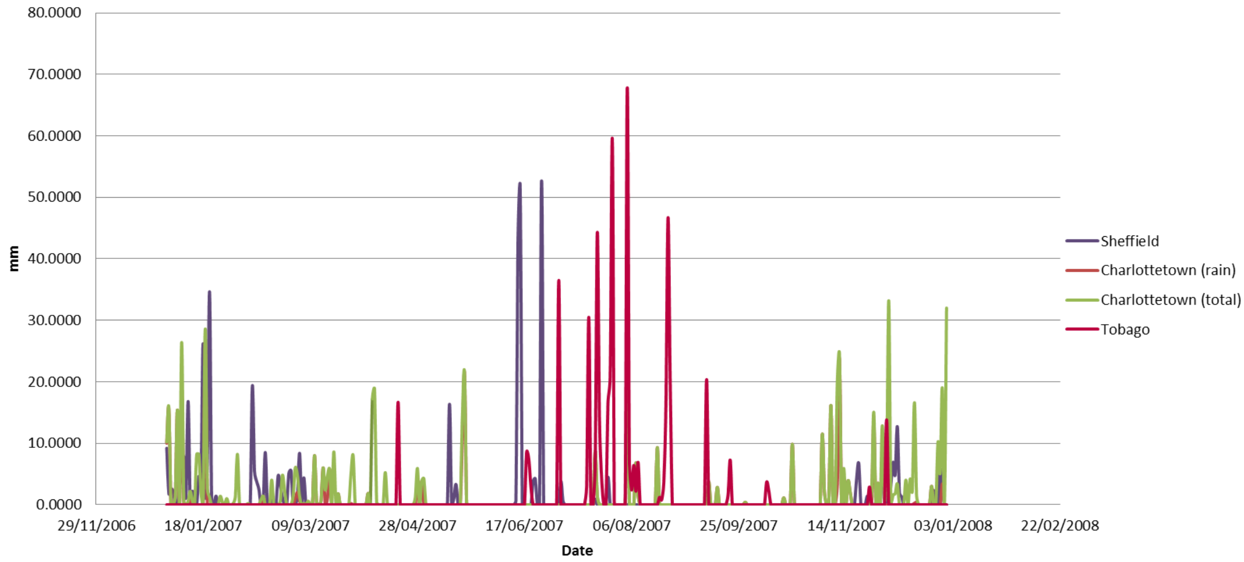

Figure 3. Application of the model to different climates. Examples given are: Sheffield (2007), Charlottetown (2007) (Prince Edwards Island, Canada) for which both rainfall and total precipitation are plotted to include snowfall, and Tobago (1995).

5.0 Future development

The model has been shown to be sensitive to a degree to the three input data variables, to daily and monthly scales. However, the degree of this sensitivity has not been quantified to determine the relationship between the input data and the difference in runoff prediction. In particular, using the reference data from the green roof test rig in Sheffield, the accuracy of the runoff prediction can be calculated. This therefore allows further scaling and weighting changes to be made to the equations used within the model to improve the accuracy of each stage.

Similarly, such quantification of the influence of each input data point over the accuracy of the estimated runoff would allow further comparison of whether additional data inputs would increase the accuracy to a significant scale. However, any further addition of data input would remove the model from fulfilling the role of a low expertise and specification model for application to the widest variety of applications.

Therefore, it is most likely that further work on the performance of the model as a basic green roof performance/runoff predictor should focus upon a rescaling of the use of the Thornthwaite equation to predict evapotranspiration. In this model Thornthwaite was used in its original format, which indicates that there may be an opportunity therein to alter the calculation slightly to increase the model's performance.

6.0 Discussion

Basing the assumption of accuracy of method upon the comparison between the observed and estimated runoff for the roof when inputting the 2007 Sheffield rainfall data (Figure 1) the model can be seen operationally to be working effectively to a certain degree. However, this is not necessarily due to efficient scaling of input parameters within the model, but rather the proportion of rainfall falling in comparison to the maximum moisture holding capacity of the roof. This is supported by a finer grain scale comparison of the 2007 rainfall data which showed that in months when there was a large amount of rain and consequent runoff, such as in January when daily runoff totals were up to 35mm, the model appears to be fairly accurate, but in months when daily totals were only as high as 10mm such as July, the model appears to be very inaccurate.

These factors however are summarised by the calculation of the deviation of the estimated runoff from the observed runoff (Figure 2), which shows that the model is most inaccurate during the summer months, with one large deviation from the observed in December. This indicates that the accuracy of the model is influenced by temperature extremes, although comparison of accuracy with rainfall (Figure 2) also adds an additional element of ADWP (antecedent dry weather period) as the periods of least accuracy appear to be associated with very short ADWP.

The key problem with the model generated from the application to different climates (Figure 3) was that of the inclusion of snowfall. Charlottetown is located on Prince Edward Island in Canada and a significant proportion of the precipitation falls as snow. At the present the model processes this precipitation as all rainfall that either runs straight off or is retained by the substrate. However, snow is likely to remain in a layer above the roof for a certain amount of time before being processed by the roof as water. Snow and rain fall throughout the year in Charlottetown, which indicates that for this particular location, snow fall could be estimated as melting upon receipt of rainfall, although this would need to include a relatively large error indication. Additionally, the presence of snow on the green roof indicates that evapotranspiration will be significantly less from the plants and substrate, and at present this effect is not accounted for within the function of the model. To therefore improve the accuracy of the model in this type of climatic context, an additional parameter of snowfall could be added.

The model, despite the sensitivity analysis so far calculated, is intrinsically flawed by the function of predicting future runoff. In order to predict future rainfall levels and patterns, averages taken from previous years are used to give the most accurate forecast, however, the use of averages by their very nature level out the effect of storm events to a 1-in-1 storm event, dependent upon the span of years taken into the average. This therefore means that the model will miss any greater storm events, and in regions where rainfall patterns are high intensity over a short time span, daily averages will smooth this to an even steady rainfall over a prolonged period. Butler and Orians (2011) suggest that the input parameter of days between rainfall, or ADWP, may be a better measure than total monthly rainfall, and explain this statement as due to the tendency of sedum spp. to switch between C3 and CAM photosynthesis.

Metselaar (2012) added an additional precaution to their model to account for the urban heat island effect, as it was considered that the impact of urban temperature differences were significant enough to influence the evapotranspiration mechanism of a green roof. Within the water flux model adjustments to the Thornthwaite equation to increase the efficiency of its estimations may provide an opportunity to also account for urban heat island differences, although this will only be quantifiable once initial evapotranspiration parameters within the equation are defined.

Detention of rainfall is dependent upon substrate permeability and depth, drainage layers, the roof size, vegetation and the slope of the roof (Hilten *et al.*, 2008). The water flux model at present is not advanced enough to take any such factors into account, yet there is the potential for the development of either multiple models for different green roof characteristics, or alternately, one model could be developed to include an additional set of input parameters to define the green roof that is being modelled.

7.0 Conclusions

Ouldboukhitine *et al.* (2011) quote buildings as representing 40% of European energy consumption sinks, accounting for 36% of the total CO_2 emissions. With the large amounts of embodied and operation energy also invested in current stormwater management (via waste water transport and treatment), green roofs offer a potential mechanism of significantly reducing the energy requirements of buildings through heat and water flux functions.

However, the usefulness of this technology is inconsequential if the ease of implementation is not facilitated. Design and function of green roofs has received a vast amount of research in recent years, and therefore the performance function has increased considerably. Therefore the mechanism by which green roofs are implemented in all future building work, development and refurbishment is largely a function of policy, knowledge share and economic viability. The development of the water flux model as a simple and easy to use tool to predict the likely runoff characteristics of a roof that could have a green roof may therein allow initial enquiries in a greater number of situations to find out if a green roof may be beneficial.

The model developed here is fundamentally basic in order to reduce the input parameters required, however, following on from further adjustment to the weighting of different input parameters within the calculation equations, the potential for this model to relatively accurately predict runoff off a generic green roof is high. Furthermore, this would allow the development, dependent upon requirement, for variations of the model to be generated for different situations, roof types or climates.

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