



Faculty of Engineering

**Stormwater Retention Performances of Green Roof under the Tropical
Climate of Sarawak**

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Stormwater Retention Performances of Green Roof under the Tropical Climate of Sarawak

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DECLARATION

The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree

Signed : _____

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Date : _____

DEDICATION

To my beloved family and friends

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ABSTRACT

The retention performance of the green roof has been widely investigated in developed countries particularly in the temperate climate region. However, available literatures concerning the retention performances in tropical region are scarce. This study is an initial attempt to investigate the retention performance of the green roof under the hot-humid tropical climate specifically in Sarawak through modeling approach. Prior to modeling, the retention capability of an extensive green roof under the actual meteorological condition in Sarawak was demonstrated, indicating 88.1% of mean retention rate and 80.8% of cumulative retention rate. There are only seven rainfall events were captured due to unavailability of suitable instruments and overflow of runoff towards the outlet of downspout pipe during heavy events. By applying twelve month past meteorological data in Kuching, Sibul and Miri into the green roof water balance model, the runoff generated from the green roof models were continuously simulated. When compared to the reported performances from other studies, the modeled results revealed that the high and stable evapotranspiration rate in Sarawak has moderated the unfavorable impact from tropical rainfall towards the long-term retention performance. On event basis, the green roof performed well in stormwater retention for most of the event but performed poorly during the event that potentially triggered the occurrence of flash flood with mean retention rate of 11.5% only. By performing Spearman's rank correlation analysis, the result shows that the event retention rate was inversely related to rainfall depth and mean rainfall intensity whilst the direct relationship between event retention rate and ADWP was found to be event size dependent. The modeled result also indicated that there were significant variations in monthly retention rate. Correlation analysis revealed that the monthly retention rate was inversely related to monthly rainfall depth. These results suggest that

rainfall depth is the salient meteorological factor that affects both the event and monthly retention rate in Sarawak. Understanding on the relationship between retention and meteorological factors allows the designer to enhance the retention capability of the green roof according to the characteristic of local climatic conditions. Although the result shows that green roof alone is unable to significantly contribute to urban runoff reduction, it may well provide effective and practical contribution towards urban stormwater management in Sarawak when it is incorporated with other BMPs. The modeled performance can be referred as the potential contribution of green roof alone in runoff reduction in future studies that focuses on large scale modeling with different BMPs.

Keywords: Retention, green roof, runoff modeling, urban stormwater management

Prestasi Takungan Air Hujan oleh Bumbung Hijau di kawasan Iklim Tropika Sarawak

ABSTRAK

Prestasi takungan air hujan oleh bumbung hijau sering dikaji di negara maju terutamanya di kawasan iklim sederhana. Walau bagaimanapun, kajian mengenai keupayaan bumbung hijau untuk mengekal air hujan di kawasan iklim tropika adalah terhad. Kajian ini merupakan usaha awal untuk mengkaji prestasi takungan oleh bumbung hijau di bawah iklim tropika khususnya Sarawak melalui permodelan. Sebelum proses permodelan, keupayaan takungan oleh sebuah bumbung hijau terletak di Sarawak telah dikaji. Ia menunjukkan 88.1% kadar takungan purata dan 80.8% kadar takungan kumulatif daripada tujuh hujan. Kajian ini merangkumi tujuh peristiwa hujan sahaja kerana kurang instrumen yang sesuai dan limpahan air larian dari longkang ke dalam saluran paip keluar bumbung hijau semasa peristiwa hujan yang lebat. Dengan menggunakan data meteorologi selama dua belas bulan di Kuching, Sibu dan Miri ke dalam “green roof water balance model”, air larian yang dihasilkan daripada model bumbung hijau telah disimulasikan. Apabila dibandingkan dengan prestasi yang dilaporkan dari kajian lain, hasil kajian menunjukkan bahawa kadar evapotranspirasi yang tinggi dan stabil di Sarawak telah menyederhanakan impak negatif dari hujan tropika ke atas prestasi takungan air dalam jangka panjang. Kajian menunjukkan bumbung hijau berfungsi dengan baik untuk kebanyakan peristiwa hujan tetapi prestasi kurang memuaskan semasa hujan yang berpotensi mencetuskan banjir kilat dengan kadar takungan sebanyak 11.5% sahaja. Dengan melakukan analisis korelasi Spearman, ia menunjukkan kadar takungan mempunyai hubungan songsang dengan kedalaman hujan dan intensiti hujan sementara hubungan langsung antara kadar pengekalan dan ADWP adalah bergantung kepada kedalaman hujan. Kajian juga menunjukkan terdapat perbezaan yang ketara dalam kadar

takungan bulanan. Analisis korelasi menunjukkan bahawa kadar takungan bulanan mempunyai hubungan songsang dengan kedalaman hujan bulanan. Kajian ini mencadangkan bahawa kedalaman hujan adalah faktor meteorologi utama yang mempengaruhi kedua-dua kadar takungan peristiwa hujan dan bulanan di Sarawak. Memahami hubungan antara takungan dan faktor meteorologi membolehkan jurutera untuk meningkatkan keupayaan takungan oleh bumbung hijau mengikut ciri-ciri keadaan iklim tempatan. Walaupun hasil kajian menunjukkan bahawa bumbung hijau sendiri tidak dapat memberi sumbangan yang tinggi dalam mengurangkan air larian bandar, ia masih mampu memberi sumbangan yang berkesan dan praktikal jika ia digabungkan dengan BMPs yang lain. Prestasi takungan oleh bumbung hijau dari hasil kajian ini boleh dirujuk sebagai sumbagan potensi oleh bumbung hijau sendiri dalam pengurangan air larian untuk kajian masa depan yang memfokuskan pada pemodelan skala besar dengan BMPs yang berbeza.

Kata kunci: *Takungan air hujan, bumbung hijau, simulasi air larian, pengurusan air ribut bandar*

TABLE OF CONTENTS

	Page
DECLARATION	i
DEDICATION	ii
ACKNOWLEDGEMENT	iii
ABSTRACT	iv
ABSTRAK	vi
TABLE OF CONTENTS	viii
LIST OF TABLE	xii
LIST OF FIGURE	xiv
LIST OF ABBREVIATION	xvii
CHAPTER 1 : INTRODUCTION	1
1.1 Overview	1
1.2 Background of Study Area	2
1.3 Problem Statement	5
1.4 Research Hypotheses	7
1.5 Objectives of Research	8
1.6 Scope of Study	9
CHAPTER 2 : LITERATURE REVIEW	10
2.1 Green Roof as BMP for Urban Stormwater Management	10
2.2 Green Roof Design	13
2.3 Working Mechanism of Stormwater Retention	15

2.4	Retention Performance of Extensive Green Roof	17
2.5	Retention Performance under Tropical Climate	22
2.6	Influences of Meteorological Factors on the Long-Term Retention Performance	23
2.7	Influences of Meteorological Factors on Event Retention Performance	26
	2.7.1 Rainfall Depth	26
	2.7.2 Rainfall Intensity	28
	2.7.3 Antecedent Dry Weather Period	29
2.8	Water Balance Model as Runoff Modeling Approach	31
2.9	Methods for Estimating Potential Evapotranspiration	36
	2.9.1 Thornthwaite Method	37
	2.9.2 Hargreaves Method	38
2.10	Method for Estimating Actual Evapotranspiration	40
2.11	Summary and Research Gaps	40
CHAPTER 3 : RESEARCH METHODOLOGY		45
3.1	Introduction	45
3.2	Field Monitoring	45
	3.2.1 Green Roof Description	45
	3.2.2 Data Collection	49
3.3	Runoff Modeling	51
	3.3.1 Study Area	51
	3.3.2 Modeling Approach	52

3.3.3	Input and Output of Modeling	54
3.3.3.1	Maximum Water Storage Capacity	54
3.3.3.2	Rainfall Data	54
3.3.3.3	Evapotranspiration Rate	56
3.3.3.4	Initial Substrate Moisture Content	57
3.3.3.5	Retention Rate	57
3.3.4	Model Implementation	59
3.4	Data Analysis	60
CHAPTER 4 : RESULTS AND DISCUSSION		64
4.1	Weather Profiles of the Study Period	64
4.2	Retention Rate of UNIMAS Green Roof	68
4.3	Event Retention Rate of the Green Roof Models	69
4.3.1	The Effect of Rainfall Depth on Retention Rate	70
4.3.2	The Effect of Peak Rainfall Intensity on Retention Rate	74
4.3.3	The Effect of ADWP on Retention Rate	77
4.4	Monthly Retention Rate of the Green Roof Models	81
4.4.1	The Effect of Monthly Rainfall Depth on Monthly Retention Rate	82
4.4.2	The Effect of Mean ADWP on Monthly Retention Rate	85
4.4.3	The Effect of Mean PET Rate on Monthly Retention Rate	88
4.5	Overall Cumulative Retention Rate of the Green Roof Models	91
4.6	Discussion	91
4.6.1	Retention Performance of UNIMAS Green Roof	91

4.6.2 Overall Retention Performance	94
4.6.3 Monthly Retention Performance	98
4.6.4 Event Retention Performance	104
CHAPTER 5 : CONCLUSION AND RECOMMENDATIONS	115
5.1 Conclusion	115
5.2 Limitations and Recommendations	118
REFERENCES	120
APPENDICES	128

LIST OF TABLE

		Page
Table 1.1	Population and average annual growth rate for Kuching, Sibul, and Miri	3
Table 2.1	Summary of reported retention performances from previous studies	42
Table 3.1	Result of Anderson-Darling Test for data from event retention analysis	62
Table 3.2	Result of Anderson-Darling Test for data from monthly retention analysis	62
Table 3.3	Interpretation of the strength of Spearman's rank correlation coefficient	63
Table 4.1	Rainfall characteristic and retention rate of monitored rainfall events at the UNIMAS green roof	69
Table 4.2	Spearman's rank correlation coefficients between monthly retention rate and different meteorological factors in Sarawak	99
Table 4.3	Multiple regression analysis for monthly retention rate	102
Table 4.4	Spearman's rank correlation coefficients between event retention rate and different meteorological factors in Sarawak during the Northeast monsoon (NE) and Southwest monsoon (SW)	107
Table 4.5	Spearman's rank correlation coefficients between event retention rate and ADWP for analysed events organized by rainfall depth	109

Table 4.6	Multiple regression analysis for event retention data	111
Table 4.7	Retention rate of the green roof during the identified significant events between November 2012 and October 2013	113

LIST OF FIGURE

	Page
Figure 1.1	3
Figure 1.2	5
Figure 2.1	11
Figure 2.2	14
Figure 2.3	15
Figure 2.4	15
Figure 2.5	17
Figure 3.1	46
Figure 3.2	47
Figure 3.3	47
Figure 3.4	48
Figure 3.5	48
Figure 3.6	49
Figure 3.7	50
Figure 3.8	50
Figure 3.9	51

Figure 3.10	Sequence of logical function run in Microsoft Excel 2010 spreadsheet to estimate the runoff depth	59
Figure 4.1	The weather profiles in Sarawak from November 2012 to October 2013	65
Figure 4.2	Proportion of rainfall event by rainfall depth (mm) in Sarawak during the study period	66
Figure 4.3	Proportion of rainfall event by peak rainfall intensity (mm/hour) in Sarawak during the study period	66
Figure 4.4	Proportion of rainfall event by ADWP (hour) in Sarawak during the study period	67
Figure 4.5	Proportion of rainfall event by retention rate	70
Figure 4.6	Boxplot indicating the event retention performances in Sarawak for different category of rainfall depth	71
Figure 4.7	Scatterplot of event retention rate against rainfall depth	73
Figure 4.8	Boxplot indicating the event retention performances in Sarawak for different category of peak rainfall intensity	75
Figure 4.9	Scatterplot of event retention rate against peak rainfall intensity	76
Figure 4.10	Boxplot indicating the event retention performances in Sarawak for different category of ADWP	79
Figure 4.11	Scatterplot of event retention rate against ADWP	80
Figure 4.12	Monthly cumulative retention rate in Sarawak	81
Figure 4.13	Trend of monthly retention rate and monthly rainfall depth	83

Figure 4.14	Scatterplot of monthly retention rate against monthly rainfall depth	84
Figure 4.15	Trend of monthly retention rate and monthly mean ADWP	86
Figure 4.16	Scatterplot of monthly retention rate against monthly mean ADWP	87
Figure 4.17	Trend of monthly retention rate and monthly mean PET rate	89
Figure 4.18	Scatterplot of monthly retention rate against monthly mean PET rate	90
Figure 4.19	Twelve-month cumulative retention performances in Sarawak	91
Figure 4.20	Cumulative rainfall-runoff profile of UNIMAS green roof during the rainfall event on 15 November 2014	93
Figure 4.21	Flow rate of rainfall-runoff from UNIMAS green roof during the rainfall event on 15 November 2014	93
Figure 4.22	Cumulative retention rate of the green roof models against cumulative rainfall at different locations in Sarawak and United Kingdom	96
Figure 4.23	Rainfall-runoff profile of the green roof model in Miri during November 2012	102
Figure 4.24	Rainfall-runoff profile of the green roof model in Miri during March 2013	102

LIST OF ABBREVIATION

ΔS	Change in storage
$^{\circ}\text{C}$	Degree Celsius
φ	Latitude
%	Percentage
π	Pi
δ	Solar declination
A	Surface area of green roof
ADWP	Antecedent dry weather periods
BMP	Best Management Practices
d_t	Relative distance Earth – Sun
DID	Department of Irrigation and Drainage
ET	Evapotranspiration
G_{sc}	Solar constant
h	Hour
I	Heat Index
i	Peak rainfall intensity
I_r	Irrigation
J	Number of day in the year
LID	Low Impact Development
m	Meter
mm	Millimeter
min	Minute

MJ	Megajoule
MSMA	Urban Stormwater Management Manual
N	Monthly sunshine hour
P	Precipitation / Rainfall
PET	Potential evapotranspiration
PWP	Permanent wilting point
r	Spearman's rank correlation coefficient
R	Runoff from green roof
R_a	Daily total extraterrestrial radiation
R_N	Runoff from non-greened roof top areas or building facades
R^2	Correlation of determination
S	Substrate moisture content
S_{t-1}	Initial substrate moisture content
S_{max}	Maximum water storage capacity
SCORE	Sarawak Corridor of Renewable Energy
SUStoM	Sarawak Urban Stormwater Management
SMEF	Soil Moisture Extraction Function
SUDS	Sustainable Urban Drainage System
t	Time step
T_i	Mean monthly temperature
T_{max}	Daily maximum temperature
T_m	Daily mean temperature
T_{min}	Daily minimum temperature
UK	United Kingdom

UNIMAS	University of Malaysia Sarawak
US	United States
V	Runoff volume from green roof
WHC _{max}	Maximum water holding capacity
WSUD	Water Sensitive Urban Design

CHAPTER 1

INTRODUCTION

1.1 Overview

Rapid urbanization due to increased population in the urban area has led to the replacement of more natural land and followed by rising in impervious surfaces area. Common impervious surfaces in the urban area consist of roads, sidewalks, and roof which water cannot infiltrate into the soil. Consequently, this has caused a dramatic rise in surface runoff during rainfall and causing problems in managing urban stormwater such as flash flood. Apart from this, urban flooding problem is further exacerbated when natural flood carrying capacity is reduced due to intense development within the floodplain and frequent occurrence of violent rainstorms. As a result, conventional drainage system was developed and commonly practiced around the globe which aimed to quickly collect runoff and discharged to downstream. However, occurrences of flood become more frequent when the conventional drainage system cannot cope with the increased runoff due to continuous expansion of urban area. Moreover, managing stormwater by using conventional approach might increases the flood risk at downstream. The negative impact of flood includes losses in lives and properties, disruption of social and economic activities, deterred potential investments in the flood prone area and costly recovery for flood victims and government (DID Malaysia, n.d.).

Vegetated rooftops, or commonly referred to as green roof is emerging among developed countries as the Best Management Practice (BMP) in some relatively new urban stormwater management's strategies such as the Water Sensitive Urban Design in the

Australia and Sustainable Urban Drainage System in the United Kingdom. The hydrological benefits of green roof is widely investigated and implemented in the European and North America region under the temperate and subtropical climate (Kasmin et al., 2014; Köhler et al., 2001; Mentens et al., 2005; Roehr & Beck, 2015). It helps to mitigate the impact of increased runoff in the dense urban area by restoring displaced vegetation in new development or as a retrofit option. They act as an on-site sources control to reduce runoff generation through retention mechanism from an impervious area. Advantageously, the land area required for the implementation of the green roof itself is zero when compared to other BMPs in urban stormwater management strategies (Hathaway, 2008; Roehr & Beck, 2015). Furthermore, the opportunity to install a green roof is ample because rooftops comprise a significant proportion of the total impervious and wasted area in the urban area.

1.2 Background of Study Area

Sarawak is the largest state in Malaysia, a tropical country located closely north of the equator with hot and humid tropical climate. It has three major urban centers namely Kuching City (Southern region), Sibü Town (Central region) and Miri City (Northern region) (Figure 1.1). According to the State Planning Unit of Sarawak (2015), Kuching is the capital city of the state with projected population over 700,000 in the year 2015 and the average growth rate between the year 2000 and 2010 is 1.9% per year (Table 1.1). Sibü is an inland town which functioned as the gateway to Sarawak Corridor of Renewable Energy (SCORE) and upper Rajang River. Meanwhile, Miri is a coastal town which served as a major industrial center, particularly in oil and gas industry. It was estimated that the

population of Sibu and Miri would reach approximately 250,000 and 300,000 respectively in the year 2015.

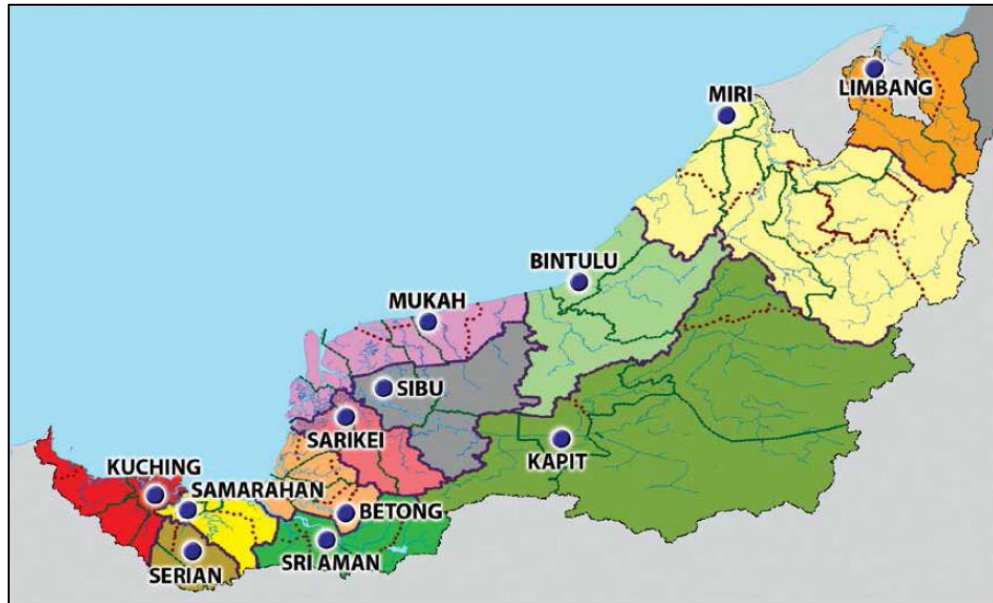


Figure 1.1: Locality map of towns and cities in Sarawak (State Planning Unit of Sarawak, 2015)

Table 1.1: Population and average annual growth rate for Kuching, Sibu, and Miri (State Planning Unit of Sarawak, 2015)

City	Population 2000	Population 2010	Population 2015 (Preliminary)	Avg. Annual Growth Rate (%) (2000- 2010)
Kuching	509,374	617,887	677,300	1.9
Sibu	218,106	247,995	249,900	1.3
Miri	228,231	300,543	319,600	2.8

In the context of climate, the state located at Borneo Island is experiencing two monsoon seasons yearly (Sarawak State Secretary, n.d). The Northeast Monsoon (Landas season) usually falls between November and February and experiencing heavy rainfall. Meanwhile, the rest of the year is known as Southwest Monsoon with comparatively less rainfall. The mean annual rainfall in Sarawak ranged from 3300.0 mm to 4600.0 mm and it

is vary according to the locality. The air temperature is relatively uniform throughout the year, which ranged from 22 °C early in the morning to 33 °C during the day (State Planning Unit of Sarawak, 2015).

The growing population in the cities of Sarawak has led to rapid urbanisation. When considering the rapid growth of urban areas and losses in green areas in recent years, there is a massive impact on the urban stormwater management planning. DID Sarawak (n.d.) stated that urbanisation is one of the main causes contributed to the occurrence of flooding in urban areas where the runoff rate is increased and flood storage is reduced as a result of development extending into and taking over flood plains and drainage corridors. In addition, it has becoming a challenging issues in managing the urban stormwater in Sarawak due to tropical rainfall which often characterized by extremely huge amount of rainwater in short period and causing inundations in the lower areas. In particular, flash flood in Sarawak commonly occurs during the high intensity, short duration, and localized rainfall event especially in the low-lying areas and natural floodplains along the river (Figure 1.2). The frequent occurrence of flash flood in the urban area even during the dry season has become a major threat to the local social-economic activities.

In order to mitigate the impacts from flooding, conventional stormwater management approach that aims to effectively capture and remove the runoff in shortest time has been implemented in Sarawak for a few decades. However, the data of recent flooding events shows that the existing conventional urban stormwater management system is still unable to effectively prevent the occurrence of flooding in the urban areas of Sarawak. The factors of urban flooding in Sarawak are mainly due to heavy downpour of rain and the pattern of urbanisation with relatively poor urban stormwater management including blockage of debris at inlet sump and drain that affects the efficiency of structural

measures to remove the runoff (DID Sarawak, n.d.).

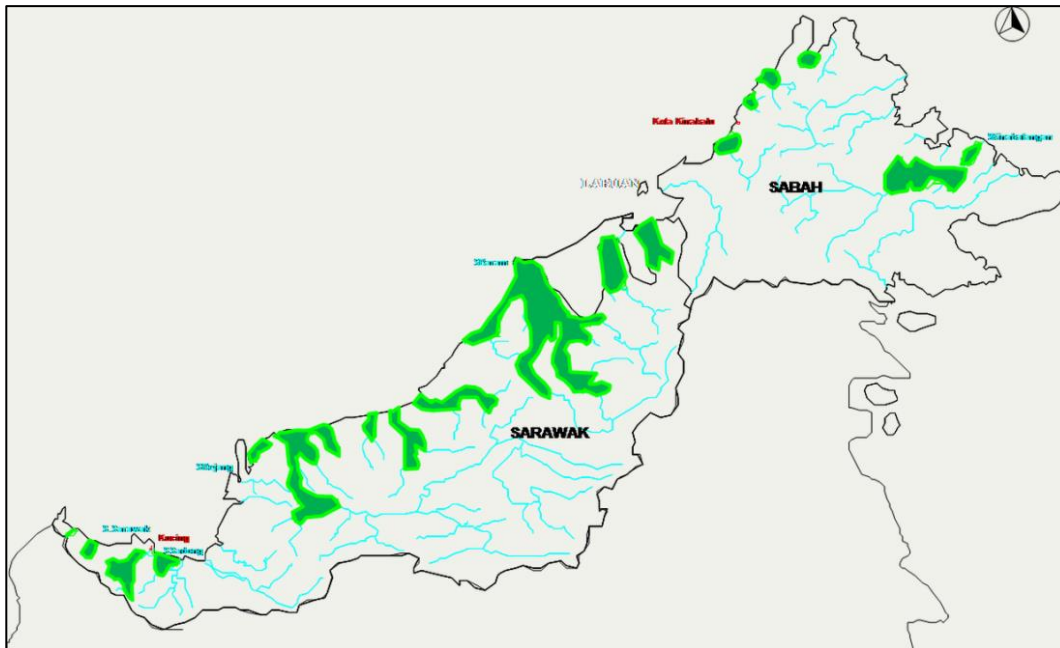


Figure 1.2: Flood prone area in East Malaysia (DID Malaysia, n.d.)

1.3 Problem Statement

In order to effectively manage the urban stormwater problems with minimal environmental damage as well as satisfying the needs for development, a new stormwater management approaches was introduced in Malaysia, known as Urban Stormwater Management Manual (MSMA). Similarly, a Sarawak Urban Stormwater Management (SUStoM) guideline was published by the DID Sarawak in the year 2016. These guidelines emphasize on “control-at-source” techniques which combine the structural measures and Best Management Practices (BMPs) to control the water quantity and quality as well as erosion and sediment control.

As one of the source level control measures, green roof has been recommended in

most of the sustainable stormwater management approaches of foreign countries as runoff quantity control measure through the mechanism of retention. Köhler et al. (2001) have suggested that hot-humid tropical regions could benefit more from the retention mechanism provided by the green roof due to the high evapotranspiration rate. Reduce in heat island effect, improve in water quality, zero land use requirement, simple installation process compare to other BMPs and high aesthetic value has further makes green roof a desired green initiatives to be adopted in the local urban stormwater management plan compared to conventional urban stormwater management system. These benefits have makes the green roofs as one of the potential BMP in managing the flooding problems in the urban area of Sarawak.

Based on the findings from existing studies, it is often reported that heavy and intense rainfall characteristic usually resulted in poor retention performance (Carson et al., 2013; Musa et al., 2011; Prowell, 2006; Voyde, 2011; Wai, Lam & Lau, 2014). Hence, it is uncertain whether the expected excellent green roof's retention performance due to the high evapotranspiration rate could be overshadowed by the heavy and intense tropical rainfall in Sarawak. On the other hand, seasonal variation of retention performance is also widely discussed in the study concerning the green roof's performance under temperate climate. Due to the significant seasonal changes in air temperature, most of the previous studies have found that green roof performed well during summer or warmer months but performed poorly during cooler months (Berghage et al., 2009; Camm, 2011; Carson et al., 2013; Chen, 2011; Hoffman et al., 2010). In addition, findings from previous studies indicated that the influence of climatic parameter on event retention rate appears to be complex and varying according to the location of green roof. Given that the local climate of Sarawak is characterized by the tropical monsoons with comparatively small fluctuation

in air temperature throughout the year, it is not practical to adopt the findings of green roof's retention performances from other studies under different climatic conditions.

At the moment, there is no standardized guideline for the design and implementation of local green roof. The manual of MSMA in Malaysia and SUStoM in Sarawak has yet to compile green roof as one of the BMPs for urban stormwater management plan. Furthermore, there is lack of local studies that explored the site-specific retention performance of an extensive green roof. Consequently, rising the awareness and implementation of green roof as part of the urban stormwater management plan in Sarawak is difficult. Therefore, there is an urged needs to preliminary investigate the potential of the green roof to serve as urban runoff quantity control measures under the climatic conditions of Sarawak. Based on the identified research gaps, the research questions for this study were:

- i. How well does an extensive green roof perform in stormwater retention under the hot-humid tropical climate in Sarawak?
- ii. How do the meteorological factors influence the event and monthly retention performances of the green roof under the hot-humid tropical of Sarawak?
- iii. What are the salient meteorological factors that affect the retention performance of an extensive green roof in the hot-humid tropical context?

1.4 Research Hypotheses

The research hypotheses of this study are:

- i. The retention rate of the green roof under the hot-humid tropical climate in Sarawak is higher compared to other climates due to higher and stable evapotranspiration rate throughout the year.

- ii. Event retention rate of the green roof in Sarawak is inversely related to the rainfall depth and rainfall intensity, and directly related to the antecedent dry weather period (ADWP) of the rainfall event.
- iii. Monthly retention rate of the green roof in Sarawak is inversely related to the monthly rainfall depth, and directly related to the mean ADWP and mean Potential Evapotranspiration (PET) rate of the respective month.
- iv. Rainfall depth is the salient meteorological factor that determines the retention performance of green roof under the hot-humid tropical climate.

1.5 Objectives of Research

Many literatures have investigated the retention performance of green roof, showing their strong variability according to several factors including the climatic conditions. However, only few studies have focused on the retention performance of the green roof under the hot-humid tropical climate conditions and defined the influencing meteorological factors on retention performance. As a result, the aim of this research is to narrow the study area to better understand how the hot-humid tropical climate of Sarawak influences the site-specific retention performances of the green roof. The aim will be accomplished by fulfilling the following specific research objectives:

- i. To demonstrate the runoff reduction capability of an extensive green roof under the actual weather conditions in Sarawak through field monitoring.
- ii. To estimate the long-term and event retention performance of the extensive green roofs across Sarawak through modeling technique.
- iii. To determine the direction and strength of relationships, if any, between retention

rate and meteorological factors of the green roof in Sarawak.

1.6 Scope of Study

This study focuses on determining the stormwater retention performance of the green roof under the tropical climatic conditions through modeling approach. The aspects looked into were the event-based, monthly and long-term retention rate, and the relationship between retention rate and specific meteorological factors. By using the green roof water balance modeling approach, the retention rate of virtual green roofs has been estimated by adopting the past meteorological data for the cities of Kuching, Sibu and Miri in between 1st November 2012 and 31st October 2013 (one year). The study has an intention to add knowledge on the capability of extensive green roof in reducing the urban runoff quantity in the tropical climate region and serve as valuable data in establishing the design guideline of green roof specifically under the tropical climatic conditions of Sarawak.

CHAPTER 2

LITERATURE REVIEW

2.1 Green Roof as BMP for Urban Stormwater Management

The growth rate of population in urban areas is rapidly increasing, causing the reduction in green spaces and replaced with large impervious areas to accommodate the development pressures. These ground surfaces such as roofs, car parks, pavement, and roads are reducing the amount of shallow infiltration, deep infiltration, and evapotranspiration while increasing the amount of runoff (Figure 2.1). Besides, impervious surfaces require the compaction of soil to prevent structural damages, sinking and settling, thus prohibiting the infiltration of rainwater into the ground. In brief, reduction in green spaces is altering the natural hydrologic cycle, including the rise in runoff volume and peak flow, and reductions in times of concentration.

Traditionally, conventional stormwater management strategy is commonly practiced where its working mechanism emphasized on effective capture and remove runoff in the shortest time. However, the effectiveness of the conventional approach in managing urban stormwater runoff is gradually reduced in constantly developing and expanding urban areas. In order to effectively manage urban stormwater problems with minimal environmental damage as well as satisfying the needs for development, a few relatively new stormwater management approaches were introduced in different countries, namely Water Sensitive Urban Design (WSUD) in the Australia, Sustainable Urban Drainage Systems (SUDS) in the United Kingdom (UK) and Low Impact Development (LID) in the United State (US). In 2001, a new Urban Stormwater Management Manual

(MSMA) was also introduced and published by the Department of Irrigation and Drainage (DID) of Malaysia. These sustainable strategies are emphasize on utilizing the mechanism of evaporating, transpiring and infiltrating stormwater through vegetation, bio-engineering measures, and natural ground condition to reduce the amount of surface runoff that close to a natural environment during rainfall events (Palla, Gnecco & Lanza, 2010).

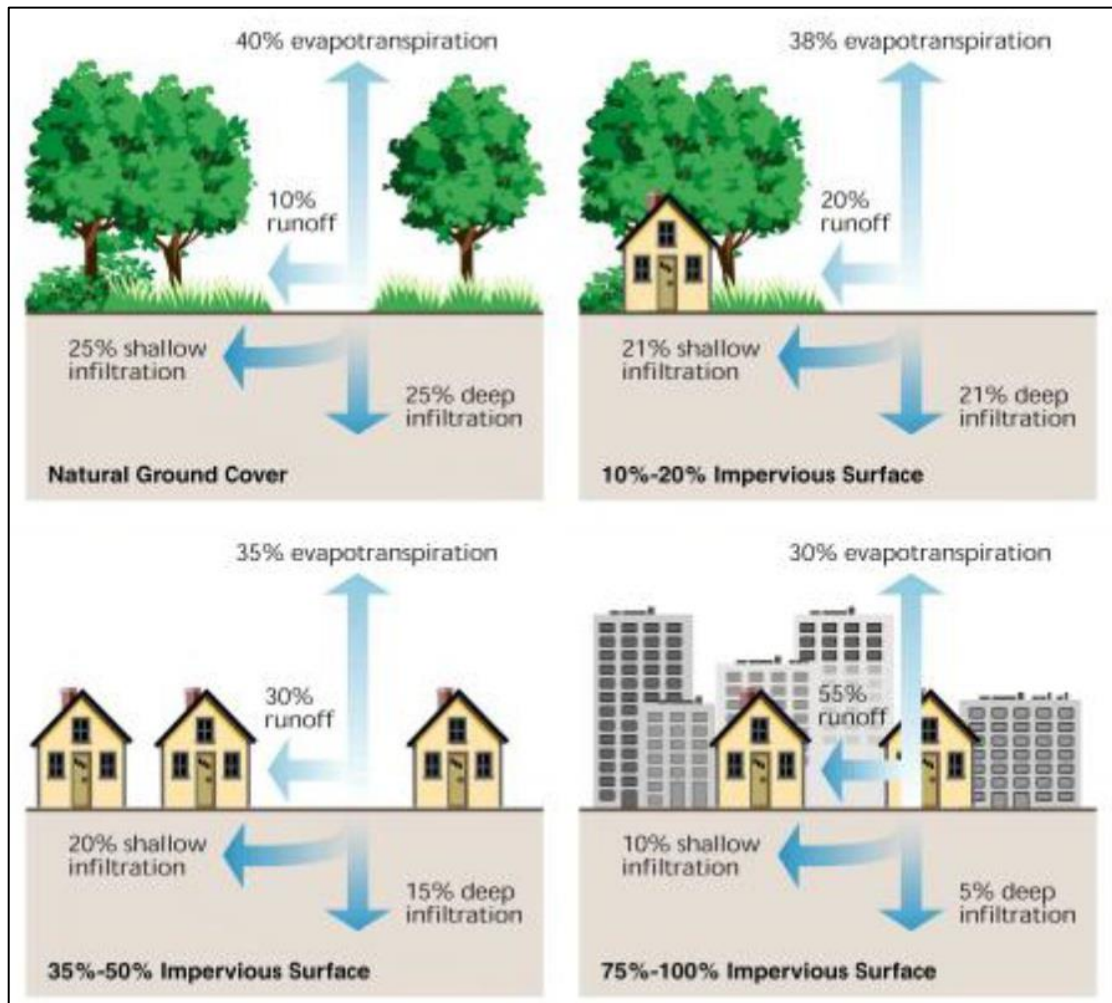


Figure 2.1: The direct relationship between impervious surface and runoff (FISRWG, 1998)

As a source level control, green roof is part of these new urban stormwater management approaches. Rooftops are generally the vacant areas that are not required for

any essential building operations, yet remain impervious and contribute to stormwater runoff. Therefore, a green roof is an ideal BMP with a significant contribution to urban stormwater management especially in dense urban areas with limited spaces. By referring to the findings from previous studies, Burszta-Adamiak (2012) has summarized the hydrological benefits of green roof into four: enable retention of stormwater, limit the maximum runoff intensity, slow down the discharge of water to the sewerage system and improve the efficiency of wastewater treatment plants during rainy periods. Although green roof has been recommended in most of the stormwater management approaches of foreign countries as a stormwater quantity control measure, the manual of MSMA in Malaysia has yet to compile green roof as one of the BMPs for urban stormwater management plan. Thus, there is no standardized guideline for the design and implementation of green roof in Malaysia.

Research and implementation of green roof was first started in Germany and followed by other European countries and North America. By considering the climatic conditions that are favorable to the growth of vegetation due to the rainfall regime throughout the year, it is common that many have assumed that the idea of green roof was mainly developed for the cold regions (Fioretti, Palla, Lanza, & Principi, 2010). In the countries beyond temperate climate region, studies concerning the hydrological performances of green roof are limited as this concept has started very late in this region compared to the European and North American countries (Krishnan & Ahmad, 2012). Among several hydrologic benefits of the green roof, retention capability of the green roof is one of the most cited hydrologic performances in existing studies. Although most of the studies have demonstrated the retention capability of the green roof through field observation or modeling approach at different locations, it was found that there are

variations in the reported retention performances from each study (Anders, 2012; Burszta-Adamiak, 2012; Carson et al., 2013; Chen, 2011; Chow et al., 2015; Fioretti et al., 2010; Gregoire et al., 2011; Hathaway et al., 2008; Krishnan & Ahmad, 2014; Lee et al., 2011; Martin, 2008; Mobilia & Longobardi, 2015; Prowell, 2006; Sherrard & Jacobs, 2012; Silvennoinen, 2014; Spengen, 2010; Stovin et al., 2007; Stovin et al., 2013; VanWoert et al., 2005; Vergroesen & Joshi, 2010; Wong & Jim, 2014). In fact, most of the studies have identified local climatic conditions as one of the factors that contributed to the variations seen between the green roofs. Thus, researchers have gained interest to investigate the site-specific retention performance of green roof.

2.2 Green Roof Design

Green roof, also known as the vegetated roof or living roof is defined as a roof with complex layered structure and partially or fully covered with vegetation (Figure 2.2). In general, a layer of waterproofing membrane and the roof protection geotextile is laid on the roof surface to keep the roots from penetrate into the roofing membrane and causing leaks, followed by a drainage layer to carry infiltrated rainwater to roof drains, and act as water storage for the plants during dry periods. In order to prevent the soil from washing away, a filter fabric is installed above the drainage layer. Lastly, a vegetation layer is placed on filter fabric with vegetation planted on the substrate, or growing medium (Palla et al., 2010). Suitable plants for vegetation layer are chosen depending on the local climate to ensure the plants are able to survive solely on the natural rainfall that reaches the roof with minimal or no irrigation.

Most of the green roof constructions are differentiated based on the thickness of

substrate growing layer and categorized in two categories: extensive (Figure 2.3) and intensive (Figure 2.4). It is common that an extensive green roof has substrate depth of 150.0 mm or below and planted with short rooting and drought resistant ground cover plants. On the other hand, intensive green roof contains substrate with thickness over 150.0 mm and planted with deeper rooting plants including shrubs and trees (Carson, Marasco, Culligan, & McGillis, 2013). Intensive green roofs have thicker layer and therefore only implemented on building designed to sustain such heavy system with continuous maintenance. Meanwhile, an extensive green roof is made of lightweight systems and do not require frequent maintenance (Palla et al., 2010). In older buildings, intensive green roofs are not a practical option as these loads may be too high. For new construction, intensive green roofs also not a favorable option due to higher construction cost resulted from the increase in construction material to support the greater load. As a result, extensive green roofs are widely applied compared to intensive green roofs especially on existing building where its implementation do not restricted by rooftop weight limitation.

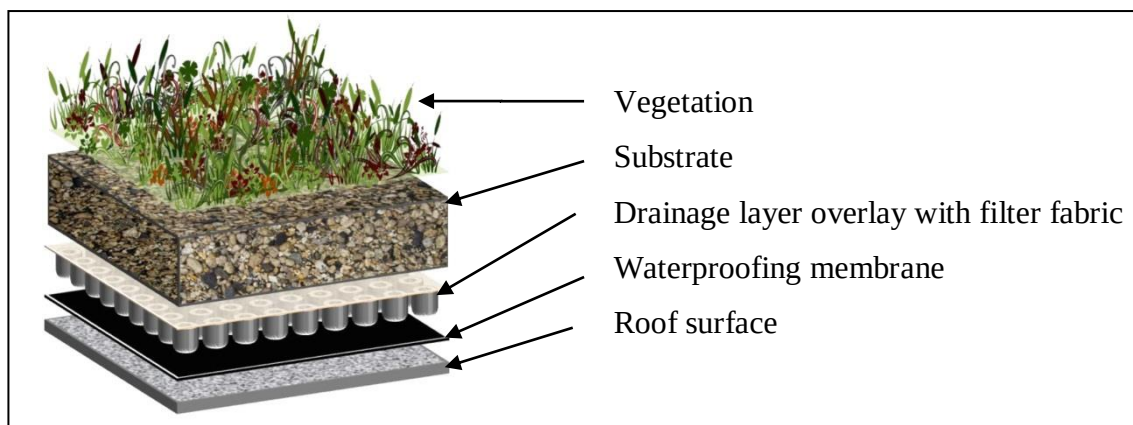


Figure 2.2: Components of an extensive green roof (Voyde, 2011)



Figure 2.3: An extensive green roof at the Ross Park Shelterhouse in Seattle, United State (Seattle Public Utilities, 2012)

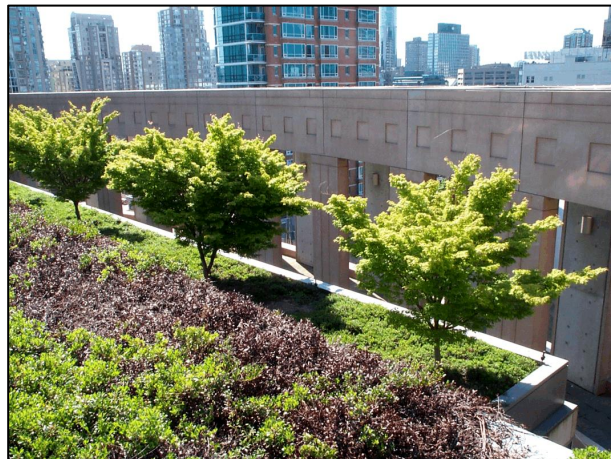


Figure 2.4: An intensive green roof at the Vancouver Public Library, Vancouver, Canada (greenroof.com, n.d.)

2.3 Working Mechanism of Stormwater Retention

The hydrological performance of green roof in term of quantity is to retain part of the stormwater. The retention is commonly represented as the percentage difference in the volume or depth between cumulative rainwater and runoff. Uhl & Schiedt (2008) described that the substrate of green roof plays a similar role with the upper soil layer as the storage

unit of stormwater. The volume of storage is provided by the pore volume of the substrate, the drainage system and surface of the vegetated layer. Paudel (2009) summarized the retention process into four main mechanisms, namely interception, absorption, evapotranspiration and runoff. Unlike a natural system in which a portion of the moisture is passed through the soil column and continues to percolate vertically to groundwater, rainwater that passes through the soil column on the green roof is intercepted by an underlying impermeable layer and routed to the building roof drains. During the rainfall events, rainwater is retained by the green roof and excess rainwater is released as runoff after the water storage capacity is fully occupied. Roehr & Beck (2015) stated that for any given rainfall event, the retention performance of a green roof is highly dependent on the water storage capacity prior to a rainfall event. Among the four mechanism summarized by Paudel (2009), evapotranspiration is the only mechanism to restore the water storage capacity by removing the rainwater retained by the green roof system during the antecedent dry weather period (ADWP). Thus, evapotranspiration rate and ADWP both plays a key role on determining the available water storage capacity of green roof system as well as the retention performance of upcoming rainfall event.

Stovin, Poë & Berretta (2013) have developed a conceptual model of moisture flux within the green roof substrate layer to illustrates how retention mechanism of a green roof vary associated with changes in environmental factors such as rainfall depth and evapotranspiration rates (Figure 2.5). According to Roehr & Beck (2015), the water which is retained by soils below the permanent wilting point is unable to be extracted by plant roots as well as not available for transpiration because this hygroscopic water is tightly held by soil particles. Thus, the difference between maximum water holding capacity (WHC_{max}) and permanent wilting point (PWP) defines the maximum water storage

capacity of the green roof ($S_{\max}$) and it is highly dependent on the configuration of each green roof.

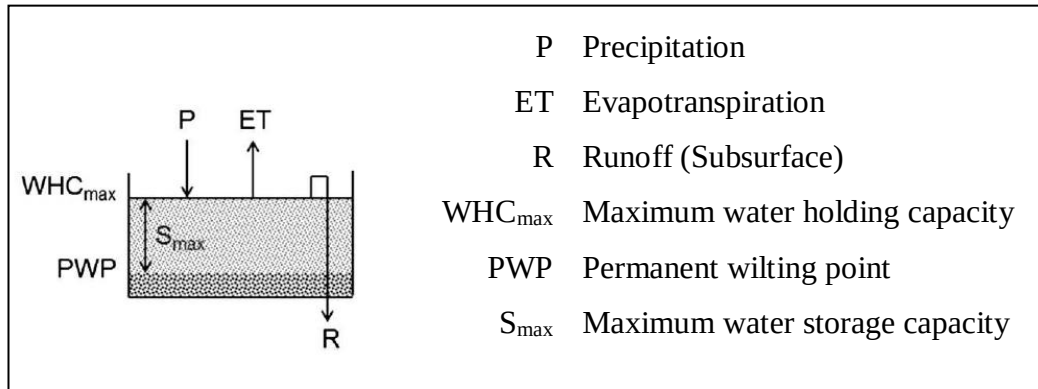


Figure 2.5: Conceptual model of moisture flux within the green roof substrate layer (Stovin et al., 2013)

It is important to note that water storage capacity is finite and the value vary according to the design of the green roof. Stovin et al. (2013) suggested that a green roof with 80.0 mm substrate depth could achieves water storage capacity of 20.0 mm while Albert (2016) estimated that growing media with 89.0 mm depth could provide a water storage capacity of about 40.0 mm. On the other hand, Bengtsson, Grahn. & Olsson (2005) found that available storage between wilting point and field capacity for a 30.0 mm soil substrate is approximately 9.0 mm. Meanwhile, VanWoert et al. (2005) estimated that the potential water retention capacities of the green roofs with media depth of 25.0 mm, 40.0 mm and 60.0 mm are 5.0 mm, 8.0 mm and 12.0 mm respectively. In general, the water storage capacity of green roof system is higher as the substrate layer is deeper.

2.4 Retention Performance of Extensive Green Roof

Numerous studies have been conducted to examine the retention capabilities of

extensive green roofs and a wide range of results have been published. At the early introduction of this approach, European and North America countries have accepted and practiced the idea of having the green roof as the measure for stormwater runoff mitigation while Asian countries just started to gain interest in the research concerning green roof in recent years. Krishnan & Ahmad (2009) reviewed the research trend and factors that affect the retention performance according to existing literatures, and summarized that the performance of a green roof is dependent on five factors, namely slope angle, vegetation, substrate, green roof age and climate. Among these factors, climate is the only external factor that highly dependent upon the location of the green roof.

The published literatures have proved that green roof is able to reduce runoff volume at different location. Most of these studies are emphasized on investigating the response of green roof system during the individual events. Meanwhile, some studies are focused on evaluating the long-term retention performance based on the monthly or seasonal retention rate of the green roof. Evaluation of event-based retention performance provides a clearer illustration on how the green roof system response to different rainfall scenario. Long-term and continuous assessments on retention performance helps to provide a realistic indicator of the expected performance of a green roof over its lifetime and moderate the variation in performance that may occur due to seasonal changes (air temperature) and unpredictable nature of rainfall events (hurricane and typhoon).

Research on the retention potential of an extensive green roof was first started by Köhler in 1985 (Köhler et al., 2001). The result indicated that the annual retention rate of a green roof in Germany was 75.0% of the entire precipitation as a median value of three years. Since then, studies have been carried out in other European countries to demonstrate the hydrological benefits of green roof across the region. For example, Silvennoinen (2014)

attempts to demonstrate the capability of the green roofs in retaining rainwater under the cold climate in Finland by monitoring several newly constructed readymade and built on site green roof platforms. The result showed that the overall retention rate ranged from 32.0% to 64.0% over the six months monitoring period. In Italy, a full-scale green roof was monitored to investigate its hydrologic behavior under the Mediterranean climate and the data presented 68.0% of mean retention rate over the 15 months of the second phase monitoring period (Fioretti et al., 2010). In Poland, two green roofs test plots have presented a promising result with mean retention rate of 82.5% and 85.7% over the one year monitoring period by excluding the snowfall occurred from December to March from the data set (Burszta-Adamiak, 2012). On the other hand, a green roof test bed in Sheffield, UK was recorded with relatively low mean retention rate of 34.0% from 11 events monitored over the spring in 2006 (Stovin, Dunnett & Hallam, 2007).

In addition to the progressive growth of green roof research in Europe, significant progress was also noticed in North America particularly in the United State. For example, Chen (2011) has monitored an extensive green roof in Pennsylvania from January 2009 to April 2011 and the result indicated that the green roof has retained 72.6% of the total runoff from 51 monitored rainfall events. In Connecticut, Gregoire & Clausen (2011) found that the monitored modular green roof system only managed to retain 41.6% of total precipitation during the treatment period under climatic conditions of Northeastern US. Meanwhile, there were several studies in the region attempted to investigate the site-specific retention performance of green roof with different design. For example, VanWoert et al. (2005) have compared the retention capability between conventional roof with gravel ballast, extensive green roof with media only and extensive green roof with vegetation in Michigan. The result indicated that extensive green roof with vegetation was recorded with

the highest overall retention rate of 60.6%. VanWoert et al. (2005) also investigated the differences in retention capability among the green roof models with various substrate depth and roof slopes. The highest overall retention rate (70.7%) was recorded from a green roof with media depth of 40.0 mm and 4% slope; while the lowest retention rate (65.9%) was observed from a green roof with media depth of 40.0 mm and 6.5% slope. In New York, three sites installed with different extensive green roof system (modular tray system, built-in-place system, and vegetated mat system) were continuously monitored and recorded with overall retention rate of 36.0%, 47.0% and 61.0% respectively (Carson et al., 2013).

By referring to the existing literatures, it was noted that there are variations in observed retention performances between the monitored green roofs across the southeast region of United States even though the climatic conditions are similar. Hathaway, Hunt & Jennings (2008) have investigated the hydrologic performance of extensive green roofs within the Eastern North Carolina's Neuse River basin and found that the green roofs have retained 64.0% of the total precipitation recorded. Similarly, green roof platforms with different soil depth and slope were found to significantly reduce the runoff under Mississippi's hot-humid subtropical climate with retention rate of 61.5% from 43 individual events (Anders, 2012). In Georgia, Prowell (2006) has followed the similar experimental design in the study of VanWoert et al. (2005) to assess the retention performance of green roof under Georgia's hot-humid subtropical climate. However, it was discovered that the retention performance is lower than the reported value from VanWoert et al. (2005) with overall retention rate of 43.0% only. The study attributed the lower retention rate in Georgia to the differences in total rainfall depth over the monitoring period. It was found that green roof in Georgia was recorded with 1400.0 mm of total

rainfall over the twelve months monitoring period compared to 556.0 mm total rainfall over the fourteen months monitoring period in the study area of VanWoert et al. (2005). The study also suggested that the absence of water retention liner or fabric is another potential factor that leads to the reduced retention performance.

In Hong Kong, a relatively low overall retention rates (11.9% - 14.1%) were noted from the green roof platforms under the local subtropical climate with frequent and heavy rainfall regime (Wong & Jim, 2014). The study suggested that the weak retention performance observed may be attributed to the frequent occurrence of heavy event during the monitoring period including a typhoon-related event with 344.0 mm rainfall. On the other hand, Lee et al. (2011) have analysed the data collected from 24 selected rainfall events and suggested that green roof could help to mitigate the urban flooding in Seoul based on the recorded high mean retention rate (90.3%). However, the size of selected rainfall events in the study of Lee et al. (2011) was only ranged from 2.0 mm to 30.9 mm and it is relatively smaller compared to the analysed event in the study of Wong & Jim (2014). Thus, it is likely that the local event size has contributes to the variations in retention performance of the green roofs between these studies under the subtropical climate.

Regardless of the wide range of reported performances across various climates and locations, most of these studies have demonstrated that stormwater retention is still an undeniable stormwater management benefit provided by the green roof. However, comparison of retention performances between the existing studies is difficult due to the differences in green roof configuration, monitoring period and climatic conditions. Thus, the site-specific retention performance of a green roof shall not be adopted from the data of another green roof for the purpose of design and planning.

2.5 Retention Performance under Tropical Climate

The idea of using green roof as stormwater management approach in the tropical climate region was first mentioned by Köhler et al. (2001) in a case study. The study revealed that retention performance of a green roof differs depending on local climate conditions particularly on the relation and the distribution between precipitation and evaporation. It was suggested that hot-humid tropical climate countries could benefit from retention capability provided by the green roof as the evapotranspiration rate under tropical climate is comparatively higher and works throughout the year. The case study has estimated an annual retention rate of approximately 65.0% of the precipitation for Rio in Brazil. However, the study also suggested that quicker saturation of the green roof's substrate in the tropical climate region has to be considered as the occurrence of storm events are considerably high compared to the temperate climate region. Thus, it is essential to investigate the influences of climate characteristic of tropical climate on the retention performance of green roof. However, studies concerning the stormwater retention performance under tropical climate are limited and most of the available studies only assessed the retention performance of small scale green roof over short monitoring period.

Among the countries in the tropical region, Singapore is the pioneer of the research in this field. In fact, retention capabilities of green roofs have been proven under the Singapore local climate conditions from several studies. For example, an extensive green roof platform in Singapore was recorded with retention rate of 57.0% with 339.0 mm of rainwater retained out of the 595.0 mm rainfall over the four separated measurement months (Spengen, 2010). Likewise, another two green roof platforms in Singapore have retained additional 55.5% and 58.0% of rainwater compared to the reference roof over the three days monitoring period (Vergroesen & Joshi, 2010). On the other hand, Qin (2013)

has recorded overall retention rate as low as 11.4% from a green roof test bed in Singapore based on the data set from limited numbers of rainfall event.

In Malaysia, Chow et al. (2015) and Krishnan & Ahmad (2014) attempted to compare the retention efficiency between green roofs planted with different species of vegetation. The result from Chow et al. (2015) shown that highest mean retention rate was seen from the green roof with a mixture of plant species (63.1%) while green roof planted with Manila grass has resulted in the lowest value (28.3%) over the 14 days monitoring period. On the other hand, Krishnan & Ahmad (2014) found that green roof planted with fern species produced the least amount of runoff compared to the green roofs planted with herb, sedum and grass species vegetation. The study also reported an overall retention rate of 28.0% from the green roofs based on the data from 31 individual rainfall events. Meanwhile, Musa et al. (2011) have performed a study that aims to obtain the effectiveness of the green roof in stormwater retention under Malaysia local climate. Based on the data from three individual events, the result indicated that the event retention rates were ranged from 16.7% to 47.9%. Generally, it can be seen that most of these studies emphasized on investigating the retention performances of small scale green roof over a short monitoring period. There is a lack of study attempts to understand how the local climate affects the retention performance of green roof under wide range of rainfall scenario.

2.6 Influences of Meteorological Factors on the Long-Term Retention Performance

In recent years, some researchers have gained interest in assessing the long-term retention performances of the green roof. Martin (2008) suggested that subdividing long-

term data into shorter reporting periods helps to ensure the variable behavior is adequately described and can be accounted for in the design and analysis process. It is common that the long-term retention performance is assessed by referring to the monthly or seasonal retention rate. These studies usually monitored the green roof over a period of not less than six months to clearly reflect the fluctuations in retention performances between the months or seasons. For example, Hoffman et al. (2010) have monitored a green roof in New York and found that the monthly retention rate was ranged from 17.0% to 72.0% over the course of a year. Sims (2015) suggested that interpreting retention performance of green roof must account for the duration of the study especially for those green roofs performed under the climate with major seasonal fluctuation. Retention performance of a green roof that monitored over particular season or month might create bias and does not accurately reflect the site-specific retention performance.

By referring to the previous studies, it is common that the retention performances of a green roof in temperate climate region were higher in the summer or warmer months of the year (Berghage et al., 2009; Camm, 2011; Carson et al., 2013; Chen, 2011; Hoffman et al., 2010). Some studies suggested that the higher retention performances observed during the summer or warmer months is caused by the high evapotranspiration rate. For example, Sims (2015) suggested that larger water storage capacity generated from high evapotranspiration rates during the hot summer months has contributed to the minimal runoff observed from the green roof in Ontario between mid-May and early September. Meanwhile, Hoffman et al. (2010) and Uhl & Schiedt (2008) stated that the poor retention performance observed during the winter was due to retention storage of green roof that decreases with lower evapotranspiration rate.

In North Carolina, Hathaway et al. (2008) discovered that evapotranspiration rate

has an effect on the retention performance of green roofs. The data indicated that the monthly retention rate in December 2003 was lower than September and October 2003 even though the monthly rainfall depth was similar. It was found that the monthly Potential Evapotranspiration (PET) rate during December 2003 (6.9 mm/month) was significantly lower compared to September and October 2003 (96.0 mm/month and 51.0 mm/month). However, the assumption that warmer or summer months would result in higher monthly retention cannot be applied to the green roof under temperate climate with wet-warm summer such as Hong Kong. Given that other conditions are similar, Wong & Jim (2014) suggested that the green roof would performs better during the dry-warm fall in Hong Kong where the evapotranspiration rate is the highest compared to other season.

A study conducted by Hathaway et al. (2008) revealed that the variations in monthly retention rate for green roofs in North Carolina were caused by the amount of rainfall for the respective month and monthly rainfall pattern. In Seattle, it was found that the retention rate of monitored green roofs during the months of the rainy season was much lower than the drier month (Seattle Public Utilities, 2012). Meanwhile, Hoffman et al. (2010) discovered that occurrence of extreme event with huge amount of rainfall has significantly contributed to the total runoff. The monthly and seasonal retention rates were elevated after the extreme events were removed from the analysis. In brief, these studies revealed that the monthly retention rate is inversely related to the amount of monthly rainfall.

Apart from the impact of larger volume of monthly rainfall, Camm (2011) found that short ADWP has contributed to the lower monthly retention rate observed from the monitored green roof during the months with increased frequency of rainfall event. Similarly, Hathaway et al. (2008) found that frequent rainfall events in spring have reduced

the monthly retention rates in April and May 2003 compared to September and October 2003. Theoretically, the water storage capacity of the green roof system will be reduced during a period of frequent rainfall due to shorter ADWP for the substrate to fully restore its water storage capacity. Thus, it is thought that the months with short mean ADWP would result in lower monthly retention.

Although significant seasonal variation in retention performances is often observed in most of the studies, Voyde (2011) and Carson et al. (2013) have found that there is no significant difference in retention performances between the seasons for the monitored green roofs in Auckland and New York. Carson et al. (2013) discovered that the small variation between seasonal performances from two of the monitored green roofs in New York was due to the event size distribution within each season and it has masked the actual seasonal trends. The result revealed that the retention performance of heavy event did not result in expected higher retention rate during the season with higher evapotranspiration. Meanwhile, Voyde (2011) explained that the small variation in seasonal retention performances of green roof in Auckland was likely due to the relatively small climate variation between the most extreme seasons (summer and winter). The study suggested that sub-tropical climate with relatively narrow variation seasonally and frequent small rainfall events will be favorable to maintain the effectiveness of green roof's retention capability throughout the year.

2.7 Influences of Meteorological Factors on Event Retention Performance

2.7.1 Rainfall Depth

Rainfall depth of an event is one of the most discussed meteorological factors in

existing studies. Theoretically, runoff should not begin to release from the green roof system prior to the saturation of field capacity by rainwater (Rohr & Beck, 2015). During a large event, it is easier for the water storage capacity of green roof system to be fully occupied (moisture content restored to field capacity) by increased moisture content. Consequently, runoff will be produced from the green roof during a heavy event. On the other hand, a smaller event could increase the substrate moisture content too but it is insufficient to fully occupy the water storage capacity (Berretta, Poë & Stovin, 2014). Hence, zero or little runoff will be produced from the green roof during a light event.

It is common that an inverse relationship was found between event retention rate and rainfall depth (Carson et al., 2013; Prowell, 2006; Voyde, 2011). In addition, excellent retention performance for a light event is frequently observed from other studies too (Burszta-Adamiak, 2012; Chen, 2011; Hoffman et al., 2010; Prowell, 2006). After organizing all rainfall events according to the event size and averaged the event retention rate within each category, some studies have displayed a consistent decreasing trend of mean retention rate with increased event size (Anders, 2012; Prowell, 2006; VanWoert et al., 2005; Wong & Jim, 2014). For example, four model-scale green roofs in Hong Kong with different substrate composition and substrate depth have presented a decrement trend in retention performance with mean retention of 72.6% - 83.9% for light events (below 2.0 mm), 35.9% - 46.7% for medium events (2.0 mm to 10.0 mm) and 15.7% - 18.9% for heavy events (above 10.0 mm) (Wong & Jim, 2014).

Based on the data recorded from the monitored green roof, Chen (2011) has been unable to develop a clear relationship between the retention rate and rainfall depth due to lack of data from the large storm. By plotting the retention rates against rainfall depth, some studies have found a decreasing trend from the scatterplot with considerable spreads within

the data where some of the large events have resulted in satisfactory retention performance while some small events were only partially retained by green roof (Camm, 2011; Spengen, 2010; Voyde, 2011). On the other hand, Carson et al. (2013) and Spengen (2010) found that some larger event size category has presented higher mean retention rate compared to smaller event size category. Spengen (2010) suggested that the irregularity observed was likely due to the small sample size of each category and the influences of ADWP. Although there is substantial variability in the magnitude of impact from rainfall depth towards retention performance among existing studies, most of these studies have agreed that rainfall depth is one of the meteorological factors that influences the retention performance of the green roof.

2.7.2 Rainfall Intensity

Among the meteorological factors cited in existing studies, the findings concerning the relationship between rainfall intensity and retention performance is comparatively limited. According to Hui & Chu (2009), the influences of rainfall intensity on retention performance of a green roof appear to be related to the infiltration capacity of the substrate layer. During an event with increased rainfall intensity, it would result in an increase of the average size of raindrops too. Then, the soil aggregates of the substrate layer are breakdown into fine soil particles by the kinetic energy of raindrops from the high-intensity event and driven into the upper soil pores when raindrops hitting the soil surface. Consequently, a thin but dense layer is formed at the soil surface and reduces the infiltration capacity of the green roof system. In short, the retention capability of the green roof system decreases with increased rainfall intensity due to reduced infiltration capacity.

In accordance to the explanation of Hui & Chu (2009), some studies have demonstrated that the retention rate decreases as the rainfall intensity increases (Musa et al., 2011; Wai, Lam & Lau, 2014). For example, Wai et al. (2014) discovered that the mean retention rate of event category of the green roof in Hong Kong was reduced with increased rainfall intensity. The result indicated that the mean retention rate for rainfall intensity size of 10.0 mm/h, 30.0 mm/h, 50.0 mm/h, 70.0 mm/h and 100.0 mm/h were 69.6%, 38.9%, 22.4%, 20.6% and 12.0% respectively. However, the relationship between the variables has yet to be thoroughly analysed. On the contrary, a green roof in Seattle has produced more runoff during a low-intensity event compared to the higher intensity event that happened earlier in the rainfall sequence (Seattle Public Utilities, 2012). It was found that the retention rate observed during the low-intensity event was lower due to the cumulative effects of both the residual soil moisture and the total volume of rainfall from the high-intensity event.

2.7.3 Antecedent Dry Weather Period

Several existing studies have agreed that retention performance of green roof is dependent upon the period of time between rainfall events, or commonly referred to the antecedent dry weather periods (ADWP) (Berghage et al., 2009; Qin, 2013; Stovin et al., 2007). Rohr & Beck (2015) stated that the retention capability of a green roof system is depends on the available water storage capacity which governed by several factors including the ADWP. The role of ADWP in retention mechanism of a green roof system is controlling the antecedent substrate moisture conditions by providing more time for evapotranspiration of antecedent moisture from the substrate. In other words, a longer

ADWP would result in better retention performance on subsequent rainfall event as the available water storage capacity is higher.

Most of the previous studies only demonstrated the effect of ADWP on retention performance by presenting the differences in retention performance between categories of longer and shorter ADWP. For example, Fioretti et al. (2010) showed that the retention rates for all events from a green roof in Italy fall below 20.0% when the ADWP was less than 96 hours and the volume reduction declined to zero for all events with the ADWP lower than 12 hours. Based on the data from a green roof in Ontario, Camm (2011) found that the mean retention rate of events with ADWP less than or equal to 48 hours was 34.0% and it was elevated to 77.7% when the ADWP exceeded 48 hours. The study also suggested that ADWP has more influence on the retention performance of the monitored green roof than event size. In general, these studies have demonstrated that the green roof would have improved retention performance when the ADWP is longer. Meanwhile, Vergroesen & Joshi (2010) have attributed the wide differences in the reduction of runoff volume (13.6% to 98.8%) observed from the green roof platforms in Singapore to the variations in ADWP. It was explained that the influences of other changing parameters on the variation of runoff are negligible since the local climate is extremely constant. However, there is no further investigation on the influences of ADWP on retention rate was performed in the study.

Based on the data recorded from the monitored green roofs, Spengen (2010) and Voyde (2011) attempted to determine the strength of the association between retention rate and ADWP. The result from the correlation analysis indicated that the correlation between the variables was relatively weak. Spengen (2010) discovered that the relationship between the variables becomes more pronounced when only events with rainfall depth above 10.0

mm were selected for analysis. It was suggested that ADWP is not a good predictor of retention performance because retention capacity can still be high when the ADWP is low because of small antecedent rain event after a long dry weather period.

2.8 Water Balance Model as Runoff Modeling Approach

Evaluating green roof retention performance from the modeled result is commonly practiced when there are limitations in instrumentation and uncontrolled weather conditions. An accurate model allows for better prediction of green roof performance and therefore improves the design and placement of green roof. To date, most models for water retention by green roof have been empirically constructed. Some of the developed models are event based and only work on the scale of one event while some are capable of long-term simulations. Selection of an appropriate model depends on the objective of studies. For efficiency and responsibility of practice, Roehr & Beck (2015) suggested that the simplest model appropriate to the level of detail required or data available should always be chosen. When only the amount of runoff from a rooftop is emphasized, a green roof specific process model is the suitable approach if adequate data are available.

Water balance model is one of the process-based models that aim to investigate the hydrological effects of green roofs. It was applied in several studies to investigate the site-specific retention performance of the green roof model at different locations, including Ontario in Canada (Martin, 2008), Southern Italy and Western Germany (Mobilia & Longobardi, 2015), Georgia (Prowell, 2006) and New Hampshire (Sherrard & Jacobs, 2012) in the United State and United Kingdom (Stovin et al., 2013). Process-based model required inputs from local weather data that provide a means to account for differences in

climate and typology (Carson, 2014). Thus, it serves well in estimating the retention performance of green roof according to the characteristic of local climate. In general, it is based on the water balance principle as follows:

$$\text{Input} = \text{Output} + \Delta S \quad (\text{Equation 2.1})$$

In a green roof water balance system, the input is the precipitation (rainfall, snow and hail) that entered the system, while the output is the runoff, evapotranspiration and the storage terms accounts for storage differences in the green roof media. The input data for precipitation is commonly refers to the past rainfall data for the location of interest. The available water storage represents the potential for rainwater retention at any time. Meanwhile, the evapotranspiration rate is estimated according to the local climate, vegetation, maximum water storage capacity of green roof system and the substrate moisture content. The model accounts all sources and fluxes of water in a defined system by balancing the inputs and outputs of water with water storage. Thus, it helps to estimate the quantity of unknown water balance component at a specific time and location based on the differences between the known components. In brief, these terms are organized into the following form to calculate runoff from a green roof:

$$R = P + I_r + R_N - ET - \Delta S \quad (\text{Equation 2.2})$$

Where;

R = green roof runoff

P = rainfall

I_r = irrigation

R_N = runoff from non-greened roof top areas or building facades

ET = evapotranspiration

ΔS = change in storage

By using the water balance model to simulate runoff, it is assumed that the runoff is produced by green roof system once the input exceeded the available water storage capacity of green roof. The generation of runoff from the green roof model is determined based on the assumption as follows:

If input < Available water storage capacity, then no runoff occurs

If input > Available water storage capacity, then runoff occurs

Based on similar theory, Stovin et al. (2013) have developed equations to simulate the amount of substrate moisture content (S) and runoff (R) from the green roof system at a specific time step (t) by referring to the amount of precipitation (P), maximum water storage capacity (S_{max}), initial substrate moisture content (S_{t-1}) and evapotranspiration (ET) as shown in Equation 2.3 and Equation 2.4. The equations balanced the water balance model at a fixed time step, and then update the substrate moisture content and runoff. The validity of the retention model was tested by comparing the simulated data with a continuously monitored extensive green roof test bed in Sheffield, UK. The finding showed that the estimated cumulative runoff profile from this model has a high accuracy with the observed cumulative runoff profile. The model was also adopted to simulate the runoff from green roofs from four locations in the UK based on the 30-years historical

weather data. The modeled result revealed that the overall retention rates for green roofs in Northwest Scotland, Cornwall, Sheffield and East Midlands were 19.2%, 33.3%, 39.7% and 59.1% respectively.

$$R_t = \begin{cases} 0, & S_{t-1} + P_t - ET_t \leq S_{\max} \\ P_t - (S_{\max} - S_{t-1}) - ET_t, & S_{t-1} + P_t - ET_t > S_{\max} \end{cases} \quad (\text{Equation 2.3})$$

$$S_t = \begin{cases} S_{t-1} + P_t - ET_t, & S_{t-1} + P_t - ET_t \leq S_{\max} \\ S_{\max}, & S_{t-1} + P_t - ET_t > S_{\max} \end{cases} \quad (\text{Equation 2.4})$$

Similarly, Mobilia & Longobardi (2015) have used another water balance-based conceptual German approach known as “LANGZEIT” to evaluate the retention performance of the green roof models under the Mediterranean and Oceanic climate between the year 2004 and 2007. The components of the model are similar to the model of Stovin et al. (2013). The modeling study revealed that the green roof’s long-term retention under the Mediterranean climate was almost half of the ones under Oceanic climate with overall retention rates of 57.0% and 90.0% respectively. In terms of seasonal performance, both green roofs appeared to perform better during the spring and summer but the performances were poorest during the autumn.

Water balance model considers the storage changes during the ADWP in the modeling process. The capability of the model in estimating runoff according to antecedent moisture conditions of the green roof system was proven in previous studies. For example, Sherrard & Jacobs (2012) observed that the green roof at University of New Hampshire has resulted in retention rate below 75.0% at most of the time during events with rainfall depth over 10.0 mm. Nevertheless, the model has successfully predicted higher retention

rate of 88.0% from the green roof during an event with rainfall depth above 10.0 mm after a very dry antecedent condition.

There are several limitations in using green roof water balance model as runoff modeling approach have been noticed and discussed existing studies. Firstly, the variations of the observed and simulated values are dependent upon the accuracy of estimated evapotranspiration values in the equation. Prowell (2006) attributed the variation seen between measured and simulated result in the study to the application of average evapotranspiration over a month in the water balance equation. The study found that the variation in local daily air temperature within a month can reach 15 °C and this is not accounted in water balance model. Thus, the change in the storage of green roof substrate was not accurately estimated and affected the simulated amount of runoff produced by the green roof. Sherrard & Jacobs (2012) also noticed that the water balance model appeared to slightly underestimate the storage restoration from evapotranspiration during a prolonged drying period.

Another limitation noted from the previous studies is that the model does not accurately reflect the delays in runoff produced by green roof because the model assumes runoff occur right after the available storage is fully occupied by rainwater. Prowell (2006) found that simulated values consistently delayed the runoff from the green roof longer than the measured values. It was suggested that the runoff might occurs earlier before the maximum water storage capacity is reached or delayed under actual conditions compared to modeled result due to the flow dynamics in the unsaturated soil media. However, the overall retention for the rainfall event from measured and simulated values was still similar. The result indicated that only two of the eighteen events differed more than 10.0% between simulated and measured values. Although the time related hydrologic behavior of green

roof cannot be accurately simulated from the green roof water balance model, this simple modeling approach still performs well in predicting the runoff quantity as proven in previous studies.

2.9 Methods for Estimating Potential Evapotranspiration

From the stormwater management perspective, evapotranspiration rate from a green roof plays a vital role as it is the only mechanism to restore the water storage capacity in the system during the ADWP and allows the green roof to retain more rainwater in the subsequent rainfall event. The mechanism is the combined effect of transpiration of moisture as vapor on the leaves of the plant, and evaporation of water from the soil or substrate (Roehr & Beck, 2015). Direct measurement of evapotranspiration is the most accurate method but it can only be achieved by using a lysimeter which involves significant investment and additional expenses for maintenance. Therefore, estimating evapotranspiration based on the Potential Evapotranspiration (PET) is a popular alternative when there is difficulty of obtaining accurate field evapotranspiration. According to Berretta et al. (2014), Potential Evapotranspiration rate is the expected evapotranspiration rate associated with a crop under well-watered conditions. Therefore, actual evapotranspiration rate will fall below the PET rate when access to soil moisture becomes restricted.

There are numerous empirical or semi-empirical equations have been developed for estimating PET rate based on the meteorological data. Predictive methods for estimating PET rate are roughly divided into three categories: temperature based equations, energy balance methods and combination equations (Voyde, 2011). Among the developed

methods, FAO-56 Penman-Monteith is the equation recommended by the World Meteorological Organization where it can precisely estimate the PET in both arid and humid climates but the low availability of the inputs data limits its application in most of the studies. On the other hand, temperature equations provide one of the simplest means of calculating PET rate because the method does not require significant amounts of data and availability of the input data is high.

2.9.1 Thornthwaite Method

According to Alkaeed et al. (2006), it is common that Thornthwaite method underestimates the PET rate in the arid area and likely to overestimate the PET rate in the humid area when air surface temperature is applied. In China, Chen et al. (2005) found that there are great differences in the annual and seasonal estimated PET value between Thornthwaite and FAO-56 Penman-Monteith method. The study suggested that the application of Thornthwaite method in China may be problematic as the method was developed based on the climatic condition in the eastern US. Nevertheless, Thornthwaite equation is still one of the popular methods in estimating the PET rate since the input data can be easily collected from most of the weather station. In general, the Thornthwaite (1948) equation is expressed as follows:

$$PET_0 = 16 \left(\frac{N}{12} \right) \left(\frac{1}{30} \right) \left(\frac{10T_i}{I} \right)^a \quad (\text{Equation 2.5})$$

Where;

$$I = \sum_1^{12} \left(\frac{T_i}{5} \right)^{1.514} \quad (\text{Equation 2.6})$$

$$a = (492390 + 17920I - 771I^2 + 0.675I^3) \times 10^{-6} \quad (\text{Equation 2.7})$$

T_i = mean monthly temperature (°C)

N = monthly sunshine hour

2.9.2 Hargreaves Method

Since the introduction of Hargreaves method, it has been assessed in several studies by comparing the result with the PET rate estimated from the FAO-56 Penman-Monteith method. For example, Alkaeed et al. (2006) discovered that the PET values estimated from Hargreaves method are highly correlated with the FAO-56 Penman-Monteith method and recommended the use of Hargreaves method when other reliable data are lacking. Similarly, Temesgen et al. (2005) found that the Hargreaves method performs well in estimating the PET rate for most location in California, but the daily PET rate was overestimated under the low wind speed and high humidity conditions while daily PET rate was underestimated under the high wind speed and low humidity condition. In Malaysia, Tukimat et al. (2012) also evaluated several PET methods in estimating the evapotranspiration rate in Kedah. The result suggested that Hargreaves method is capable of estimating the local evapotranspiration rate with minimum error. In brief, the 1985 Hargreaves equation (Hargreaves & Samani, 1985) is expressed as follows:

$$PET_0 = 0.0023(0.408R_a)(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} \quad (\text{Equation 2.8})$$

Where;

PET_0 = potential evapotranspiration rate (mm day⁻¹)

T_{mean} = daily mean temperature (°C)

T_{max} = daily maximum temperature (°C)

T_{min} = daily minimum temperature (°C)

R_a = daily total extraterrestrial radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$)

0.408 = factor to convert MJ m^{-2} to mm

Then, the daily total extraterrestrial radiation is determined by using equation developed by Duffie & Beckman (2013) as shown in Equation 2.9, or after simplified as shown in Equation 2.10.

$$R_a = \frac{24(60)}{\pi} G_{SC} d_t (\omega_s \sin \varphi \sin \delta + \cos \varphi \cos \delta \sin \omega_s) \quad (\text{Equation 2.9})$$

$$R_a = 37.6 d_t (\omega_s \sin \varphi \sin \delta + \cos \varphi \cos \delta \sin \omega_s) \quad (\text{Equation 2.10})$$

$$d_t = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right) \quad (\text{Equation 2.11})$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right) \quad (\text{Equation 2.12})$$

Where;

R_a = daily total extraterrestrial radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$)

G_{SC} = solar constant ($0.0820 \text{ MJ m}^{-2} \text{ min}^{-1}$)

d_t = relative distance Earth – Sun

δ = solar declination

ω_s = $\arccos(-\tan \varphi \tan \delta)$

φ = latitude, negative for Southern hemisphere

J = number of day in the year (between 1 and 365)

2.10 Method for Estimating Actual Evapotranspiration

It is important to note that the estimated PET only represents the evapotranspiration under well-watered conditions. Under actual conditions, it is hard for the green roof system to be constantly maintained under the well-watered conditions. Thus, the evapotranspiration rates will fall over time during the ADWP with the losses of moisture. In order to accurately estimate the change of evapotranspiration over time, Zhao et al. (2013) has developed a method for estimating the actual evapotranspiration under the conditions of restricted moisture availability known as the Soil Moisture Extraction Function (SMEF) model. The model considers the change in the substrate moisture condition while estimating the actual evapotranspiration from the PET value. This method describes the evapotranspiration as a function of PET multiplied by the ratio of actual moisture content to the field capacity of the substrate. In accordance with the description of the conceptual hydrological flux model (Figure 2.5), the field capacity term was replaced by the maximum water storage capacity ($S_{\max}$) in the denominator as shown below:

$$ET_t = PET_t \times \frac{S_{t-1}}{S_{\max}} \quad (\text{Equation 2.13})$$

2.11 Summary and Research Gaps

As summarized in Table 2.1, the findings from the studies concerning the green roof have shown large variation in the retention performances. The reported cumulative retention rate from existing studies ranged from 11.9% in Hong Kong to 72.6% in Pennsylvania, US. Meanwhile, the reported mean retention rates were comparatively higher,

with values ranging from 28.3% in Malaysia to 90.3% in South Korea. Apart from the design of green roof and monitoring period, most of the literatures have attributed the influences of different meteorological factors on the reported retention performances. Among the meteorological factors, rainfall depth is often reported as the meteorological parameter that has noticeable influences the retention performance of the individual event, followed by ADWP and rainfall intensity. Most of the findings from previous studies have shown that the retention performance was improved during the event with lower rainfall depth, smaller rainfall intensity or longer ADWP. However, some studies have discovered contrary result and suggested that conflicted relationships were complicated by other factors.

Exploring the seasonal changes of retention performance of green roof is another topic that has been focused in previous studies. It has been found in several studies concerning the retention performance of green roof under temperate climate that green roof performs better in retention during the warmer month or summer. Fluctuation of evapotranspiration rate is often reported as the factor that causes the variations in the seasonal performances. Apart from this, few studies have discovered that the retention performance of green roof between months or season is affected by the monthly rainfall depth and ADWP. However, some studies have found that there is no significant variation in the monthly retention performance throughout the year. It was suggested that the findings are likely due to the event size distribution within each season and relatively small climate variations.

Table 2.1: Summary of reported retention performances from previous studies

Study	Cumulative Retention (%)	Mean Retention (%)	Location	Duration	Roof Type	Media Depth (mm)
Anders (2012)	61.5	-	Mississippi, US	10.5 months	Model	102-152
Burszta-Adamiak (2012)	-	82.5 85.7	Poland	12 months	Model	-
Carson et al. (2013)	36.0 47.0 61.0	-	New York, US	13 months	Building	32 100 100
Chen (2011)	72.6	-	Pennsylvania US	28 months	Building	100
Chow et al. (2015)	-	28.3 - 63.1	Selangor, Malaysia	14 days	Model	-
Fioretti et al. (2010)	-	68.0	Italy	15 months	Building	200
Gregoire et al. (2011)	41.6	-	Connecticut, US	12 months	Building	102
Hathaway et al. (2008)	64.0	-	North Carolina, US	15 months	Building	75 100
Krishnan & Ahmad (2014)	28.0	-	Johor, Malaysia	62 days	Model	100
Lee et al. (2011)	-	90.3	Seoul, South Korea	35 months	Building	100
Prowell (2006)	43.0	67.0	Georgia, US	12 months	Model	100
Silvennoinen (2014)	32.0 – 64.0	-	Finland	6 months	Model	60 100
Spengen (2010)	57.0	75.0	Singapore	4 separated months	Platform	120
Stovin et al. (2007)	-	34.0	Sheffield, UK	Spring	Model	80
VanWoert et al. (2005)	60.6 – 70.7	-	Michigan, US	14 months	Model	25-60
Vergroesen & Joshi (2010)	-	55.5 58.0	Singapore	3 days	Model	150
Wong & Jim (2014)	11.9 - 14.1	38.9 - 45.3	Hong Kong	10 months	Model	40-120

In general, most the prior studies have focused on assessing the retention capability of the green roof and investigating the relationships between different meteorological

parameters and retention performances, particularly under the temperate climate region. At the moment, knowledge on how hot-humid tropical climate influences the retention performance of an extensive green roof is very limited. By far, there are only a few studies were conducted to assess the retention performance of the green roof at peninsular Malaysia and Singapore. The focuses of these studies are mainly placed on determining the efficiency of a given design green roof on reducing the runoff quantity and compared the performance of green roofs with different design and configuration. There is a lack of study that focuses on investigating the influences of various meteorological parameters toward the retention performance. By considering the great differences between the temperate climate and hot-humid tropical climate which characterized by the considerably high rainfall and air temperature throughout the year, it is unpractical to adopt the result from other studies to assess the retention performance of green roof under the tropical climate.

By referring to the identified research gap, this study attempts to developed the relationships between the different meteorological factors and retention performance, and assess the retention performance of an extensive green roof under the hot-humid tropical climate. In particular, emphasis is placed on studying the green roof's retention performance in Sarawak. Continuous modeling is performed to simulate the runoff from green roof in long-term by using the green roof water balance model and past meteorological data. The findings aim to provide the potential retention performances of the green roof under different rainfall scenarios in Sarawak including those events that could trigger the occurrence of flash flood. Aside from the acceptance of local, absence of proper design guidelines for green roof is one of the constraints that lead to lack of implementation of this BMP in Sarawak. It is hoping that well understanding on how the

meteorological factors influences the retention performance under Sarawak's tropical climate could be valuable information for designer, developer or policymakers when designing a green roof to optimize its retention performance according to local climate conditions while adhering to the weight restriction of rooftop.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

In order to achieve the research objectives, this study was conducted in two parts. The first part of this study aims to collect the rainfall-runoff data from an extensive green roof under the actual rainfall event. This section attempts to demonstrate the capability of an actual green roof to reduce stormwater runoff under the Sarawak's climatic conditions prior to the modeling. By using the green roof water balance model, the second part of this study focuses on runoff modeling for the green roof models based on a set of given meteorological conditions. By referring to the result, the green roof retention performance under the hot-humid tropical climate of Sarawak was assessed. In addition, the analysis section determines how different meteorological factors affect the event retention and monthly retention of a green roof. In brief, the flow of methodology to achieve the research objectives is illustrated in Figure 3.1.

3.2 Field Monitoring

3.2.1 Green Roof Description

The experimental site is an extensive green roof located at the East Campus of UNIMAS, Kota Samarahan (1.460824 N, 110.452699 E) (Figure 3.2). The monitored green roof is one of the components of MSMA pilot project in Sarawak and functioned as a

permanent reinforced concrete motorcycle shed (Figure 3.3). The structure was constructed in the year 2012 with overall rooftop area of 81.25 m² (16.25 m x 5.00 m) including the concrete edge of parapet wall (Figure 3.4). The vegetated section occupied approximately 72.0% of the total area while the remaining is non-greened rooftop surface. The non-greened area includes a roof drain that helps to drain the runoff generated from green roof to the downpour pipe. The roof drain has no slope with an uneven concrete surface.

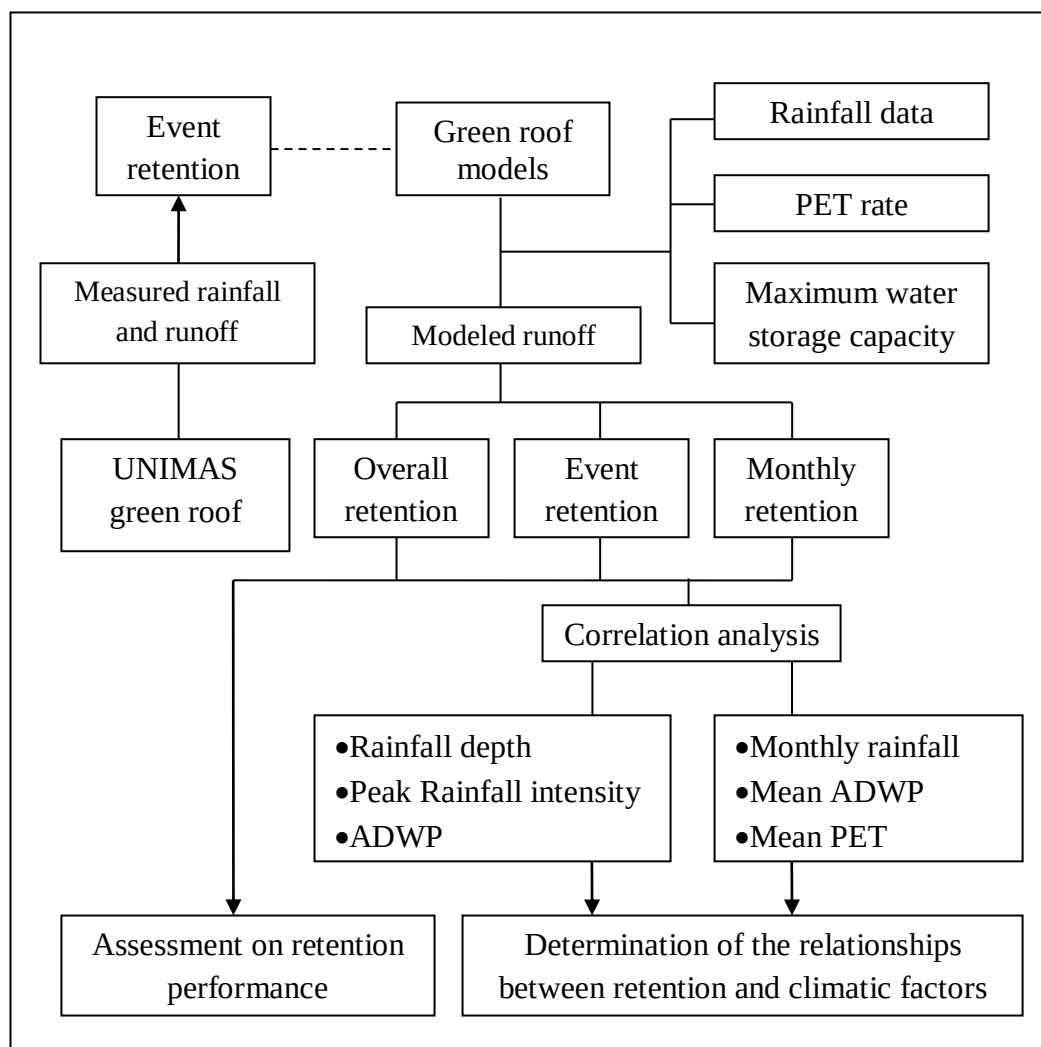


Figure 3.1: The flow of methodology



Figure 3.2: Location of UNIMAS green roof (yellow box) situated at East Campus of UNIMAS (Google Maps, n.d.)



(a) Condition of green roof



(b) General view

Figure 3.3: UNIMAS Green roof

UNIMAS green roof is a typical extensive green roof with a flat surface and without the irrigation system. Figure 3.5 illustrates the detailed cross section of the green roof installed above the roof deck. The main sedum species planted on the approximately 140.0 mm depth of substrate is *Axonopus compressus* (cow grass) as shown in Figure 3.6 (a). The selected sedum is commonly found in Sarawak and it required little or no maintenance where it does not need fertilizer and irrigation unless the weather is

consistently hot and dry over a period of several weeks. The second layer is the substrate layer that functioned as space where the rainwater is stored and the roots of sedum grow. The chosen material for the substrate is the common agricultural soil in Sarawak. On the bottom of the substrate layer, there is a geosynthetic sheet drain which served as the drainage layer as shown in Figure 3.6 (b). The vegetation on the roof is well established and has life period on the roof for over a year before the runoff data was collected.

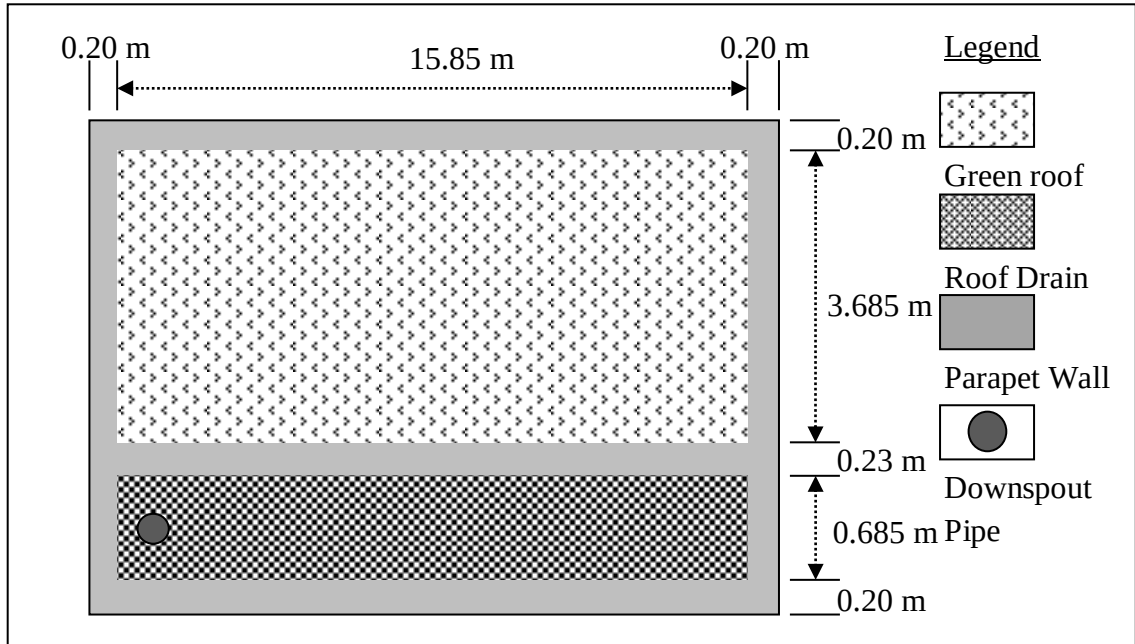


Figure 3.4: Illustration of roof plan dimension of UNIMAS green roof

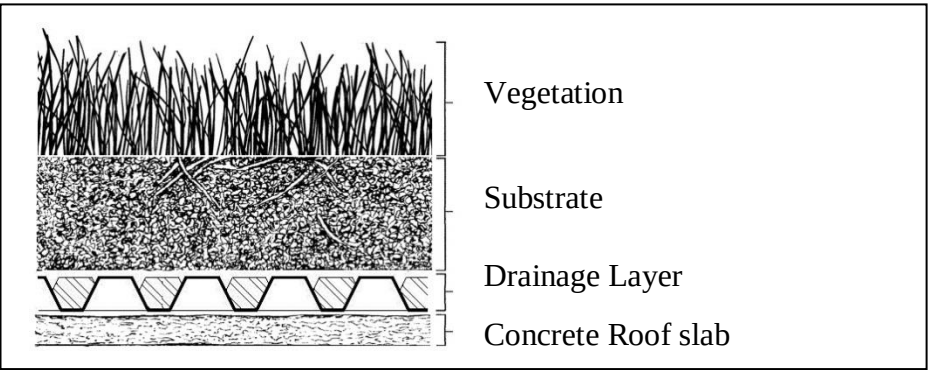


Figure 3.5: Cross section of UNIMAS green roof



(a) *Axonopus compressus*



(b) Geosynthetic sheet drain

Figure 3.6: Components of UNIMAS Green Roof

3.2.2 Data Collection

The rainfall-runoff data from UNIMAS green roof was recorded from individual rainfall event occurred between May 2014 and December 2014. The field experimental setup for rainfall depth measurement includes an EM - Model ARG100 tipping bucket rain gauge (Figure 3.7 a) equipped with a data logger to record rainfall with a tipping bucket. The rain gauge has a depth resolution of 0.2 mm and it was configured to take rainfall depth readings at the 1-minute interval. By using a spirit level, the rim of the gauge was leveled prior to each session of field measurements to ensure it remains level. When runoff was generated from the green roof, it was diverted towards the inlet of downspout pipe which located at the end of the roof drain (Figure 3.7 b). Then, it was collected by using a measuring bucket with maximum storage capacity of 7 litre at the outlet of downspout pipe. The nearly filled bucket was replaced with another empty bucket to avoid overflow of runoff from the bucket interrupts the runoff measurement. The runoff was continuously monitored and recorded with a time resolution of 5 minutes.



(a) ARG100 automatic rain gauge



(b) Measuring bucket

Figure 3.7: Rainfall-runoff measurement setup during rainfall event



Figure 3.8: Overflow of stormwater from swale into outlet of downspout pipe is observed during a heavy event on 21 December 2014.

In the present study, it is unable to continuously monitor the runoff profile due to unavailability of instruments for automatic recording from the laboratory. Thus, runoff data was measured manually from the site. The limitation to this method is that rainfall-runoff data can only be captured when there is rainfall event happened during the field measurement session which was scheduled every weekend. Another limitation is that runoff measurement is restricted by the depth of swale at the outlet of downspout pipe. The continuous measurement of runoff data was interrupted during several intense rainfall

events. The overflow of runoff from swale into the bucket and downspout pipe outlet was observed when the water level in the swale was higher than the outlet level of downspout pipe (Figure 3.8). Therefore, it reduced the amount of rainfall-runoff dataset for analysis as some dataset which obstructed by the overflow were removed.

3.3 Runoff Modeling

3.3.1 Study Area

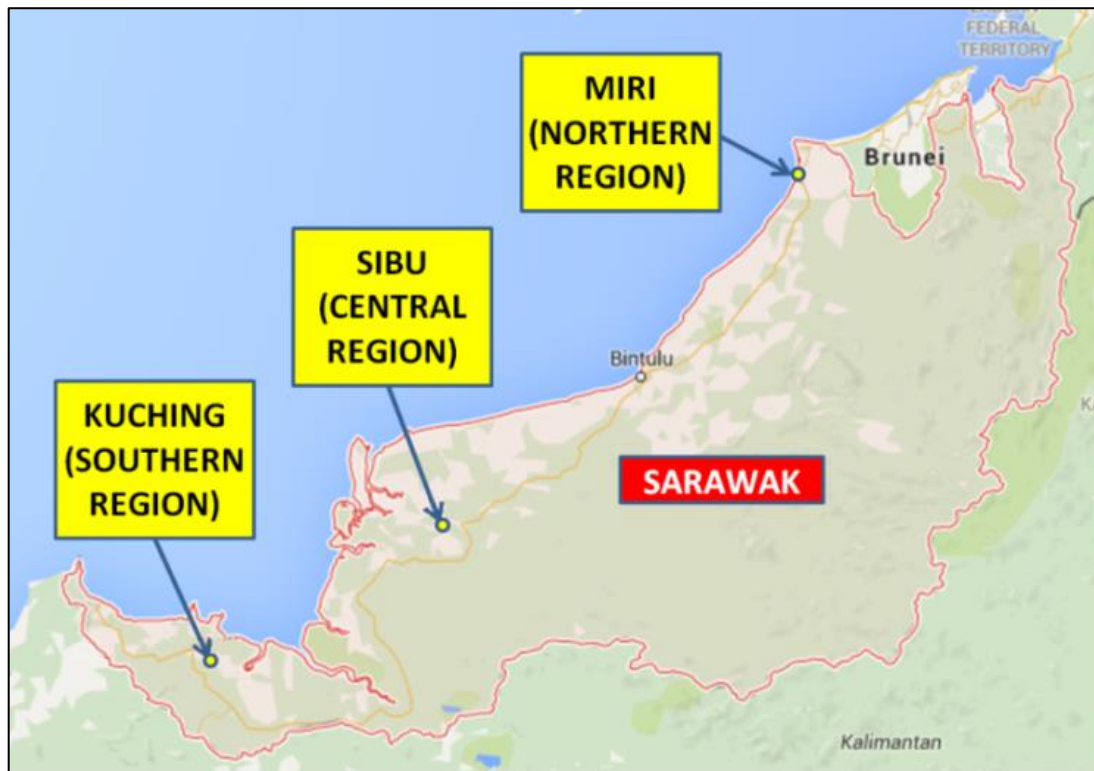


Figure 3.9: Selected location for green roof models

In order to assess the influences of local climate towards the retention performance of the green roof, one location from each region in Sarawak was selected, namely Kuching in the Southern region, Sibu in the Central region and Miri in the Northern region (Figure

3.9). Although the selected locations are experiencing similar climate, historical weather record indicated there is differences in the trend and magnitude of rainfall and air temperature throughout the year. Thus, it is expected that the retention performance of the green roof at the different regions in Sarawak will vary. By using the runoff modeling approach and past meteorological record for each location, the retention performances of the green roof models across Sarawak were determined.

3.3.2 Modeling Approach

Water balance model was selected as the modeling approach to simulate the runoff from the green roof model in the present study as it has been widely applied in previous studies. It was assumed that the green roof model has no irrigation system because it is common that selected plants for vegetation layer are drought resistant. In addition, it was assumed that there is no runoff was generated from the non-greened rooftop section during the modeling as the output is represented in unit area of the green roof surface. Thus, these components were excluded from the green roof water balance model. In brief, the green roof water balance model structure was simplified as follows:

$$R = \Delta S + P - ET \quad \text{(Equation 3.1)}$$

Where;

R = runoff from green roof (mm)

ΔS = change in storage (mm)

P = rainfall depth (mm)

ET = evapotranspiration (mm)

In order to estimate the runoff generated from green roof model, a conceptual model of moisture flux within the green roof substrate layer developed by Stovin et al. (2013) was adopted to determine the unknown water balance component (Equation 2.3 and Equation 2.4). The validity of the retention model was tested by comparing the simulated data with a continuously monitored extensive green roof test bed in Sheffield, UK. The finding showed that the estimated cumulative runoff profile from this model has a high accuracy with the observed cumulative runoff profile. This generic model was also adopted by Kasmin et al. (2014) to show the effectiveness of a similarly configured green roof model under the climatic conditions at Southern region of Peninsular Malaysia. The study highlights the usefulness of a generic model for determining the green roof performance under different climatic setting. It is a desired approach to estimate the runoff produced from the green roof system at different locations as it accounts the influences of the different green roof's configuration (maximum water storage capacity) and climatic conditions (rainfall depth and evapotranspiration rate). The model able to continuously perform a moistures balance at hourly time step that keeps track on how much rainwater is stored within the green roof system and leaves the system as runoff after the water storage capacity is fully occupied. Then, the amount of antecedent moisture content and runoff produced from the green roof model was continuously estimated from the model. Continuous modeling accounted the combined effects of meteorological conditions prior to the rainfall event and during the rainfall event to explain the retention of the green roof under the hot-humid tropical climate of Sarawak.

3.3.3 Input and Output of Modeling

3.3.3.1 Maximum Water Storage Capacity

The maximum water storage capacity ($S_{\max}$) of green roof model in the study was pre-determined and fixed throughout the modeling process. Since there is no data or guidelines of green roof configuration available in Malaysia to provide standardized water storage capacity of green roof yet comply with the rooftop loading restriction, it is important to adopt a value that is practical and achievable by a typical extensive green roof. In general, it is common that the maximum water storage capacity increases with greater substrate depth. In the present study, the monitored UNIMAS green roof which specifically designed and constructed to sustain the loading of green roof layer with substrate depth of 140.0 mm. However, a green roof designed with 140.0 mm depth of substrate layer would limit the implementation of green roof in Sarawak due to increase in the cost of rooftop construction of new building and restriction on rooftop loading of existing building. For this reason, a green roof with shallower substrate layer is most likely preferable for local developer or practitioner. In order to ensure that the modeled result is meaningful and able to reflect the retention performance of the green roof which potentially to be implemented in Sarawak, the substrate depth for the typical green roof model in this study is assumed to be 80.0 mm only with 20.0 mm of maximum water storage capacity as suggested in the modeling study of Stovin et al. (2013).

3.3.3.2 Rainfall Data

As the local climate was characterized by two monsoons (Northeast monsoon from

November to February, Southwest monsoon from March to October) the runoff simulation was performed according to the full cycle months of the monsoons. Thus, the rainfall data (P) from November 2012 to October 2013 was collected from the Department of Irrigation and Drainage (DID) Sarawak to use as the meteorological input of green roof water balance model. These data were recorded at hourly time-step in the unit of millimeter depth from the weather stations located in Kuching (Southern region), Sibul (Central region), and Miri (Northern region) to represent the local weather conditions of each region in the state.

In order to classify individual event from continuous rainfall record, the minimum inter-event time (MIT) was determined prior to the modeling. The MIT is the minimum time period in which the antecedent runoff does not influence the runoff by the later rainfall event (Joo et al., 2014). In the present modelling study, the retention performance of the green roof is emphasized and the detention effect or delay of runoff occurrence is not considered throughout the modelling process. As the computation of retention rate is only referred to the total cumulative rainfall and runoff at the end of a rainfall event, the modelling approach adopted in this study simulates the hourly runoff data generated from the green roof by balancing the input and output of moisture within the respective hourly time step only. The green roof model will not generate any runoff during the hourly time step with no rain (ADWP). Thus, the simulated hourly runoff data for each hourly time step is independent and it will not be delayed or interfere the runoff data of subsequent hour. By taking these points into consideration, a minimum ADWP of 1 hour is selected as the MIT in the present modelling study to identified individual rainfall event from continuous hourly rainfall data. The total rainfall depth of individual event was calculated as the sum of consecutive hourly rainfall depth. Meanwhile, annual rainfall and monthly

rainfall depth were calculated as the cumulative rainfall depth throughout the month and year respectively.

3.3.3.3 Evapotranspiration Rate

In the present study, Hargreaves equation was selected to determine the PET rate where the method only requires data of air temperature that is readily available at all weather stations in Sarawak. The study of Tukimat et al. (2012) has shown that Hargreaves method is capable of estimating the evapotranspiration rate in Malaysia with minimum error. The air temperature data provided by Meteorological Department of Malaysia were recorded from the airport weather stations in Kuching, Sibul and Miri. The sum of the monthly mean values for daily maximum air temperature and daily minimum air temperature was averaged to obtain the mean daily air temperatures (T_m) for each month from November 2012 to October 2013. Meanwhile, the daily total extraterrestrial radiation was calculated according to the latitude of weather station.

By referring to the values of mean daily air temperature and daily total extraterrestrial radiation, the mean daily PET rate for each month was calculated from the Hargreaves equation. Then, the mean daily PET rate was divided by 24 hours to obtain the mean hourly PET rate. Therefore, it was assumed that every hour of the respective month is having the same value of PET rate in the unit of millimeter per hour. In order to estimate the hourly evapotranspiration rate (ET_t) according to the change in moisture content of substrate, SMEF model developed by Zhao et al. (as cited in Stovin et al., 2013) was adopted by multiplying the hourly PET rate with the ratio of initial substrate moisture content (S_{t-1}) to the maximum water storage capacity (S_{max}).

3.3.3.4 Initial Substrate Moisture Content

In the present modeling study, the period before the starting date of runoff modeling was set to be on October, which commonly experiences relatively higher and frequent rainfall compared to other months of Southwest monsoon. The short ADWP due to frequent rainfall restrict the mechanism of evapotranspiration to completely remove the moisture. Thus, it is difficult for the green roof to maintain its maximum water storage capacity and it is unpractical to assume that the initial substrate moisture content at the first hourly time-step of 1st November 2012 to be zero. By taking the actual weather conditions into consideration, the initial substrate moisture content of the green roof model at the first hour time step (S_0) was set to be 50.0% of the maximum water storage capacity ($0.5S_{\max}$ or 10.0 mm). This assumption minimized the magnitude of the storage error when the initial moisture content is unknown. Besides, errors resulted from the initial moisture content estimation is negligible after a long ADWP that emptied that storage or a heavy event that saturated the storage. The assumed value of initial substrate moisture content was also used to determine the hourly evapotranspiration rate (ET_1) of first hourly time-step by using the SMEF model.

3.3.3.5 Retention Rate

The retention rate of an individual event was calculated as the proportion of retention depth over the total rainfall depth of an event (Equation 3.2). Similarly, the monthly and overall cumulative retention rate was calculated as the proportion of cumulative retention depth over cumulative rainfall depth for particular month and year respectively. The retention depth was computed in the unit of millimeter based on the

differences between rainfall depth and runoff depth.

$$\text{Retention Rate} = \frac{P-R}{P} \times 100\% \quad (\text{Equation 3.2})$$

Where;

R = runoff from green roof (mm)

P = rainfall (mm)

For the volumetric runoff data measured from UNIMAS green roof, the runoff quantity in the unit of litre was converted into an equivalent depth of runoff in the unit of millimeter according to the total roof surface area in the equation as shown below:

$$R = \frac{V}{A} \quad (\text{Equation 3.3})$$

Where

R = runoff from green roof (mm)

V = runoff volume from green roof (Litre)

A = surface area of green roof (m²)

When determining the runoff depth from UNIMAS green roof, the surface area of roof drain and parapet wall within the roof surface were included as part of the green roof surface area. This is justified by the fact that both roof drain and parapet wall are essential parts of an actual green roof for drainage purpose and served as boundary to avoid overflow from rooftop. In addition, the runoff measured from the downspout pipe was

produced from the overall roof surface. Thus, the actual retention capability of the full scale green roof was reflected in the retention rate without extracting the runoff generated from non-vegetated area. For the parapet wall at the perimeter of the roof, the surface area was taken as half by assuming the rainwater falls within this surface area was equally drained into the roof and outside the roof edge.

3.3.4 Model Implementation

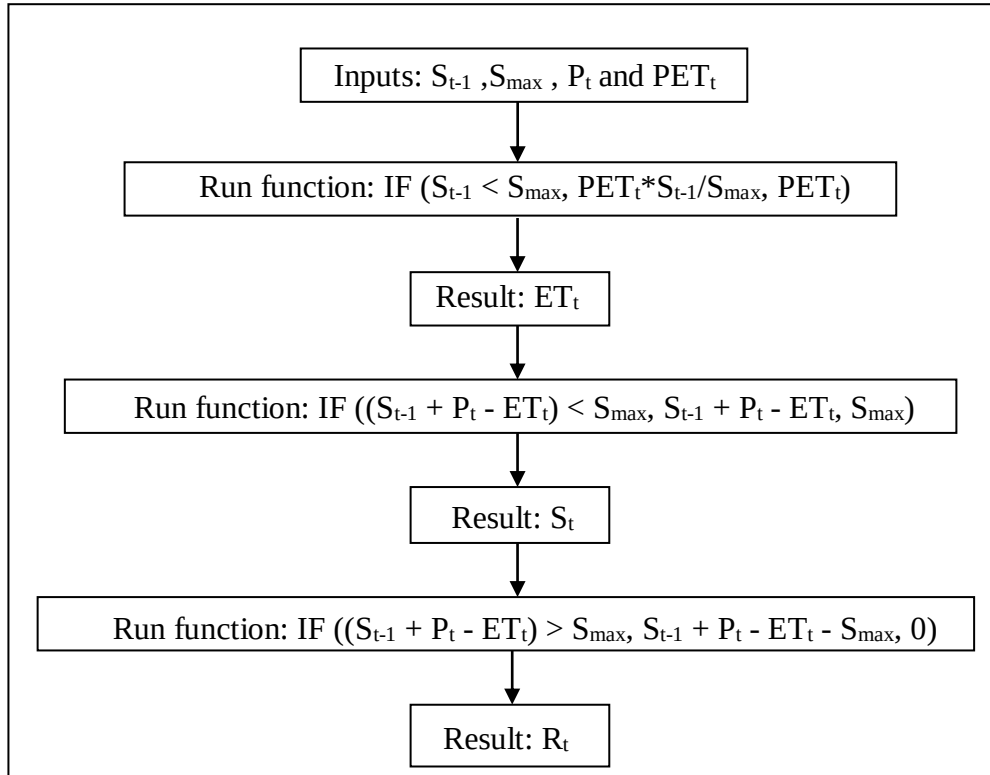


Figure 3.10: Sequence of logical function run in Microsoft Excel 2010 spreadsheet to estimate the runoff depth

In order to run the model continuously for 8760 hours (365 days or twelve months), the substrate moisture content and runoff determination functions (Equation 2.3 and Equation 2.4) developed by Stovin et al. (2013) were inserted into Microsoft Excel

Spreadsheet (2010) with the built-in logical function 'IF'. As shown in Figure 3.10, the hourly evapotranspiration rate and substrate moisture content was continuously updated at hourly time step, and then the moisture input and output was balanced to obtain the hourly runoff from the green roof model.

3.4 Data Analysis

Based on the modeled result, the retention rate of each rainfall event was determined. The event retention performances of the green roof under different rainfall scenarios and the variations in monthly retention performance over the twelve-month study period were presented. In order to test the hypothesis and the suggestion of Köhler et al. (2001), the findings in the present study was compared with the reported performances from other climates to determine whether the high and stable evapotranspiration under the hot-humid tropical climate could improve the retention performance. In addition, the potential of the green roof to be applied as an effective BMP in local urban stormwater management was determined based on its performance during significant events. According to DID Sarawak (n.d), convective rain with more than 60.0 mm of rainfall depth in 2 to 4 hours duration may cause flash floods. Based on the criteria, the events that potentially caused the occurrences of flash flood were identified and its retention performances were assessed.

One of the purposes of this study is to understand the direction and strength of the relationships between different meteorological factors and retention rate. In addition, the study also aims to identify the salient meteorological factors that have important roles on event-based and monthly retention of the green roof in a hot-humid tropical context. The

objectives can be achieved by performing correlations analysis between the variables. There are three meteorological factors were examined as explanatory variables to event retention rate, including the rainfall depth (mm), peak rainfall intensity (mm/hour) and ADWP (hour). The data were organized by monsoon for analysis, defined as Northeast monsoon (November 2012 to February 2013) and Southwest monsoon (March 2013 to October 2013) to check the potential variations in the retention performances between the monsoons. Meanwhile, the meteorological factors selected to examine its relationship with the monthly retention rate were monthly rainfall depth (mm), mean ADWP (hour) and mean hourly PET rate (mm/hour).

As shown in Table 3.1 and Table 3.2, data were checked for normality using the Anderson Darling test and the monthly retention and meteorological data were normal, however the event-based retention and meteorological data were not, hence non-parametric analyses were employed to determine the direction and strength of the possible relationships between the variables by referring to the Spearman's rank correlation coefficient (r). A positive value of correlation coefficient indicates that the variables are positively associated while a negative value indicates that the variables are negatively associated. When the value of correlation coefficient is closer to +1 or -1, the strength of correlation between the variables is stronger (Table 3.3). Meanwhile, a nearly zero correlation coefficients indicate that there is no association between the variables. By performing the correlation analysis, the strength of the correlations between the meteorological factors was determined and compared to identify the salient meteorological factors with significant effect on the event and monthly retention rate of the green roof in Sarawak. All the correlation analysis was carried out by using MaxStat Lite (version 3.06).

Table 3.1: Result of Anderson-Darling Test for data from event retention analysis

Anderson-Darling Test	Kuching		Sibu		Miri	
	NE	SW	NE	SW	NE	SW
Number of data pairs (XY)	170	210	164	203	136	183
Rainfall Depth						
<i>p</i> -value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Pass normality test ($p > 0.05$)?	No	No	No	No	No	No
Mean Rainfall Intensity						
<i>p</i> -value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Pass normality test ($p > 0.05$)?	No	No	No	No	No	No
ADWP						
<i>p</i> -value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Pass normality test ($p > 0.05$)?	No	No	No	No	No	No
Event Retention Rate						
<i>p</i> -value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Pass normality test ($p > 0.05$)?	No	No	No	No	No	No

Table 3.2: Result of Anderson-Darling Test for data from monthly retention analysis

Anderson-Darling Test	Kuching	Sibu	Miri
Number of data pairs (XY)	12	12	12
Monthly Rainfall			
<i>p</i> -value	0.4606	0.8178	0.9896
Pass normality test ($p > 0.05$)?	Yes	Yes	Yes
Mean ADWP			
<i>p</i> -value	0.5789	0.3493	0.5389
Pass normality test ($p > 0.05$)?	Yes	Yes	Yes
Mean PET rate			
<i>p</i> -value	0.5398	0.6357	0.1444
Pass normality test ($p > 0.05$)?	Yes	Yes	Yes
Monthly Retention Rate			
<i>p</i> -value	0.5725	0.7362	0.2213
Pass normality test ($p > 0.05$)?	Yes	Yes	Yes

Table 3.3: Interpretation of the strength of Spearman's rank correlation coefficient

Range of Spearman's rank correlation coefficient, r	Strength of correlation
$0 < r \leq 0.30 / 0 > r \geq -0.30$	Weak positive (negative) correlation
$0.30 < r \leq 0.50 / -0.30 > r \geq -0.50$	Moderate positive (negative) correlation
$0.50 < r \leq 0.80 / -0.50 > r \geq -0.80$	Strong positive (negative) correlation
$0.80 < r \leq 1.00 / -0.80 > r \geq -1.00$	Very strong positive (negative) correlation

Given the need for practitioners to statistically assess combination of influencing meteorological factors towards event-based or monthly retention performance for purpose of urban stormwater management, multiple regression analysis is also adapted in the present study to develop predictive relationship between various meteorological factors and retention by using Minitab 18. However, the large number of possible combinations of the meteorological factors precludes an exhaustive assessment of all combinations. Therefore, stepwise multiple regression analysis was performed where the independent variables were added one by one and final result only keeps those that contribute to the model significantly as the final independent variables. The strength of correlation was evaluated based on the coefficient of determination, R^2 where an R^2 of 1 indicates that the regression line perfectly fits the data while an R^2 of 0 indicates that the regression model explains none of the variability of the retention data around its mean. The significance of each regression coefficient was tested using a t-test and p -value of 0.05 was considered in this study.

CHAPTER 4

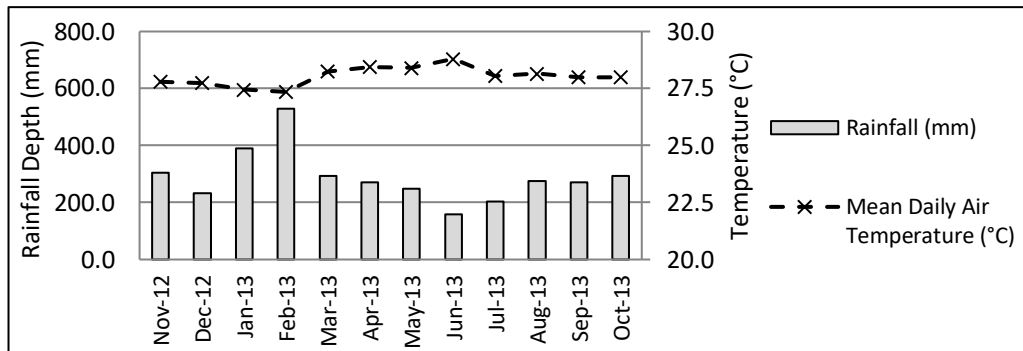
RESULTS AND DISCUSSION

4.1 Weather Profiles of the Study Period

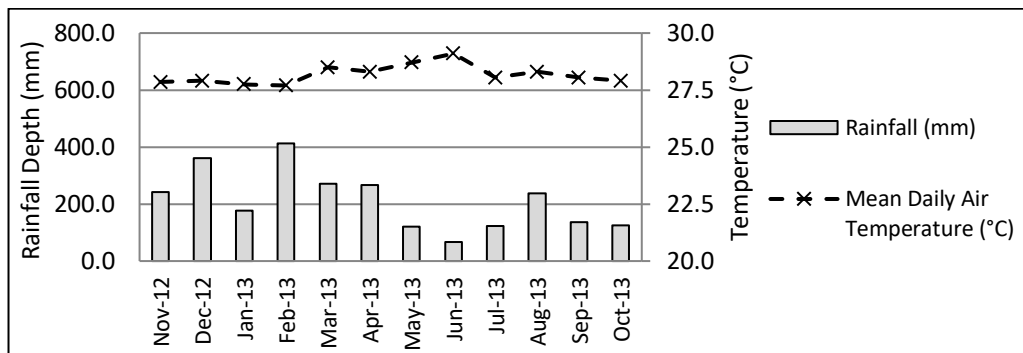
The weather profiles in Kuching, Sibü and Miri from November 2012 to October 2013 are presented in Figure 4.1. The trend of the monthly mean air temperature between the locations was fairly similar. The figure shows that the mean air temperature gradually increased from November 2012 and starts to decline after it has reached the highest mean air temperature in July 2013. It is apparent that the monthly mean air temperatures were comparatively higher during the beginning of Southwest monsoon (March 2013 to June 2013). In Kuching and Sibü, the lowest monthly mean air temperature was recorded in February 2013 whilst the lowest monthly mean air temperature in Miri was seen in July 2013. Overall, there were no significant fluctuations in mean air temperature throughout the twelve month study period as the mean air temperatures were maintained within the range of 27.1°C and 29.1°C.

The total rainfall depth of the study period was 3466.0 mm in Kuching, 2541.0 mm in Sibü and 3063.5 mm in Miri. Although the Northeast monsoon only spans across four months out of the twelve months study period, there were about 40.0% - 47.0% of the total rainfall falls within the four months, depending on locations. The data indicates that the cumulative rainfalls during the Northeast monsoon were 1455.0 mm, 1192.0 mm and 1425.5 mm for Kuching, Sibü and Miri respectively. At the same time, the frequency of rainfall events during the Northeast monsoon was also higher than the Southwest monsoon. The average ADWP per event during the Northeast monsoon was below 20 hours while the

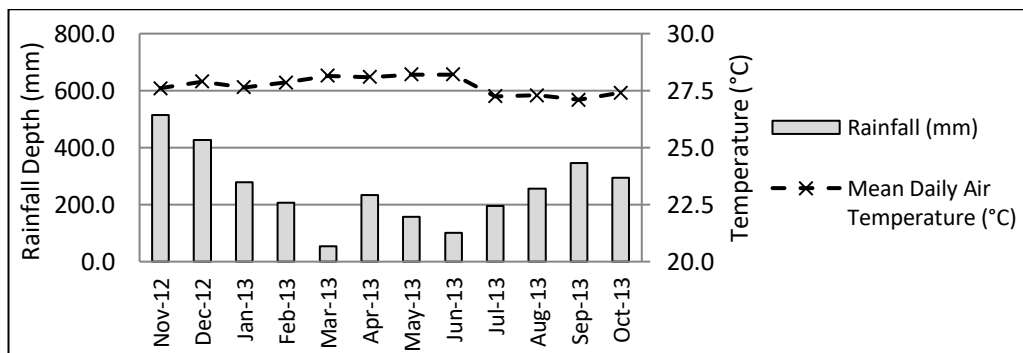
average ADWP per event during the Southwest monsoon was longer than 25 hours.



(a) Kuching



(b) Sibul



(c) Miri

Figure 4.1: The weather profiles in Sarawak from November 2012 to October 2013

Under the influences of Northeast monsoon, the monthly rainfall depths from November 2012 to February 2013 were higher whilst the rest of the months were

comparatively dry. For Kuching and Sibü, both locations were recorded with the highest monthly rainfall depth in February 2013, while Miri recorded with the highest monthly rainfall in November 2012. On the other hand, the driest month during the study period was recorded in June 2013 for both Kuching and Sibü, and March 2013 for Miri.

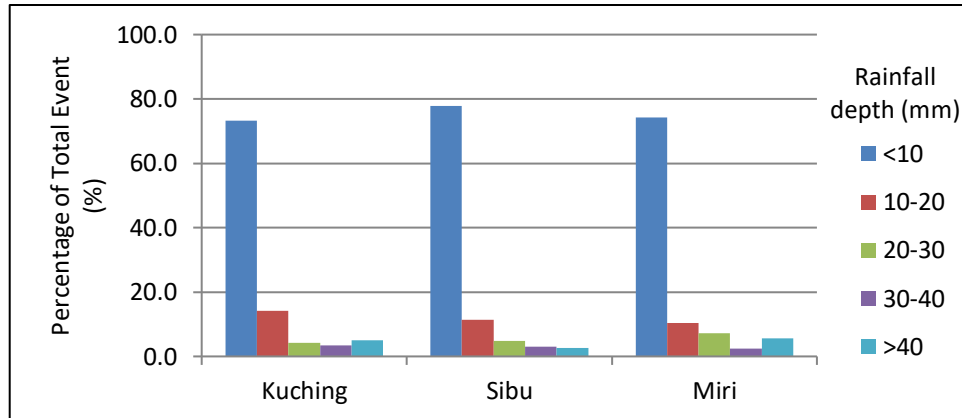


Figure 4.2: Proportion of rainfall event by rainfall depth (mm) in Sarawak during the study period

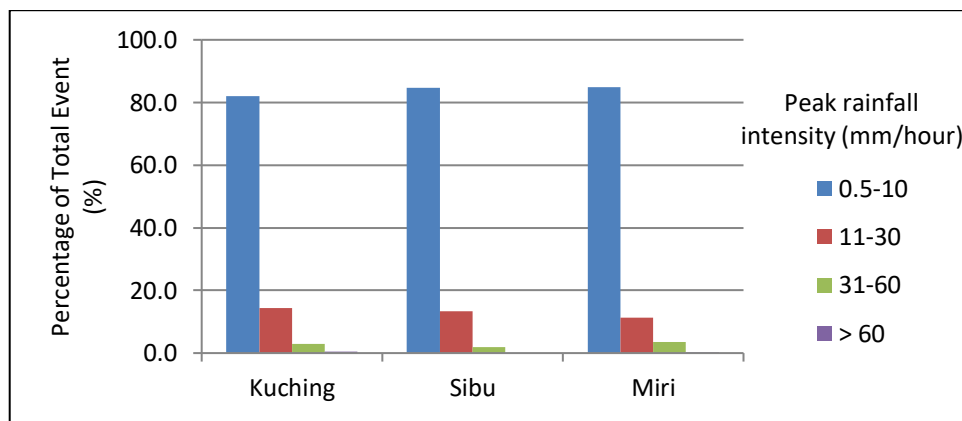


Figure 4.3: Proportion of rainfall event by peak rainfall intensity (mm/hour) in Sarawak during the study period

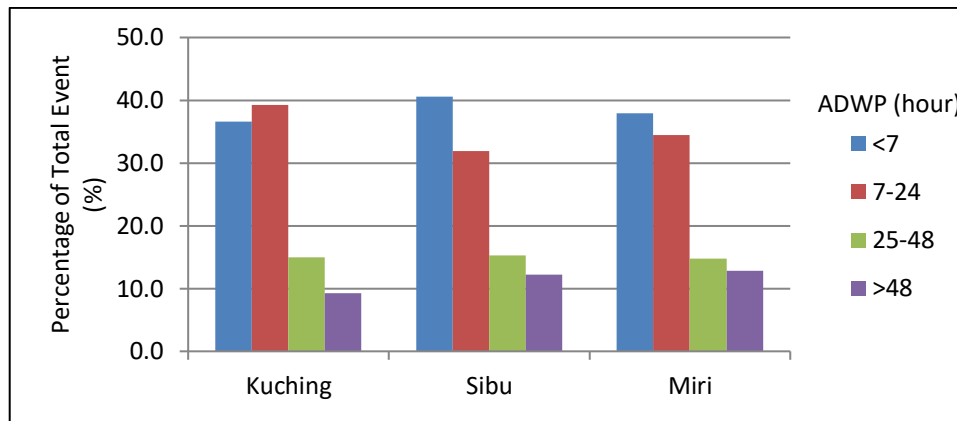


Figure 4.4: Proportion of rainfall event by ADWP (hour) in Sarawak during the study period

During the study period, there were total 380, 367 and 319 individual rainfall events recorded in Kuching, Sibul and Miri respectively with event size ranged between 0.5 mm and 131.5 mm. The proportion of rainfall event organized by rainfall depth, peak rainfall intensity and ADWP were displayed in Figure 4.2, Figure 4.3 and Figure 4.4. Overall, the analysed rainfall events were dominated by event with total rainfall depth below 10.0 mm by occupying 73.2%, 77.9% and 74.3% of the total recorded events in Kuching, Sibul and Miri respectively. The frequency of the event recorded with rainfall depth greater than 40.0 mm was considerably low, where it has only occupied 5.0%, 2.7% and 5.6% of the total events in Kuching, Sibul and Miri respectively.

The rainfall data shows that the highest peak rainfall intensity recorded in Kuching, Sibul and Miri were 88.5 mm/hour, 53.0 mm/hour and 67.5 mm/hour respectively. When the events were grouped according to the rainfall intensity classification of DID Sarawak (n.d.), the data shows that the analysed events were dominated by events recorded with peak rainfall intensity below 10.0 mm/hours while events with peak rainfall intensity greater than 10.0 mm/hour occurred occasionally. The proportions of the events recorded with ADWP below 7 hours and 7 - 24 hours during the study period were similar. The

events with ADWP below 7 hours and 7 – 24 hours have occupied about 36.6% - 40.6% and 31.9% - 39.2% of the total events respectively, depending on locations. Meanwhile, there were only 9.2%, 12.3% and 12.9% of the analysed events were recorded with ADWP longer than 48 hours in Kuching, Sibul and Miri respectively.

4.2 Retention Rate of UNIMAS Green Roof

The rainfall-runoff data were collected on every weekend from the UNIMAS green roof located at Kota Samarahan (Southern region of Sarawak) between May 2014 and November 2014. However, only seven set of the rainfall-runoff data were successfully captured during this period as some of the collected data were incomplete due to the overflow of runoff from the swale into bucket and downspout pipe outlet. The size of recorded events ranged between 1.0 mm and 16.6 mm. Detailed hydrological data for each event is presented in Appendix A. The retention performances of each monitored event are summarised in Table 4.1. Overall, the cumulative retention rate and mean retention rate from the seven events were 80.8% and 88.1% respectively. The highest retention rate was seen from a 1.0 mm event while the lowest retention was recorded during the 16.6 mm event. In term of volumetric retention, the highest retention depth of 14.62 mm was recorded from an 15.0 mm event.

Table 4.1: Rainfall characteristic and retention rate of monitored rainfall events at the UNIMAS green roof

Event	Date	Rainfall depth (mm)	Rainfall intensity (mm/h)	Retention (mm)	Retention (%)
1	10 May 2014	1.0	8.57	0.99	98.8
2	31 May 2014	15.0	12.33	14.62	97.5
3	08 Jun 2014	3.2	8.73	3.11	97.2
4	13 Jul 2014	2.0	7.50	1.97	98.2
5	17 Aug 2014	11.6	3.53	7.87	67.8
6	24 Aug 2014	4.8	11.08	4.40	91.7
7	15 Nov 2014	16.6	22.64	10.82	65.2

4.3 Event Retention Rate of the Green Roof Models

By using the past metrological data from November 2012 to October 2013 as the input for green roof water balance model, the retention rates for each individual rainfall events in Kuching, Sibul and Miri were computed based on the modeled runoff data. Detailed hydrological data and retention performances for each of the individual events are presented in Appendix F, Appendix G and Appendix H. In brief, the event retention rates differed widely from 1.9% - 100.0% in Kuching, 2.7% - 100.0% in Sibul and 2.4% - 100.0% in Miri. Figure 4.5 summarises the proportion of total event according to the retention rate. It can be seen that the events with retention rate greater than 80.0% accounted more than 50.0% of total events at three locations. Among the green roof models, Sibul had the highest proportion of the event with excellent retention performance, followed by Miri and Kuching. In particular, the number of rainfall event that was completely retained by the green roof models was 202 in Kuching and 224 in both Sibul and Miri. The figure also shows that Sibul had the smallest percentage of total rainfall event

with retention rate below 30.0%. Overall, the green roof model in Sibü had the highest mean retention rate (79.5%), followed by Miri (74.5%) and Kuching (72.5%).

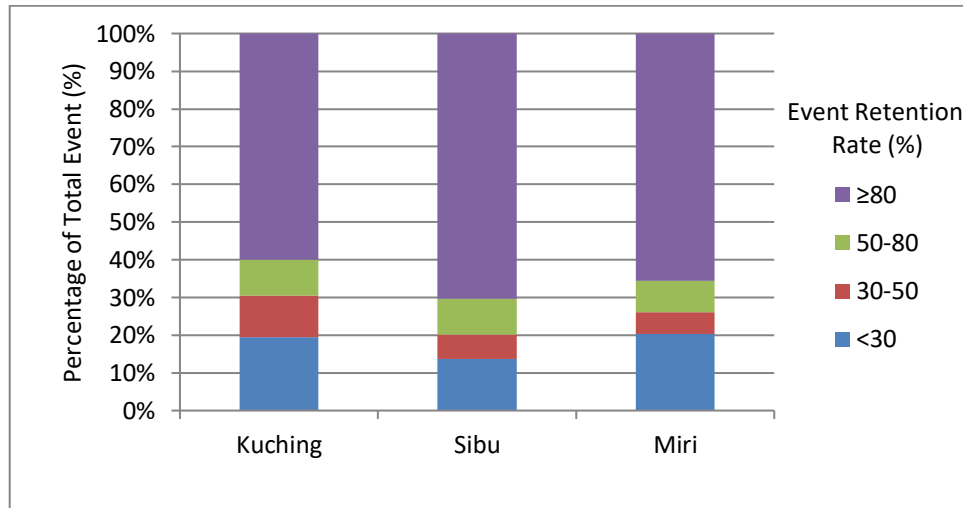
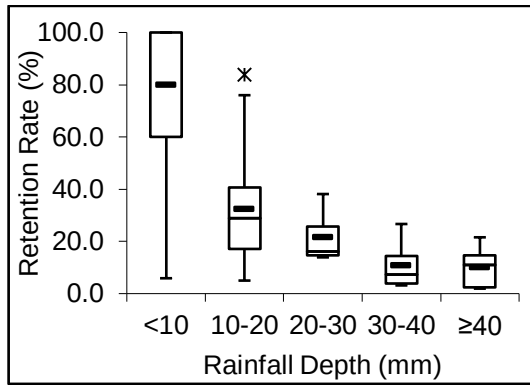


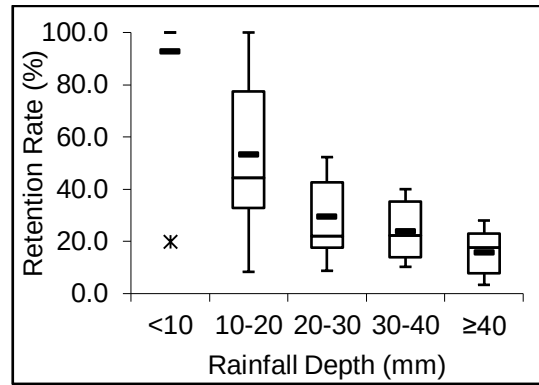
Figure 4.5: Proportion of rainfall event by retention rate

4.3.1 The Effect of Rainfall Depth on Retention Rate

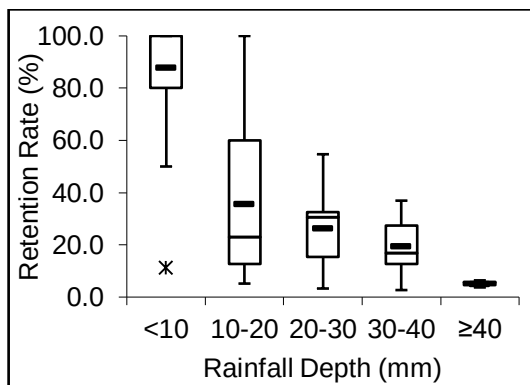
The event retention performances of the green roof models within the monsoons were organised by rainfall depth as shown in Figure 4.6. The figure shows that, generally, the mean retention rate decreased as the rainfall depth increased for both monsoons except for an irregularity seen from the data of Miri during the Northeast monsoon. As can be seen from the interquartile range of the boxplots, the variations in event retention rates were higher as the rainfall depth decreased except for the events below 10.0 mm. The variations in retention rate were smallest for the event with rainfall depth greater than 40.0 mm.



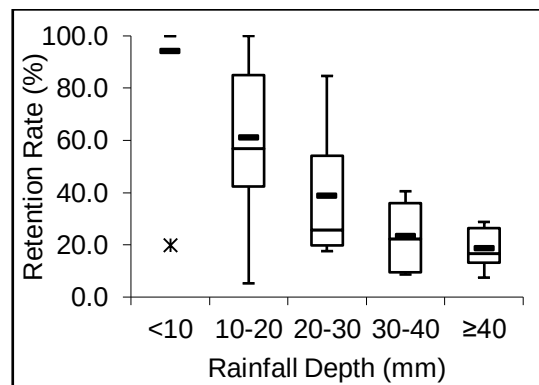
(a) Kuching – Northeast monsoon



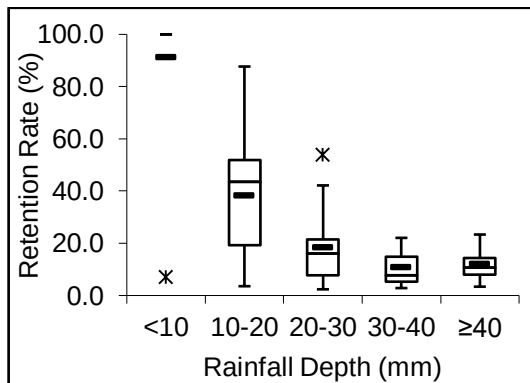
(b) Kuching – Southwest monsoon



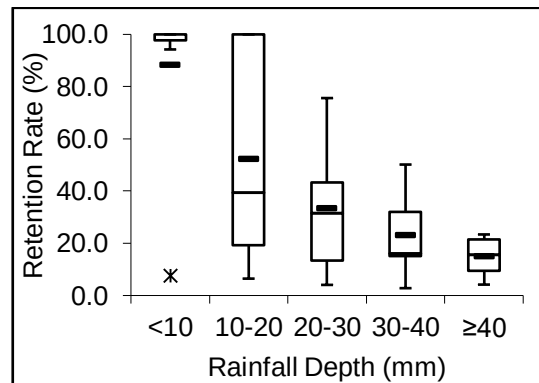
(c) Sibü – Northeast monsoon



(d) Sibü – Southwest monsoon



(e) Miri – Northeast monsoon



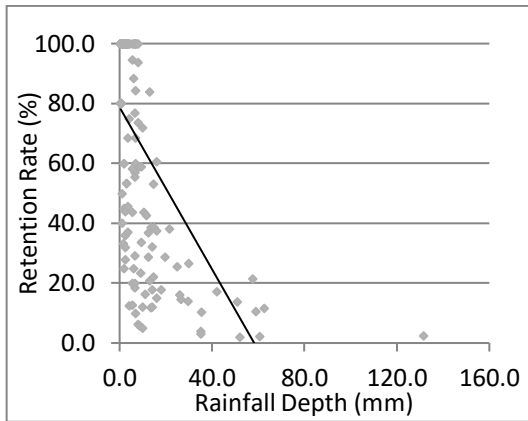
(f) Miri – Southwest monsoon

Figure 4.6: Boxplot indicating the event retention performances in Sarawak for different category of rainfall depth

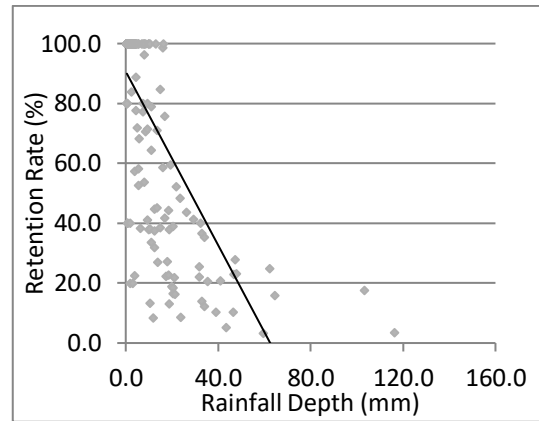
Despite the differences in monsoon, the result revealed that the mean retention rates of the events below 10.0 mm for all green roof models were higher than 80.0% and the

median values were extremely high at 100.0%. When the rainfall depth exceeded 10.0 mm, the mean retention rates declined significantly to about 32.5% - 38.5% during the Northeast monsoon and 52.4% - 61.3% during the Southwest monsoon. Meanwhile, the mean retention rates of the events above 40.0 mm were only 10.2% in Kuching, 5.2% in Sibü and 12.1% in Miri during the Northeast monsoon. The retention performances of similar events were slightly higher during the Southwest monsoon (16.0% in Kuching, 18.9% in Sibü, 15.2% in Miri). On comparison, it can be seen that the mean retention rates of similar events size categories during the Southwest monsoon were higher compared to Northeast monsoon.

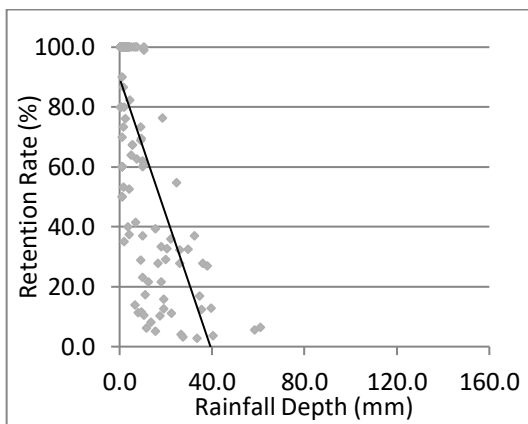
Figure 4.7 illustrates the variation in event retention rate in relation to event rainfall depth. The scatterplots generally shows a decrement trend in retention rate with increased rainfall depth. The result from Spearman's rank correlation analysis showed that the correlation coefficients for all green roof models were higher than -0.500. During the Northeast monsoon, the correlation coefficients between the variables were -0.741, -0.742 and -0.815 for Kuching, Sibü and Miri respectively. Meanwhile, the correlations coefficients between the variables during the Southwest monsoon were -0.759, -0.579 and -0.631 for Kuching, Sibü and Miri respectively. The correlations found between the retention rate and rainfall depth appeared to be statistically significant ($p\text{-value} < 0.05$).



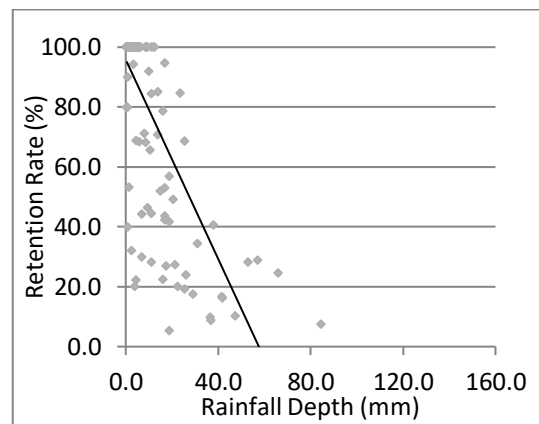
(a) Kuching – Northeast monsoon



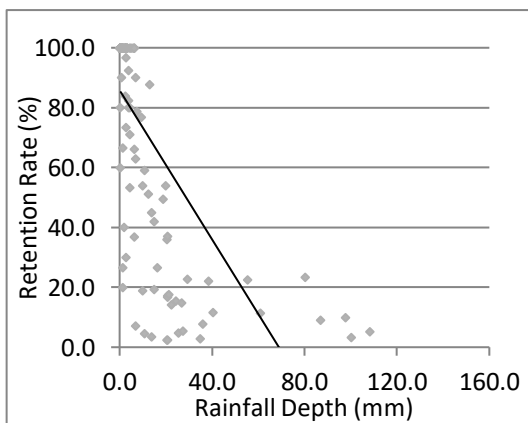
(b) Kuching – Southwest monsoon



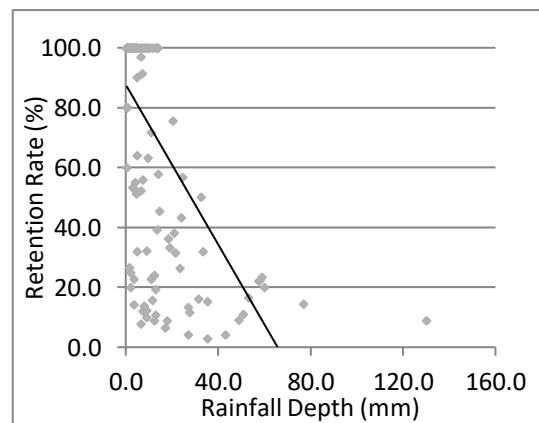
(c) Sibü – Northeast monsoon



(d) Sibü – Southwest monsoon



(e) Miri – Northeast monsoon



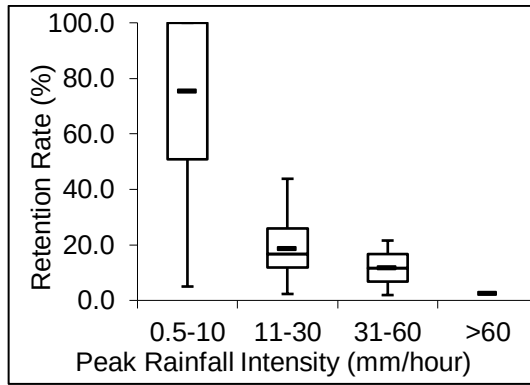
(f) Miri – Southwest monsoon

Figure 4.7: Scatterplot of event retention rate against rainfall depth

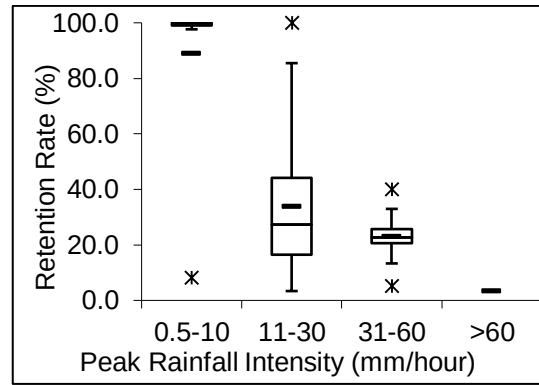
4.3.2 The Effect of Peak Rainfall Intensity on Retention Rate

The event retention performances of different category of peak rainfall intensity were displayed in Figure 4.8. The boxplots show that both the mean and median retention rate gradually decreased with increased peak rainfall intensity. For event category with peak rainfall intensity below 10.0 mm/hour, all green roof models had 100.0% median retention rates for both monsoons while the mean retention rates were higher than 80.0% except for Kuching during the Northeast monsoon with mean retention rate of 75.4%. As displayed in Figure 4.8, the variations in retention rate gradually reduced with increased peak rainfall intensity.

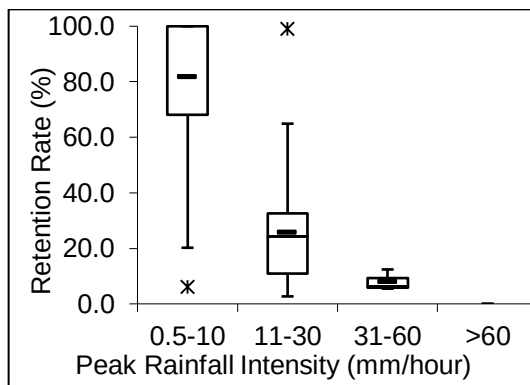
For 11.0 mm/hour – 30.0 mm/hour events, the mean retention rates decreased to about 15.0% - 25.7% during Northeast monsoon and 29.7% - 43.9% during Southwest monsoon, depending on the locations. On the other hand, the mean retention rate of the events with peak rainfall intensity 31.0 mm/hour – 60 mm/hour were only about 8.1% - 11.7% during the Northeast monsoon and 17.0% - 23.1% during the Southwest monsoon, depending on the locations. However, the boxplots unable to present the retention performance of event with peak rainfall intensity greater than 60.0 mm/hour due to lack of data. Overall, all green roof models have presented higher mean retention rate for similar category of event during the Southwest monsoon compared to Northeast monsoon.



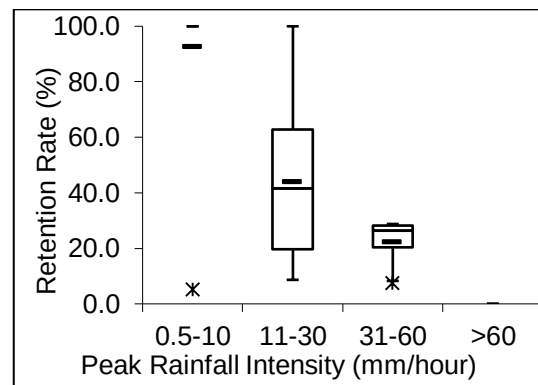
(a) Kuching – Northeast monsoon



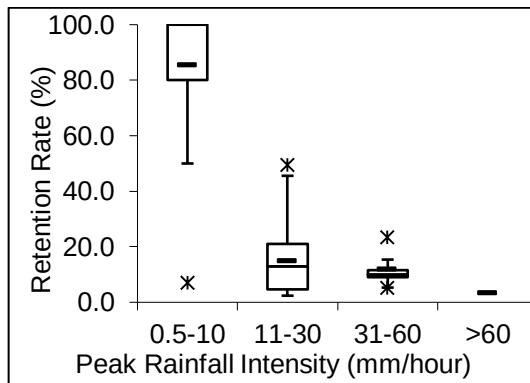
(b) Kuching – Southwest monsoon



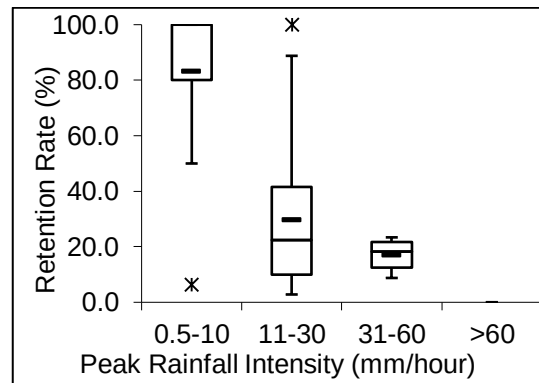
(c) Sibü – Northeast monsoon



(d) Sibü – Southwest monsoon

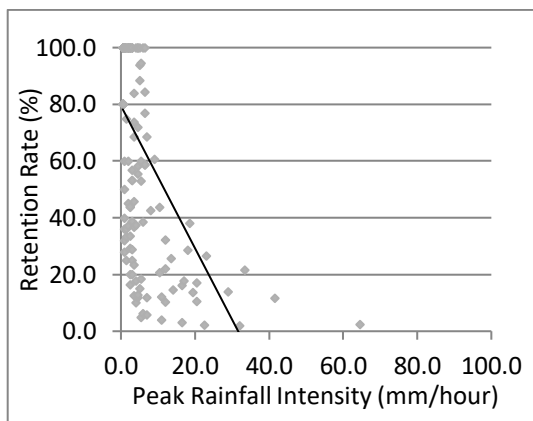


(e) Miri – Northeast monsoon

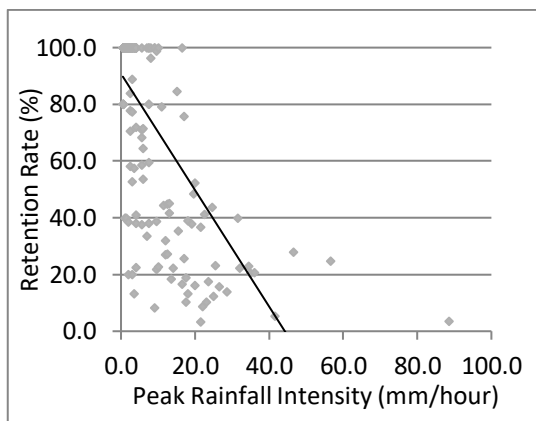


(f) Miri – Southwest monsoon

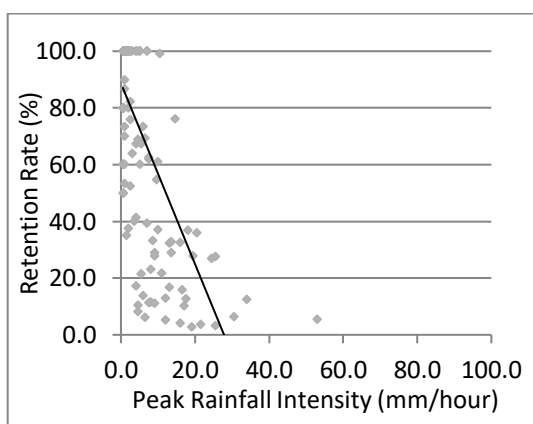
Figure 4.8: Boxplot indicating the event retention performances in Sarawak for different category of peak rainfall intensity



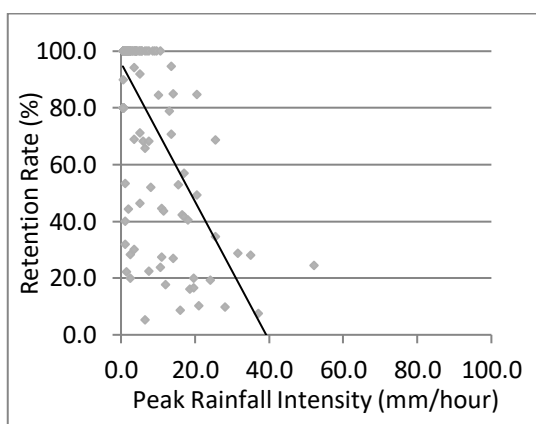
(a) Kuching – Northeast monsoon



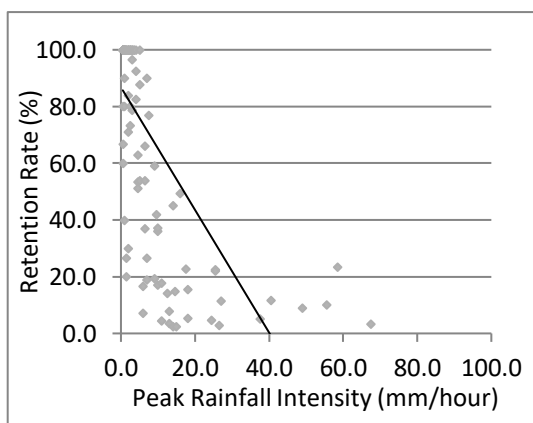
(b) Kuching – Southwest monsoon



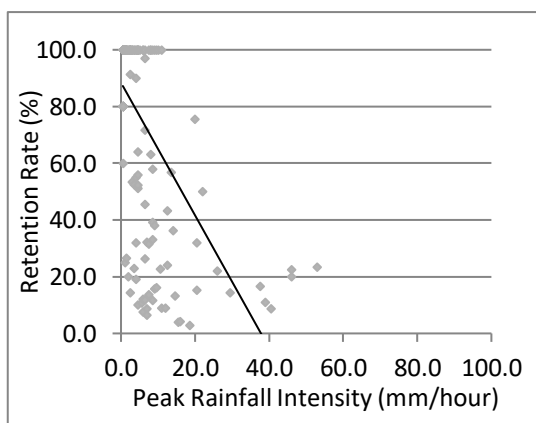
(c) Sibü – Northeast monsoon



(d) Sibü – Southwest monsoon



(e) Miri – Northeast monsoon



(f) Miri – Southwest monsoon

Figure 4.9: Scatterplot of event retention rate against peak rainfall intensity

Figure 4.9 displays the scatterplots of event retention rate plotted against the peak rainfall intensity. It shows a decrement trend in retention rate with increased peak rainfall intensity. By performing the Spearman's rank correlation analysis, it was revealed that the strength of correlation between the variables in Kuching were -0.715 during the Northeast monsoon and -0.741 during the southwest monsoon. In Sibü, the correlation coefficients between the variables were -0.704 during Northeast monsoon and -0.556 during the Southwest monsoon. Meanwhile, the strengths of correlation between retention rate and peak rainfall intensity for Miri were -0.807 during the Northeast monsoon and -0.619 during the Southwest monsoon. The negative correlations between the variables were deemed to be statistically significant ($p\text{-value} < 0.05$)

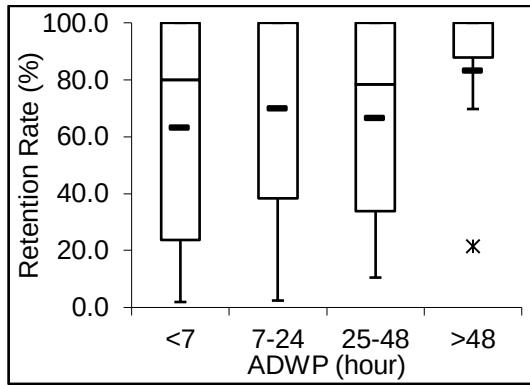
4.3.3 The Effect of ADWP on Retention Rate

Figure 4.10 illustrates the retention performances of analysed events under different category of ADWP. It can be seen that the variations in retention rate were relatively large for all categories of ADWP. A consistent increment in mean retention rate with increased ADWP was only seen from the data in Miri for both monsoons and Sibü during the Northeast monsoon. The green roof model in Kuching did not present the expected increment trend in mean retention rate with longer ADWP. The figure indicates that the mean retention rates from several categories of event with longer ADWP were lower compared to other event categories with shorter ADWP.

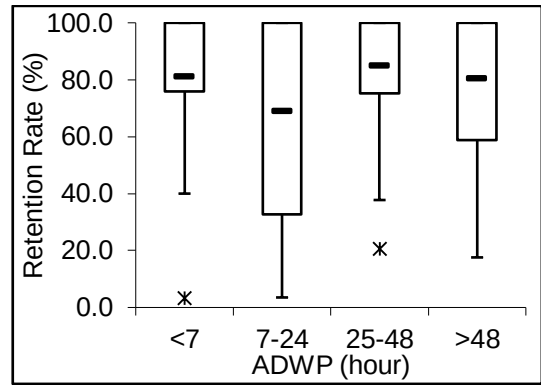
Overall, the median retention rates were 100.0% for nearly all categories of event with ADWP greater than 6 hours. For events with ADWP longer than 48 hours, the mean retention rates were about 89.7% - 95.8% for Sibü and Miri. Meanwhile, the mean

retention rates of similar event category in Kuching were only 83.2% during Northeast monsoon and 80.5% during Southwest monsoon. For events with ADWP shorter than 7 hours, the figure indicates that the mean retention ranged between 63.2% - 67.9% during Northeast monsoon and 66.9% - 83.5% during Southwest monsoon, depending on locations.

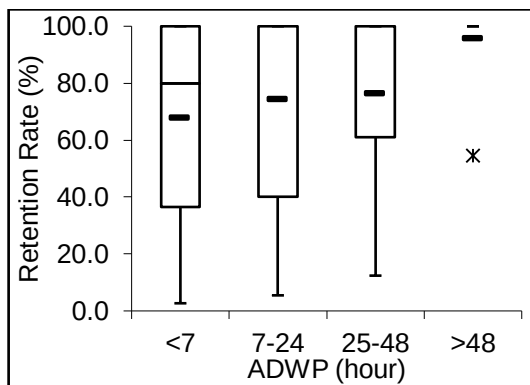
When the retention rates were plotted against the ADWP as shown in Figure 4.11, it is obvious that there were no clear associations between the retention rate and ADWP were seen from the scatterplots. The Spearman's rank correlation coefficients between the retention rate and ADWP were lower than 0.300. In particular, the correlation coefficients between the variables were 0.160 for Kuching, 0.249 for Sibu and 0.226 for Miri during the Northeast monsoon. On the other hand, the correlation coefficients were 0.055 for Kuching, 0.186 for Sibu and 0.281 for Miri during the Southwest monsoon. All the positive correlations found between the variables were statistically significant ($p\text{-value} < 0.05$) except for Kuching during the Southwest monsoon.



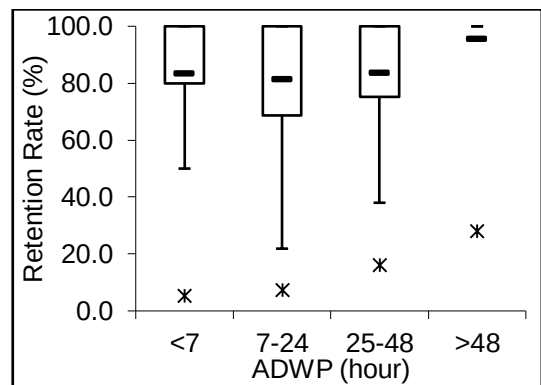
(a) Kuching – Northeast monsoon



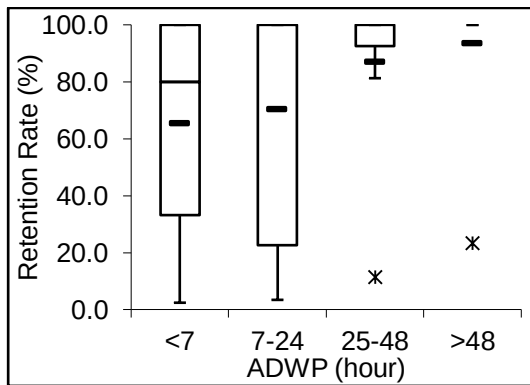
(b) Kuching – Southwest monsoon



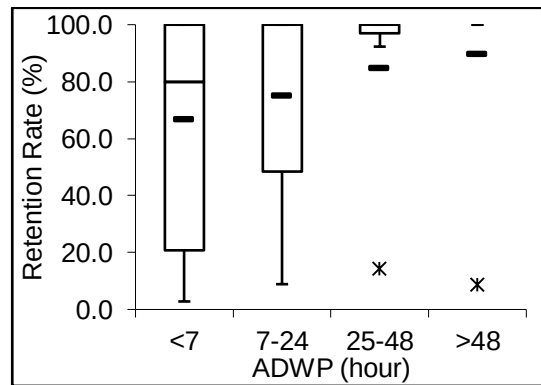
(c) Sibü – Northeast monsoon



(d) Sibü – Southwest monsoon

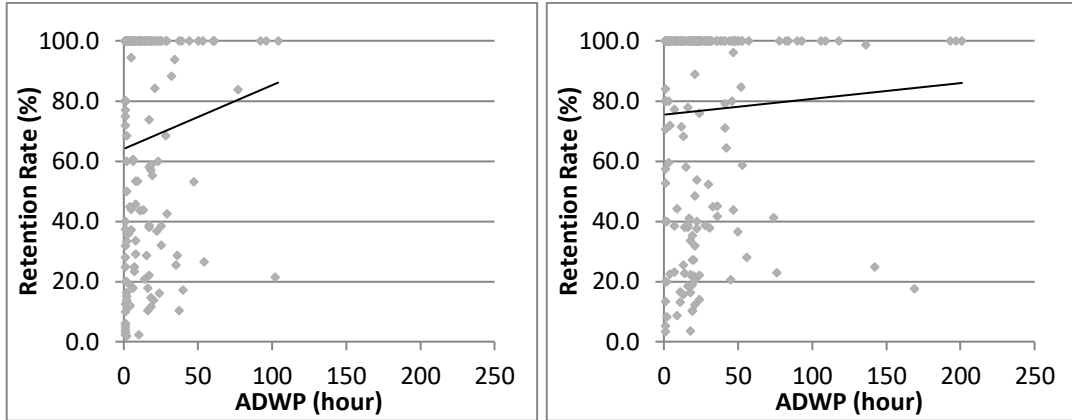


(e) Miri – Northeast monsoon



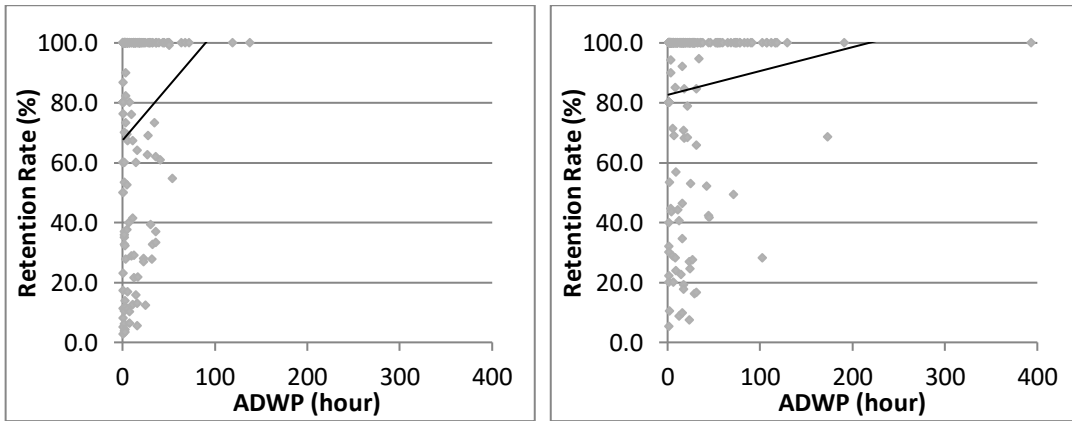
(f) Miri – Southwest monsoon

Figure 4.10: Boxplot indicating the event retention performances in Sarawak for different category of ADWP



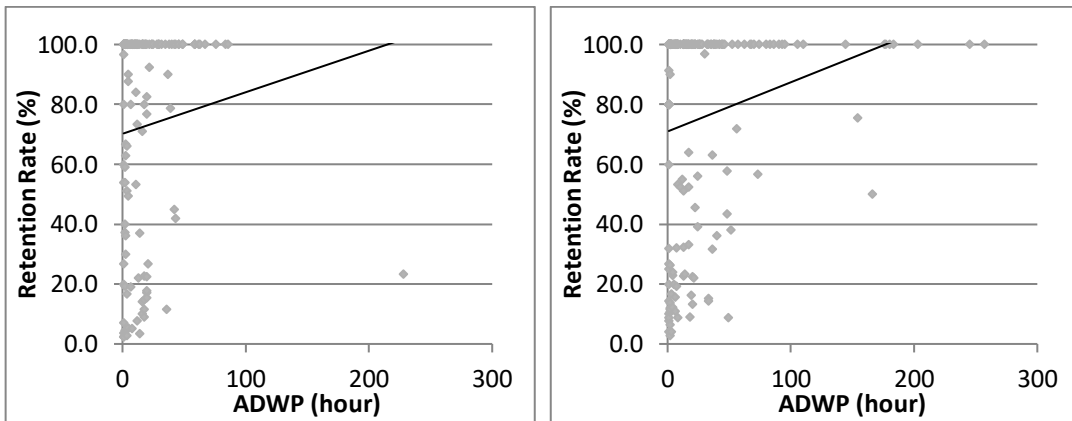
(a) Kuching – Northeast monsoon

(b) Kuching – Southwest monsoon



(c) Sibul – Northeast monsoon

(d) Sibul – Southwest monsoon



(e) Miri – Northeast monsoon

(f) Miri – Southwest monsoon

Figure 4.11: Scatterplot of event retention rate against ADWP

4.4 Monthly Retention Rate of the Green Roof Models

Figure 4.12 displays the monthly retention rates for the green roof models in Kuching, Sibü and Miri. The values were computed as the proportion of cumulative retention depth over the cumulative rainfall depth within the respective month. The figure shows that all green roof models had the lowest monthly retention rate during the months within Northeast monsoon. Likewise, all green roof models also had the highest monthly retention rate during the months within Southwest monsoon. The monthly retention rates for the green roof model in Miri were generally lower during the months of Northeast monsoon. The lowest monthly retention rate in Miri was reported during November 2012 (20.8%). The monthly retention rate gradually inclined to the highest value in March 2013 (99.1%) and decreased again to 28.1% during October 2013.

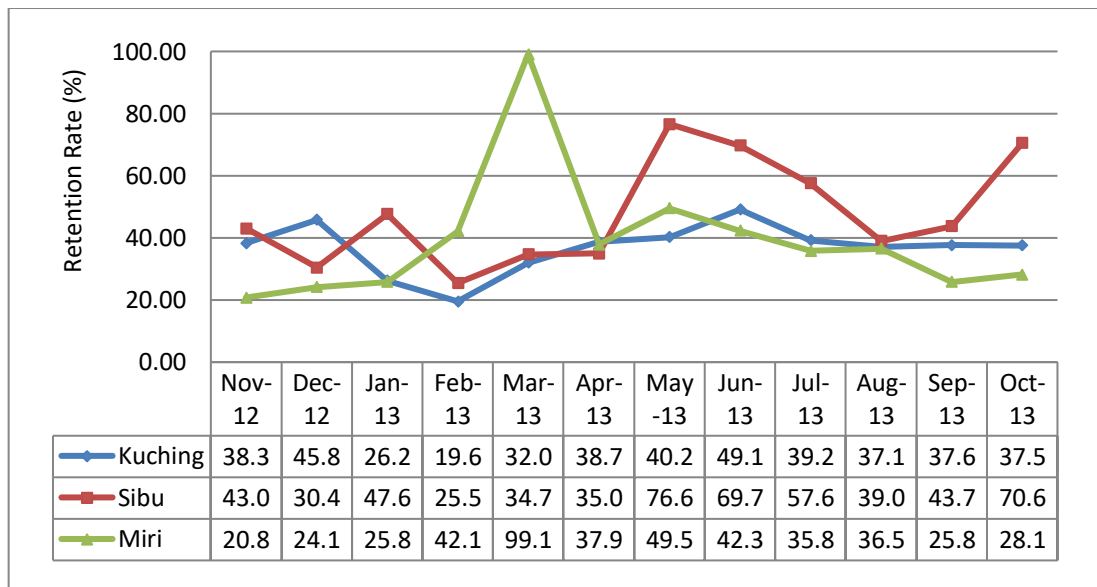


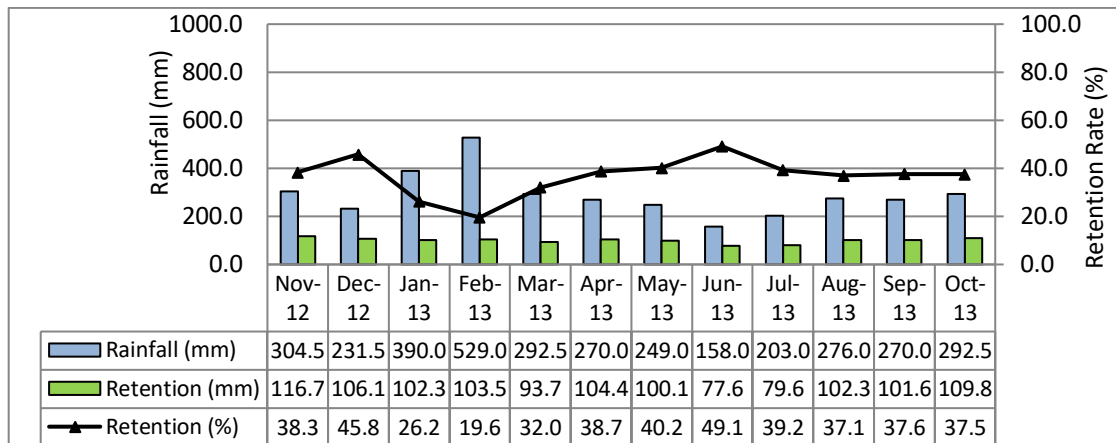
Figure 4.12: Monthly cumulative retention rate in Sarawak

On the contrary, the green roof models in Kuching and Sibü did not result in significantly lower monthly retention rates during the months within the Northeast

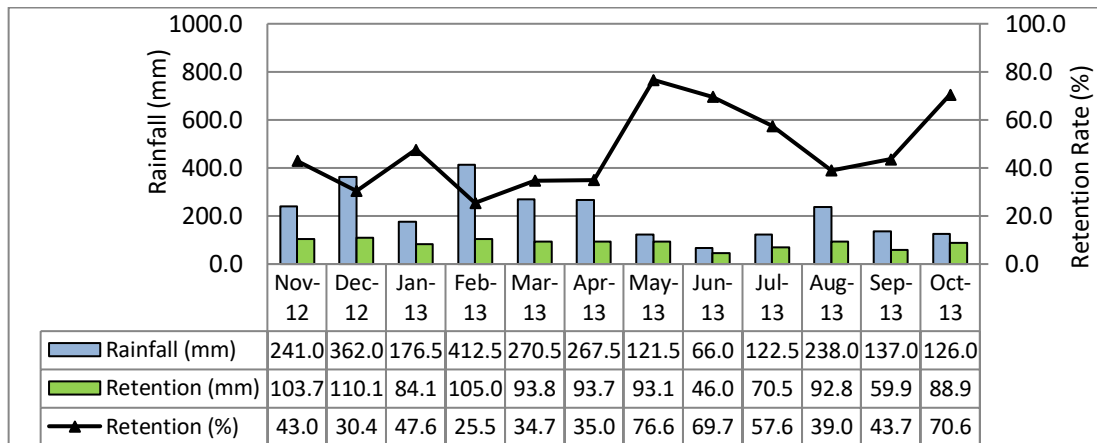
monsoon. Although both green roof models had the lowest monthly retention rate in February 2013 (19.6% in Kuching, 25.5% in Sibul), there were several months during the Northeast monsoon still had higher monthly retention performances compared to the months within the Southwest monsoon. The highest monthly retention rates in Kuching and Sibul were reported during June 2013 (49.1%) and May 2013 (76.6%) respectively.

4.4.1 The Effect of Monthly Rainfall Depth on Monthly Retention Rate

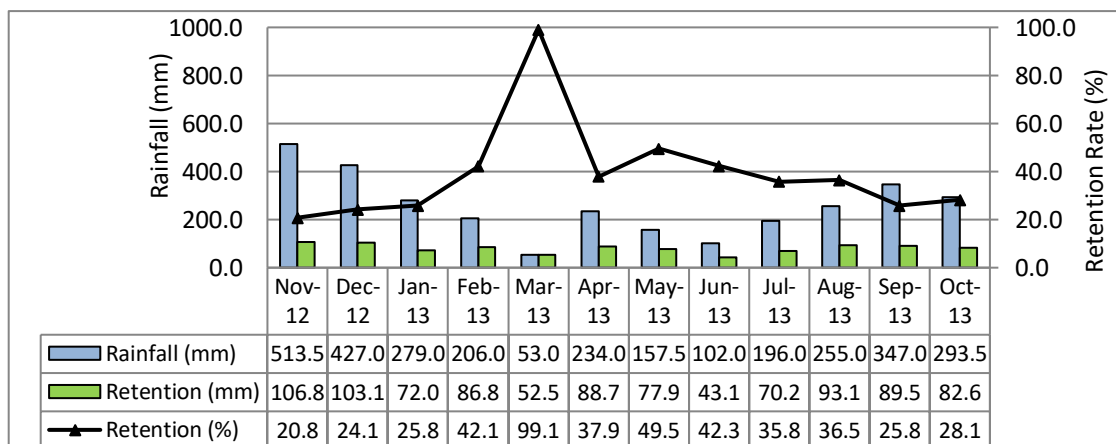
Figure 4.13 illustrates the trend of monthly retention rate and monthly rainfall depth in Kuching, Sibul and Miri. The figure indicates that there were inversely related patterns between the trends of monthly retention rate and monthly rainfall depth. For example, the monthly retention rate for the green roof model in Miri continuously inclined from 20.8% to 99.1% when the monthly rainfall decreased from 513.5 mm to 53.0 mm between November 2012 and March 2013. Similar pattern was seen from most of the consecutive months except for a few irregularities from the green roof models in Sibul and Miri.



(a) Kuching



(b) Sibü



(c) Miri

Figure 4.13: Trend of monthly retention rate and monthly rainfall depth

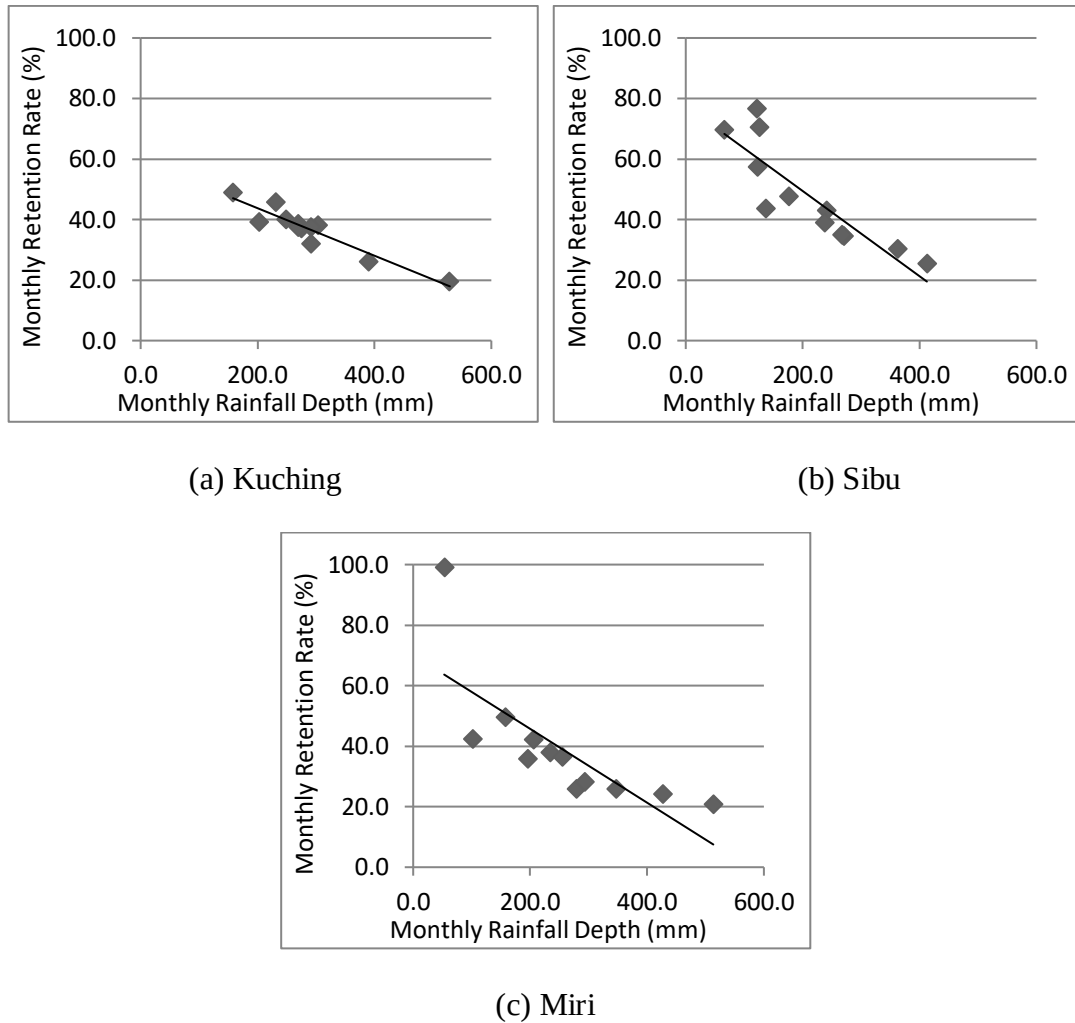


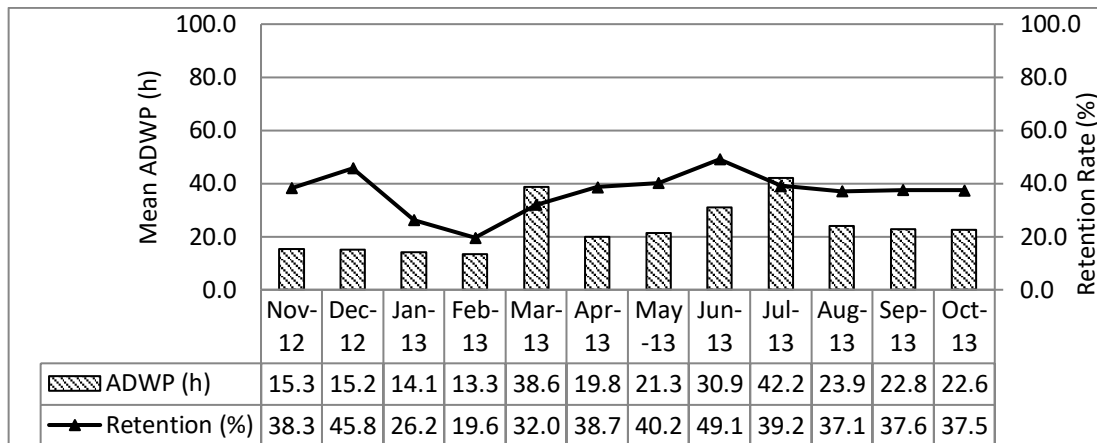
Figure 4.14: Scatterplot of monthly retention rate against monthly rainfall depth

When the monthly retention rates were plotted against monthly rainfall depth as shown in Figure 4.14, the scatterplots show a clear decrement trend between the variables with minimum numbers of outliers. The scatterplots indicate that all green roof models had the lowest monthly retention rate during the month with the highest monthly rainfall depth. For the green roof models in Kuching and Miri, the month with the lowest monthly rainfall depth also had the highest monthly retention rate. By performing the Spearman's rank correlation analysis, it was found that the monthly retention rates for all green roof models were highly correlated with the monthly rainfall depth ($r = -0.891$ for Kuching, $r = -0.951$

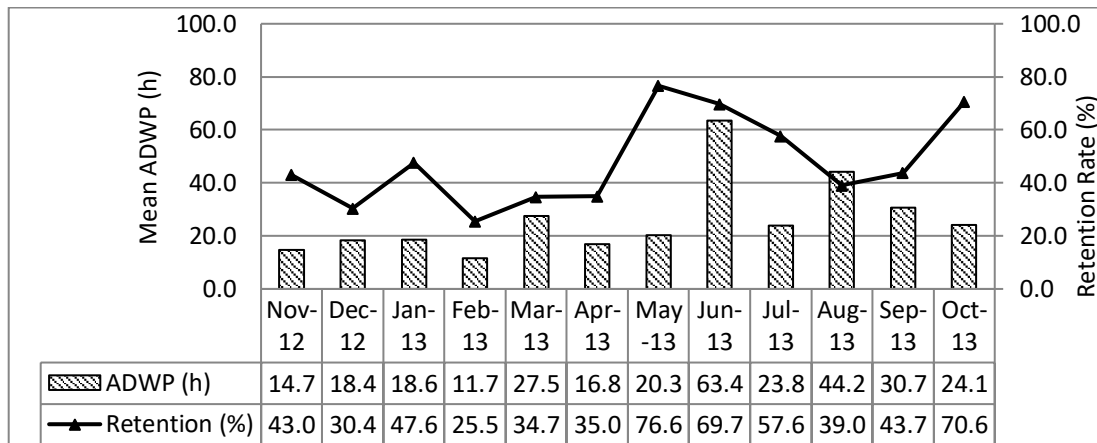
for Sibü, $r = -0.939$ for Miri). The negative correlations between the variables were found to be statistically significant ($p\text{-value} < 0.05$).

4.4.2 The Effect of Mean ADWP on Monthly Retention Rate

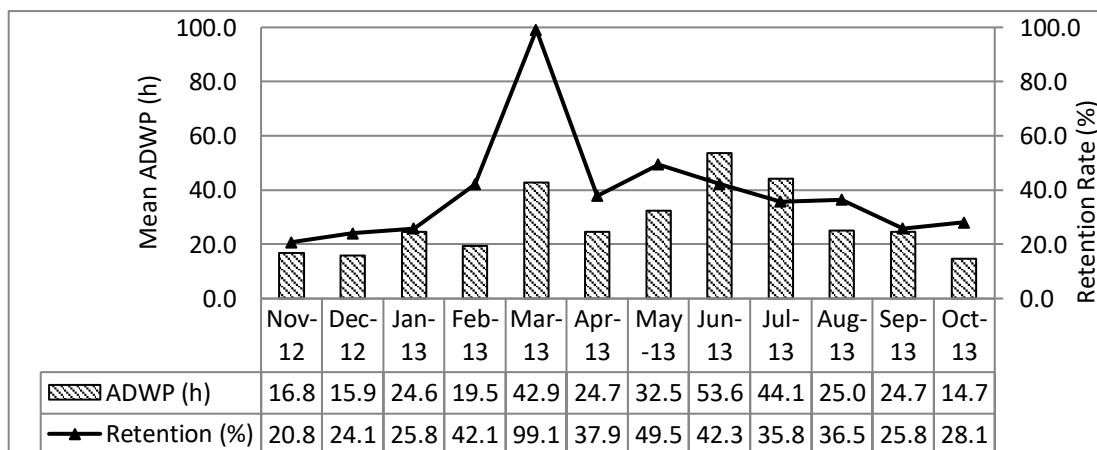
Based on the modeled result, Figure 4.15 displays the trend of monthly retention rate and mean ADWP from November 2012 to October 2013. By referring to the pattern between the variables, a similar trend between the mean ADWP and monthly retention rate was seen from several consecutive months. For example, the monthly retention rate for the green roof model in Kuching inclined from 38.7% to 49.1% when the monthly mean ADWP increased from 19.8 hours to 30.9 hours between April and June. Nevertheless, majority of the analysed months did not exhibit the similar trend. For instance, the monthly retention rate in Sibü increased from 39.0% in August to 70.6% in October even though the mean ADWP decreased from 44.2 hours to 24.1 hours.



(a) Kuching



(b) Sibul



(c) Miri

Figure 4.15: Trend of monthly retention rate and monthly mean ADWP

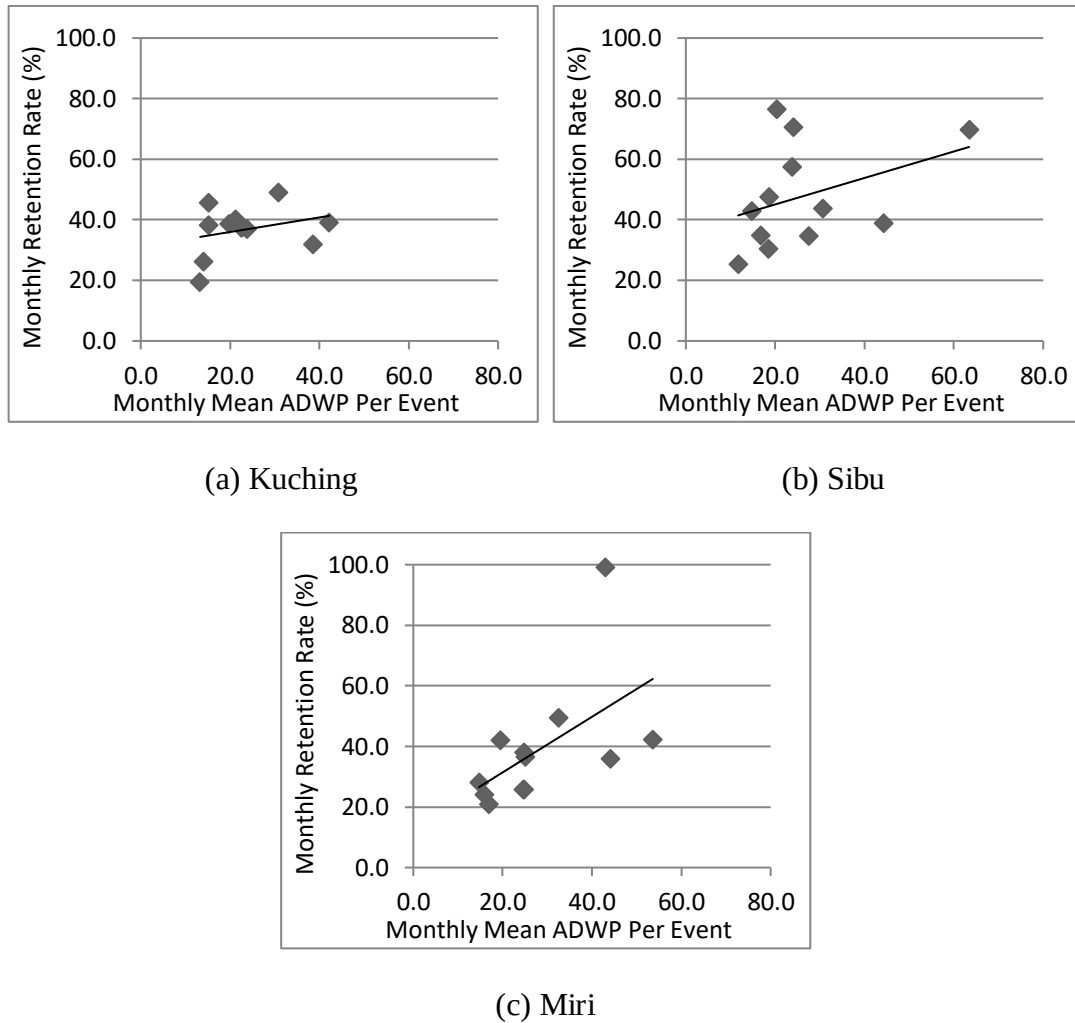


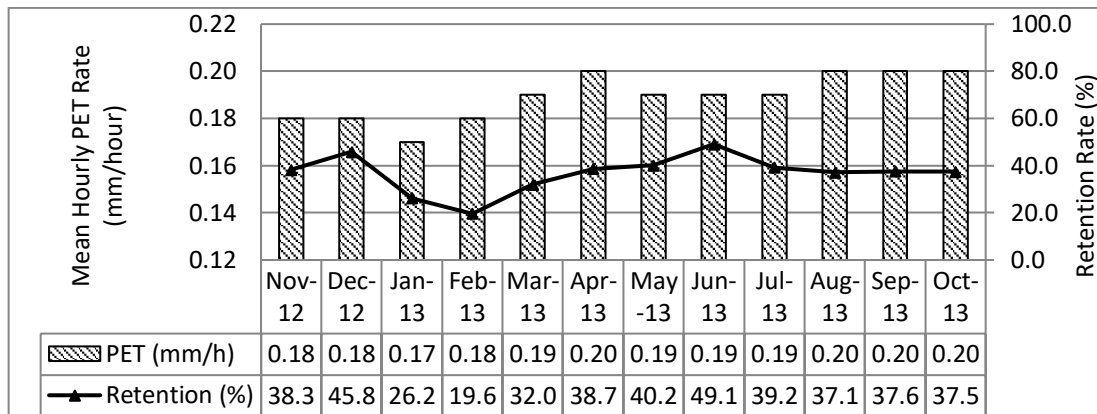
Figure 4.16: Scatterplot of monthly retention rate against monthly mean ADWP

When the monthly retention rates were plotted against the monthly mean ADWP as shown in Figure 4.16, it can be seen that there were no clear associations between the variables with considerable spread within the data. In Kuching and Sibul, the month with the shortest mean ADWP had the lowest monthly retention rate. However, it was also noted that several analysed months with considerably short mean ADWP had higher monthly retention rate compared to the other months with longer mean ADWP. For example, the green roof model in Sibul had monthly retention rate of 47.6% in January 2013 even though the mean ADWP was comparatively shorter (18.6 hours). The monthly

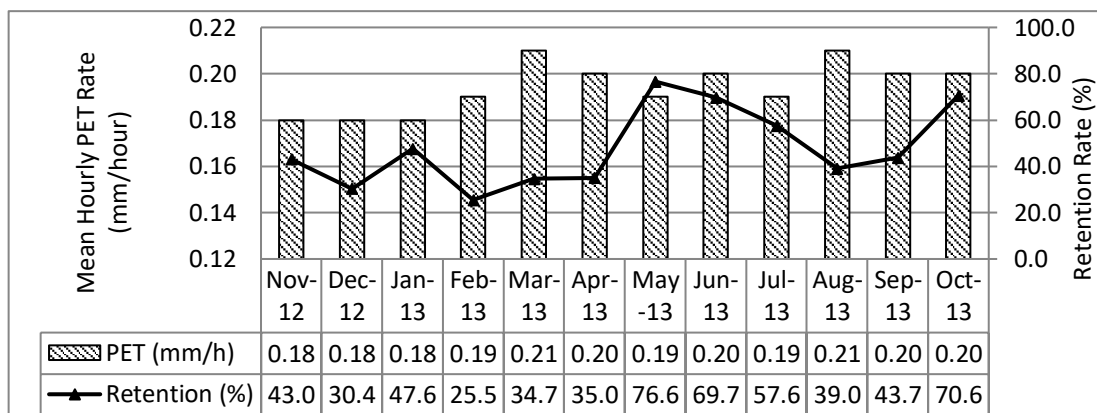
retention rate was higher than the rest of the months with longer mean ADWP including March 2013 (27.5 hours), August 2013 (44.2 hours) and September 2013 (30.7 hours). The scatterplots also indicates that none of the analysed months with the longest mean ADWP had the highest monthly retention rate. By performing the Spearman's rank correlation analysis, a strong positive correlation was found between the variables for the green roof model in Miri ($r = 0.661$). Meanwhile, weak and moderate positive correlations were found between the variables for Kuching ($r = 0.273$) and Sibul ($r = 0.427$). All the positive correlations found between the monthly retention rate and mean ADWP were deemed to be not statistically significant except for Miri ($p\text{-value} < 0.05$).

4.4.3 The Effect of Mean PET Rate on Monthly Retention Rate

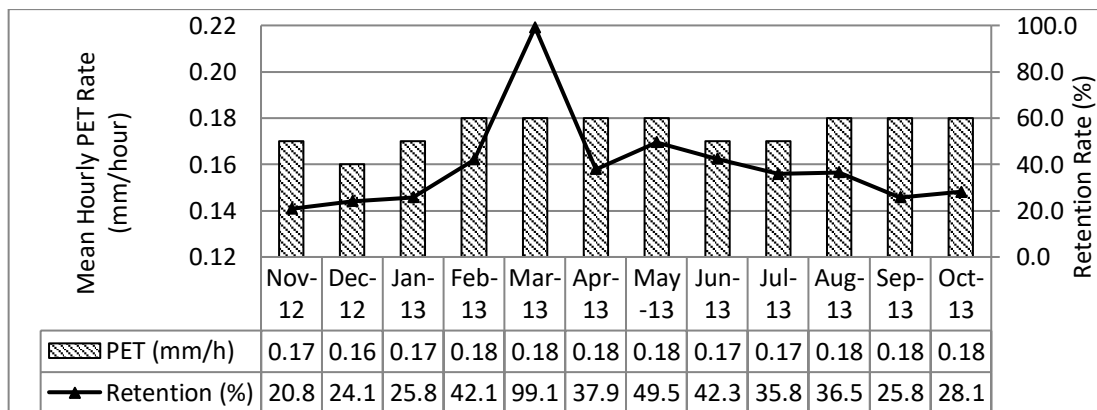
Figure 4.17 displays the trend of monthly retention rate and mean PET rate for all green roof models during the study period. As shown in Figure 4.17, the monthly retention rate for most of the consecutive months did not present the expected increment trend with increased mean PET rate. For example, an increment in monthly retention rate from 34.7% to 76.6% was seen from the green roof model in Sibul even though the mean PET rate decreased from 0.21 mm/hour to 0.19 mm/hour between March and May 2013. In addition, significant fluctuations in monthly retention performances were noticed from Figure 4.17 even though the mean PET rates were fairly stable for consecutive months. For instance, the hourly PET rates in Miri remained at 0.18 mm/hour from February to May 2013, yet the figure displays a great variation in monthly retention rate between the months.



(a) Kuching



(b) Sibiu



(c) Miri

Figure 4.17: Trend of monthly retention rate and monthly mean PET rate

When the monthly retention rates were plotted against the mean hourly PET rates

as displayed in Figure 4.18, there were no clear associations were seen between the variables for all green roof models. By performing the Spearman's rank correlation analysis, it was found that the correlations between the monthly retention rate and mean hourly PET rate for the green roof models in Kuching and Sibul were very weak ($r = 0.106$ for Kuching, $r = -0.007$ for Sibul). Meanwhile, a strong positive correlation was found between the monthly retention rate and mean PET rate for the green roof model in Miri($r = 0.529$). However, none of the correlations were found to be statistically significant ($p\text{-value} > 0.05$).

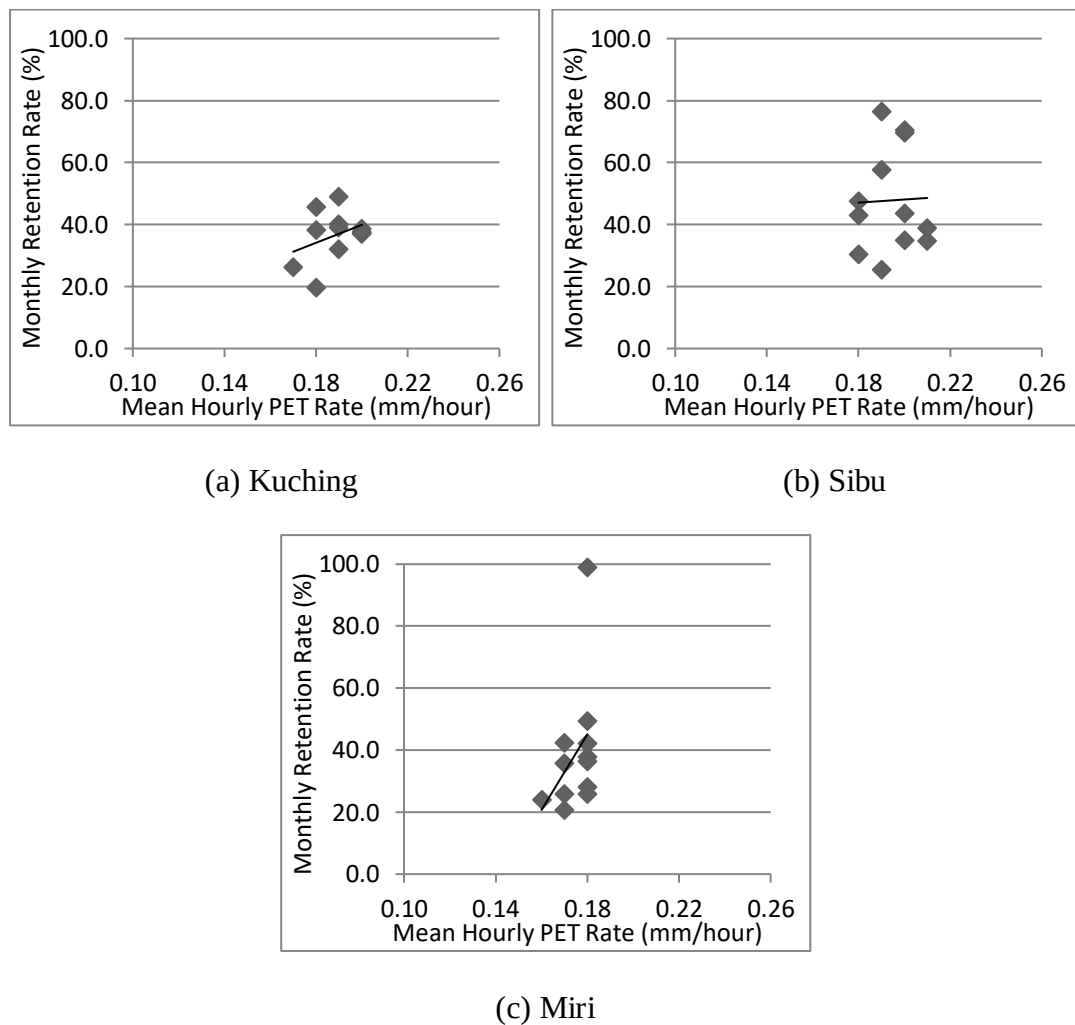


Figure 4.18: Scatterplot of monthly retention rate against monthly mean PET rate

4.5 Overall Cumulative Retention Rate of the Green Roof Models

The overall cumulative retention performances of the green roof models are illustrated in Figure 4.19. The overall cumulative retention rates were computed based on the proportion of cumulative retention depth to the cumulative rainfall depth over the twelve month study period. The cumulative retention rates for the green roof models in Kuching, Sibü and Miri were 34.6%, 41.0% and 31.5% respectively. The result indicated that the amount of rainwater retained in Kuching was highest (1197.8 mm), followed by Sibü (1041.5 mm) and Miri (966.3 mm). Although the volumetric retention in Sibü was lower than Kuching, the green roof model in Sibü has presented the highest degree of retention as the cumulative rainfall depth was comparatively lower.

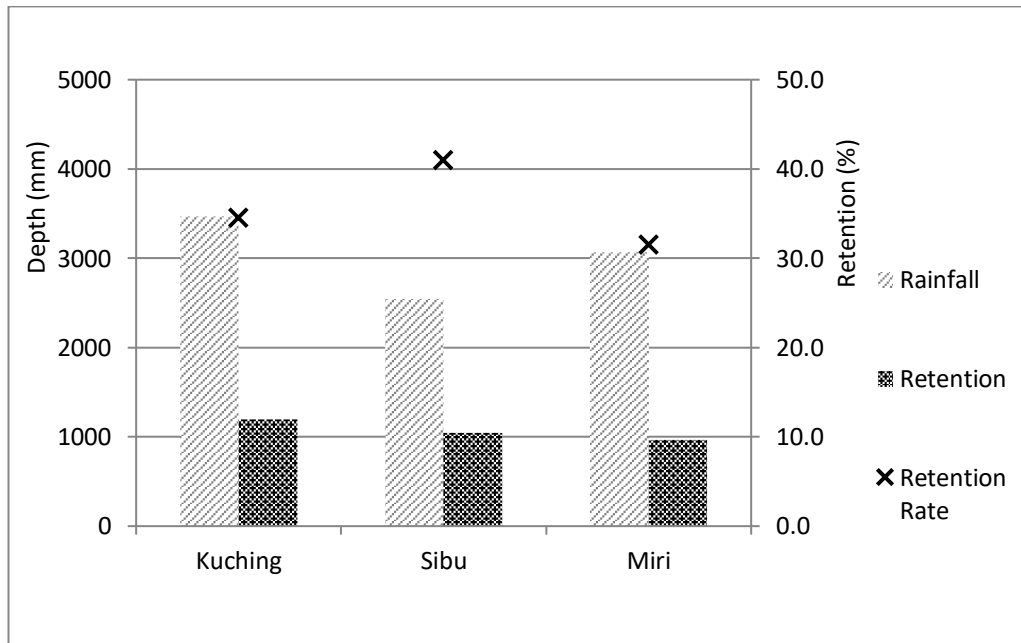


Figure 4.19: Twelve-month cumulative retention performances in Sarawak

4.6 Discussion

4.6.1 Retention Performance of UNIMAS Green Roof

Although more field data are needed to make conclusive statements about the urban stormwater mitigation performance of the green roof in Sarawak, the result from the pilot study at UNIMAS green roof provides evidence that a typical extensive green roof is capable of reducing the runoff from the roof under the actual rainfall scenario in Sarawak. The event retention rates (65.2% - 98.8%) reported from seven monitored event were significantly higher than the reported values from Musa et al. (2011) in peninsular Malaysia which only ranged between 16.7% and 47.9%. The higher retention performance in the present study is most likely due to the absence of heavy event that could result in poor retention performance. In addition, the variation in retention performances could be due to the shallow depth of the green roof model (± 80.0 mm) adopted in the study of Musa et al. (2011) compared to the UNIMAS green roof (approximately 140.0 mm). The reported one-month life period of the green roof's vegetation in the study of Musa et al. (2011) might also reduce the retention capacity as the soil was not bonded firmly compared to the vegetation condition of UNIMAS green roof with more than one year life period prior to field monitoring.

By referring to the highest retention depth recorded from the monitored events, the result suggested that the maximum water storage capacity of the UNIMAS green roof may be equal to or greater than 14.62 mm. By taking into consideration that long ADWP are required to completely remove the antecedent moisture and the evapotranspiration rate falls over time with restricted moisture conditions, it is reasonable to assume that the retention capacity of the UNIMAS green roof was not optimized prior to the event recorded with 14.62 mm retention depth as portion of the water storage was occupied by

the antecedent moisture from the previous event. Thus, it is most likely that the maximum water storage capacity of the UNIMAS green roof was greater than 14.62 mm.

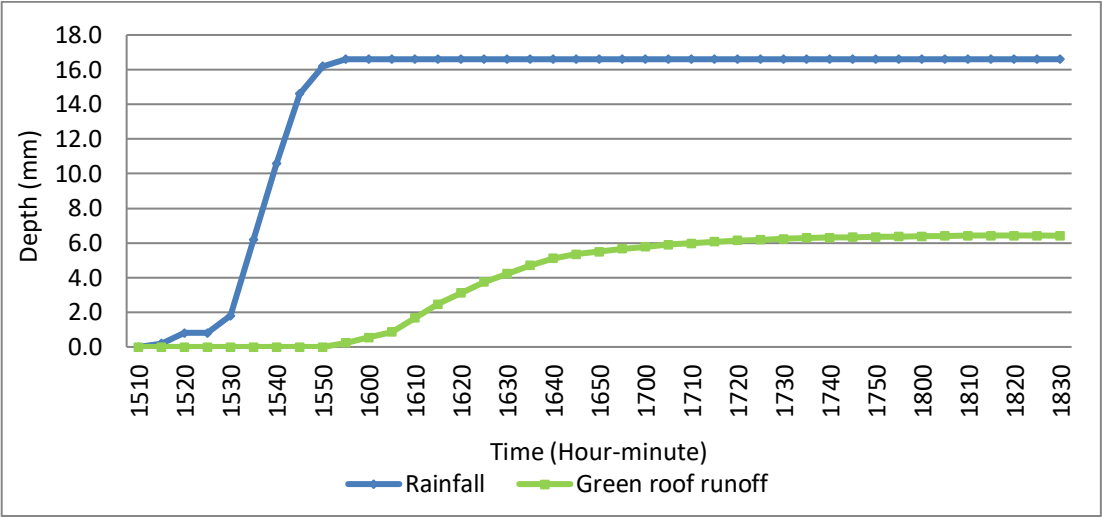


Figure 4.20: Cumulative rainfall-runoff profile of UNIMAS green roof during the rainfall event on 15 November 2014

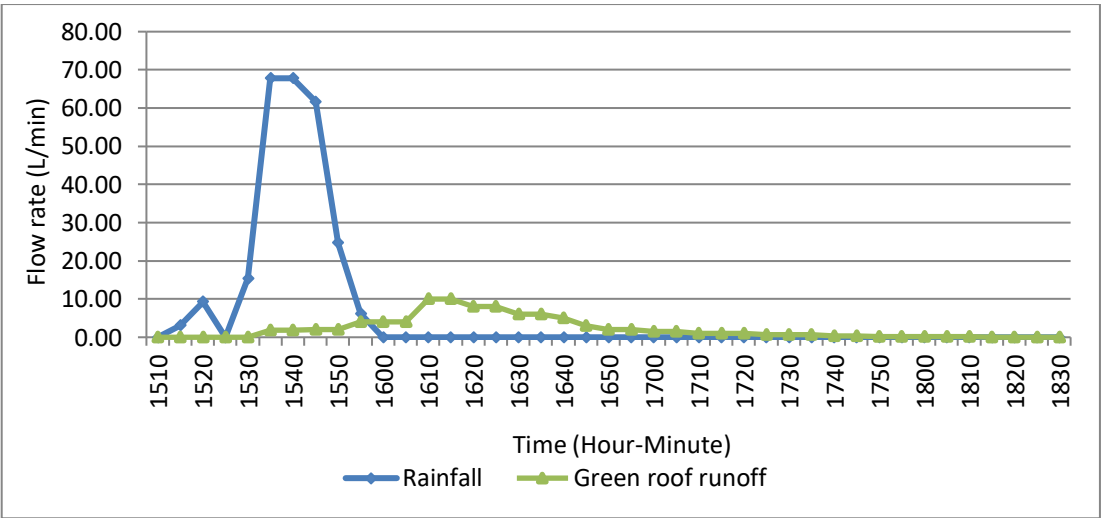


Figure 4.21: Flow rate of rainfall-runoff from UNIMAS green roof during the rainfall event on 15 November 2014

Since the size of the rainfall events recorded from the UNIMAS green roof were fairly small, the collected data were unable to reflect the actual retention performance of the UNIMAS green roof during the significant event. Nevertheless, the result preliminary

showed that the green roof still able to retain above 90.0% of the rainfall during the events with rainfall depth greater than 10.0 mm. Instead of runoff retention, the detention effect and peak flow reduction were also noticed from the field data. As shown in Figure 4.20 and Figure 4.21, the rainfall-runoff profile of the rainfall event during 15 November 2014 illustrates that the runoff generation from the roof was delayed and peak flow of runoff was reduced. However, a full understanding of the field hydrological performances offered by the green roof under the climatic conditions of Sarawak will probably require long-term monitoring with automatic monitoring system.

4.6.2 Overall Retention Performance

The twelve-month cumulative retention rate for the green roof models in Kuching (34.6%), Sibü (41.0%) and Miri (31.5%) falls within the range of the reported performances from previous studies (Table 2.1). On comparison, the green roof model in Sibü displayed higher cumulative retention rate than Kuching and Miri. Some studies have suggested that the reduced cumulative retention performance of the green roof was due to the occurrence of heavy event during the monitoring period (Sims, 2015; Wong & Jim, 2014). By referring to the rainfall data, the occurrences of event with rainfall depth greater than 40.0 mm in Kuching and Miri were nearly twice of the similar event in Sibü. The result indicated that the runoff generated from these events has contributed significantly to the cumulative runoff in Kuching (46.3%) and Miri (52.7%) compared to Sibü (31.4%). As a result, the overall cumulative retention rates in Kuching and Miri were reduced with increased cumulative runoff. Likewise, higher proportion of the runoff generated from heavy event also reduced the cumulative retention rate in Miri compared to Kuching.

Overall, the cumulative retention performances in Sarawak were comparable to the reported values from the green roofs in New York (Carson et al., 2013), Connecticut (Gregoire et al., 2011) and Georgia (Prowell, 2006) in the US. However, direct comparisons with other studies are difficult due to the variations in green roof configuration and research methodology. In order to provide a fair comparison between the studies to assess the overall retention performance under the hot-humid tropical climate, particular attention is paid to a research in the UK by Stovin et al. (2013). The study investigated the local cumulative retention performances of a green roof over 30 years period by using similar modeling approach on the green roof models with the same maximum water storage capacity in the present study. Hence, the influences from the green roof configuration and research methodology on the variations seen between the retention performances were minimized. Since the rainfall and runoff data in the study of Stovin et al. (2013) were analysed for 30 years period, the comparison in retention performances was made by referring to the average annual cumulative retention rate (twelve-month cumulative retention performance). The comparison attempts to highlights the effect from high evapotranspiration rate from hot-humid tropical climate on the long-term retention performance compared to other climates.

In general, the reported mean annual rainfalls for NW Scotland (2708.0 mm), Cornwall (1365.0 mm), Sheffield (838.0 mm) and East Midlands (496.0 mm) were lower than Sarawak. Figure 4.22 shows that the cumulative retention rates for the green roof models in the UK decreased with increased cumulative rainfall depth. The highest cumulative retention rate was seen from the green roof model in East Midlands (59.1%), followed by Sheffield (39.7%), Cornwall (33.3%) and NW Scotland (19.2%). When comparing the results from both studies, it can be seen that the cumulative rainfall depth in

Sarawak were two times higher than Cornwall, Sheffield and East Midlands. Sims (2015) has assessed the cumulative retention performances of the green roofs under three different climatic conditions and concluded that climates with less rainfall will retain a much higher percentage of rainfall compared to wet climate. On contrary to the finding of Sims (2015), the cumulative retention rates in Sarawak were still comparable to the reported performances of Cornwall and Sheffield. In addition, it was found that the cumulative retention rate for the green roof model in NW Scotland was lower than the cumulative retention rates in Kuching and Miri even though it had smaller cumulative rainfall depth.

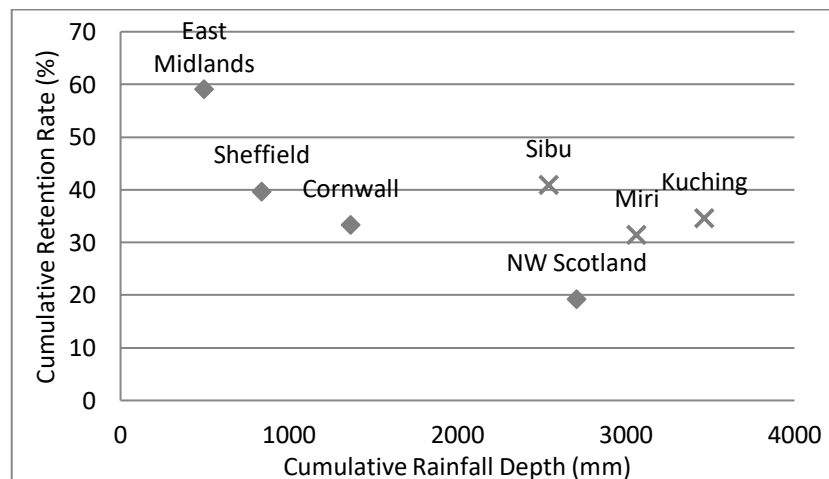


Figure 4.22: Cumulative retention rate of the green roof models against cumulative rainfall at different locations in Sarawak and United Kingdom

The variation in the reported retention performances between the UK and Sarawak are most likely due to the fluctuations of evapotranspiration rate. By referring to the computed PET rate, it was found that the daily PET rate in Sarawak remains above 3.80 mm/day throughout the twelve month study period. Meanwhile, Stovin et al. (2013) has reported significant fluctuations in the daily PET rate between the months in the UK. For instance, the PET rate in the UK during the summer months was similar to Sarawak yet it

dropped below 1.00 mm/day during the winter months. Given that the water storage capacity restored by the evapotranspiration mechanism as well as the accumulated amount of rainwater retained by green roof in long-term can be significant, it is thought that the stable and high evapotranspiration rate in Sarawak throughout the year has moderated the unfavorable impact from the high cumulative rainfall depth and thus elevated the long-term cumulative retention rate.

Although it may be true that the high and stable evapotranspiration from hot-humid tropical climate able to improve the long-term retention performance, it is important not to overemphasize the beneficial effect from the evapotranspiration rate as the effect could be masked by the amount of rainfall too. For example, the green roof model in East Midlands had higher cumulative retention rate than the reported performances in Sarawak even though the volumetric retention of East Midlands (average 293.1 mm per year) was lower than Sarawak (966.3 mm – 1197.7 mm). A closer look at the data indicates that the 30 years mean annual rainfall in East Midlands was significantly lower (496.0 mm) compared to the twelve month cumulative rainfall depth in Sarawak (2541.0 mm – 3466.0 mm). It is obvious that the high and stable evapotranspiration rate in Sarawak has increased the volumetric retention but the overall cumulative retention rates were reduced due to significantly higher cumulative rainfall in Sarawak compared to East Midlands.

Given these points, the finding partially supports the earlier hypothesis and the suggestion of Köhler et al. (2001) which stated that the hot-humid tropical region could benefit from the retention of the green roof due to higher and stable evapotranspiration rate. Given that there is no significant variation in the cumulative rainfall, the findings suggest that high and stable evapotranspiration rate from hot-humid tropical climate will increase the volumetric retention as well as the long-term retention rate in Sarawak. However, the

degree of the beneficial effect from the evapotranspiration towards the long-term retention performance of the green roof under the hot-humid tropical climate will be less pronounced when compared to other climate with extremely low cumulative rainfall.

4.6.3 Monthly Retention Performance

In addition to event retention performance, the results also indicated that there were variations in monthly retention performances from the green roof models in Sarawak. In Miri, the monthly retention rate for the green roof model varied from 20.8% in January 2017 to 99.1% in March 2017. The result also showed that the green roof model in Miri had the lowest monthly retention rate for most of the month compared to Kuching and Miri. Meanwhile, the green roof model in Sibü had relatively high monthly retention performance as the monthly retention rates occupied the upper range of the overall performances compared to Kuching and Miri. The green roof models in Kuching had the smallest variation in monthly retention performances during the study period, with monthly retention rate ranging from 19.6% in February 2013 to 49.1% in June 2013. In short, the variations seen in monthly retention rate of the green roof models indicates that there were significant influences from meteorological factors on the monthly retention performances of the green roof. Thus, correlation analysis was performed to determine the effect from different meteorological factors towards the monthly retention rate. Overall, the strengths of correlation between monthly retention rate and meteorological factors were summarised in Table 4.2.

Most of the prior studies have attributed the seasonal and monthly variations in retention performance to the differences in evapotranspiration rate between the seasons

(Hoffman et al., 2010; Sims, 2015; Uhl & Schiedt, 2008). The correlation analysis revealed that monthly retention rates in Miri was positively correlated with mean PET, indicating the monthly retention rate tends to increase with higher mean PET rate. On the other hand, the correlations found between the variables for the green roof models in Kuching and Sibul were very weak. The result suggested that the mean PET rate had very minimal or no effect on the monthly retention rate. It is important to note that the fluctuations in evapotranspiration rate under the hot-humid tropical climate are fairly small compared to other climates. Thus, it is not surprising to find that the monthly mean PET rate did not present strong correlation with the monthly retention rate.

Table 4.2: Spearman's rank correlation coefficients between monthly retention rate and different meteorological factors in Sarawak

Meteorological factor	Rainfall depth	Mean ADWP	Mean PET rate
Kuching	-0.891*	0.273	0.106
Sibu	-0.951*	0.427	-0.007
Miri	-0.939*	0.661*	0.529

*Correlation is statistically significant with $p\text{-value} < 0.05$

The result of correlation analysis indicated that mean ADWP had weak to moderate positive correlations with monthly retention rate in Kuching and Sibul, and stronger positive correlation between the variables was seen from the green roof model in Miri. However, the positive correlations between the variables for Kuching and Sibul were found to be not statistically significant. As can be seen from Figure 4.16, the variations in monthly retention rate were mostly seen from the months with shorter mean ADWP, indicating shorter mean ADWP does not necessarily result in lower monthly retention rate. It is thought that the event size distribution within the respective months has masked the

expected associations between monthly retention rate and mean ADWP.

For example, the green roof model in Sibuh managed to retain 76.6% of the monthly rainfall in May 2013 even though the mean ADWP was only 20.3 hours. The rainfall data shows that the frequency of rainfall in May 2013 was relatively high but nearly all the rainfall events were smaller than 5.0 mm. Thus, the green roof has less dependence on the ADWP to increase its water storage capacity as well as the monthly retention performance because the water storage capacity required to retain a small event is ample. On the other hand, the green roof model in Sibuh only managed to retain 39.0% of the monthly rainfall in August 2013 even though the mean ADWP was approximately twice of May 2013 (38.6 hours). A closer look at the data indicated that the low monthly retention rate was attributed to the huge amount of runoff generated from several heavy events particularly during the 84.5 mm event on 19 August 2013. It appeared that the ADWP will have stronger effect on monthly retention rate under the climates with relatively small variations in event size.

The correlation analysis revealed that the monthly retention rate had very strong and statistically significant positive correlations with monthly rainfall depth for all green roof models. The result indicated that the monthly retention rate of the green roof tends to increase with decreased monthly rainfall depth. In addition, the trend of monthly retention rate also showed a strong dependence on the trend of monthly rainfall depth between the consecutive months. The findings in the present study is consistent with the finding of Hathaway et al. (2008) which also found that the variation in monthly retention rate was affected by both the amount and trend of monthly rainfall depth. As can be seen from Table 4.2, monthly rainfall depth had significantly stronger correlation with monthly retention rate compared to other meteorological factors. It was revealed that the monthly

rainfall depth is the primary meteorological factor that affects the monthly retention rate in Sarawak.

The significant effect from the monthly rainfall depth towards the monthly retention rate can be related to the frequency of heavy event (Carson, 2014; Camm, 2011). For example, the rainfall-runoff profile during the month with lowest monthly retention rate in Miri indicates that there were frequent occurrences of rainfall events associated with several heavy events (Figure 4.23). On comparison, the rainfall-runoff profile during March 2013 with extremely high monthly retention rate in Miri displays an extended period of no runoff due to the absence of heavy event (Figure 4.24). It is unlikely for the green roof to be saturated when there is no heavy events occur over a period. Hence, the subsequent rainfall events will result in higher retention rate due to sufficient initial water storage capacity for retention. On the other hand, the occurrences of heavy event will quickly saturate the water storage capacity and impact the retention capability of the green roof during the subsequent rainfall events. In addition, heavy event also contributes a great amount of runoff as the water storage capacity of the green roof is finite. Consequently, the total runoff of the respective month increase and monthly retention rate decrease due to increased runoff contributed by the heavy event and the accumulated effect from series of rainfall event impacted by the heavy event.

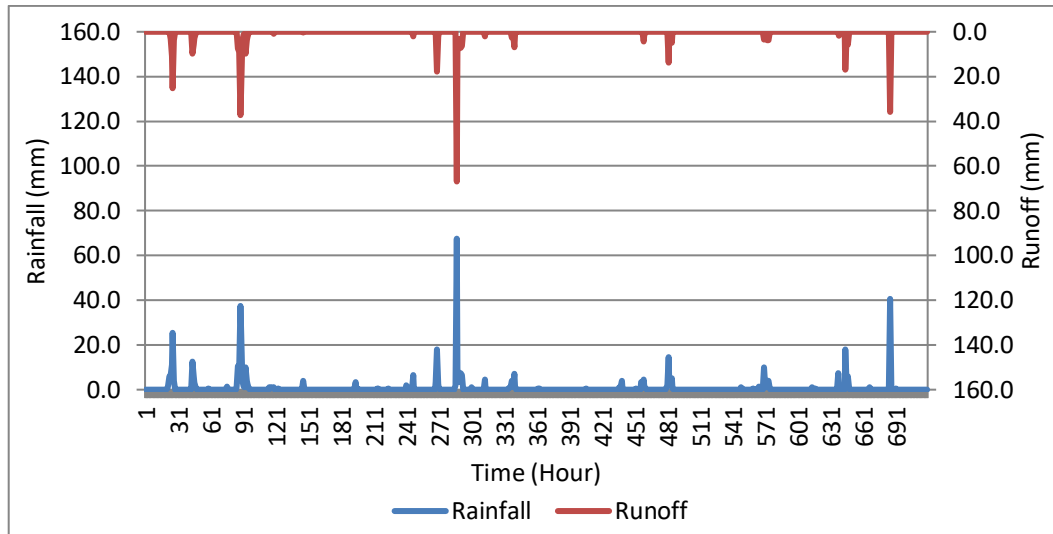


Figure 4.23: Rainfall-runoff profile of the green roof model in Miri during November 2012

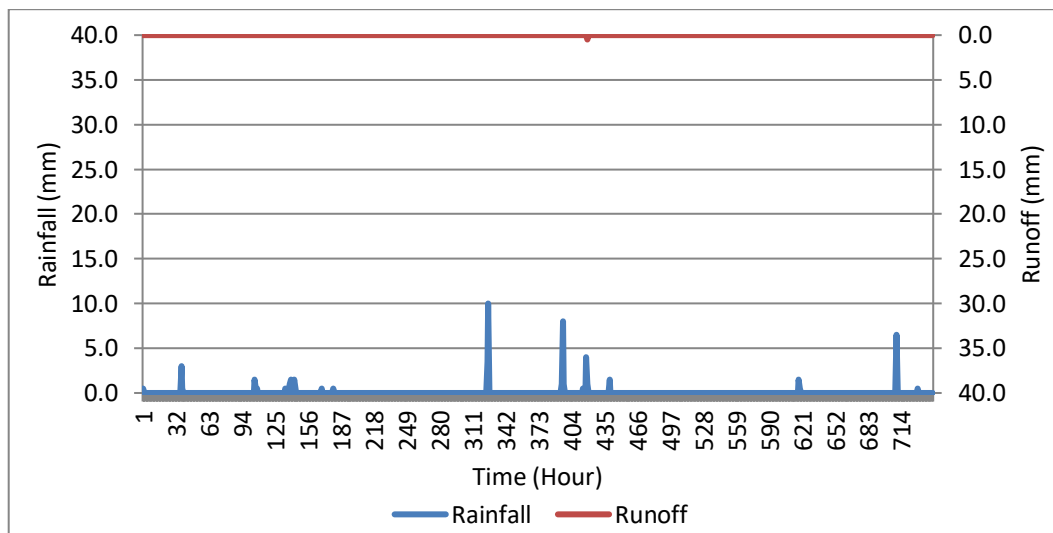


Figure 4.24: Rainfall-runoff profile of the green roof model in Miri during March 2013

Table 4.3: Multiple regression analysis for monthly retention rate

Location	Regression equation	R^2 (%)	t-statistic
Kuching	Retention = 70.22 – 0.09354 P – 0.2754 ADWP (4.1)	95.47	-13.17*, -3.87*
Sibu	Retention = 77.60 – 0.1408 P (4.2)	76.46	-5.70*
Miri	Retention = 70.15 – 0.1221 P (4.3)	58.29	-3.74*

* p -value < 0.01

Multiple regression analysis was performed to develop predictive relationship between meteorological factors and monthly retention rate of green roof to any given month in Sarawak. Table 4.3 presented the best-fitting regression equation resulted from stepwise multiple regression analysis. The t-statistics are presented in the same order as the parameter in the equation. Overall, the regression equation for Kuching has the highest R^2 value which account for 95.47% of variance, follow by the regression equation for Sibul ($R^2 = 76.46$) and Miri ($R^2 = 58.29$). It can be seen that all regression equation for monthly retention identified monthly rainfall depth as significant predictor while equation (4.1) considered ADWP as well. The result is in accordance with the strong correlation found between monthly retention and monthly rainfall depth for all green roof models from the spearman rank correlation analysis. It was also noted that the mean PET rate was eliminated from all regression equation as being non-significant, indicating the usefulness of using mean PET rate as the predictor in predicting the monthly retention in Sarawak is minimal. In contrast to the expected positive relationship, it was noted that regression coefficient for the ADWP in equation (4.1) for Kuching appeared to be negative, demonstrating that the monthly retention decrease with longer mean ADWP. As discussed in correlation analysis, it can be related to frequency of heavy event among the analysed month that has possibly masked the expected relationship between the monthly retention and mean ADWP. Although the regression equation is simple and shows a good R^2 , it is suggested that more meteorological factors can be taken into consideration for multiple regression analysis and validated with empirical data to improve the reliability of the regression equation in predicting the monthly retention.

4.6.4 Event Retention Performance

The high mean retention rate of the green roof models in Kuching (72.5%), Sibul (79.5%) and Miri (74.5%) indicated that the retention works for most of the rainfall events in Sarawak. The mean retention rates were higher than the reported performances in Italy (Fioretti et al., 2010) and Georgia, US (Prowell, 2006) but lower than the reported performances in Poland (Burszta-Adamiak, 2012), Seoul (Lee et al., 2011) as well as observed retention performance from UNIMAS green roof in Sarawak. The higher mean retention rate reported from other studies is partly due to the smaller event size of analysed events. As the rainfall depth of the analysed events were relatively low, it is easier for most of the event to be highly retained. In addition, absence of heavy event with poor retention performance will lower the overall mean retention rate. For example, the rainfall depth of the analysed event in Seoul only ranged between 2.0 mm and 30.9 mm (Lee et al., 2011). The events with rainfall depth greater than 20.0 mm only occurred twice during the study period. The result indicated that nearly all the rainfall events have resulted in retention rate exceeding 80.0%. Consequently, the overall mean retention rate was higher (90.3%) compared to present study.

Although the reported high mean retention rates seem encouraging, it must be remembered that the analysed events from three locations were greatly dominated by the event below 10.0 mm. As can be seen from Figure 4.6, the median retention rates for events below 10.0 mm were 100.0% despite the differences in locations and monsoons. It indicates that majority of the events below 10.0 mm were completely retained by the green roof models. This is consistent with the findings from other studies which often reported excellent retention performance from light event (Burszta-Adamiak, 2012; Carson, 2014; Chen, 2011; Hoffman et al., 2010; Prowell, 2006). As a result, the mean retention rates

were elevated due to predominance occurrence of light events. It is thought that averaging the event retention rate unable to thoroughly reflect the overall retention performance of the green roof in Sarawak as the data could be easily skewed by the performances from large number of small events.

From Figure 4.5, it can be seen that the event with retention rate below 30.0% occupied about 13.6% to 20.4% of the analysed events, depending on the locations. The reduction in retention performance can be attributed to the influences of rainfall depth and peak rainfall intensity. There were consistent decrements in mean retention rates from each green roof models with increased rainfall depth and peak rainfall intensity (Figure 4.6 and Figure 4.8). The beneficial effect of runoff reduction from the green roof declined to a minimum when the rainfall depth exceeded 40.0 mm and peak rainfall intensity higher than 30.0 mm/hour. In contrast to expectation, the retention performances of the rainfall events with very short ADWP (< 7 hours) were considerably high with mean retention rates ranging from 63.2% to 83.5%, depending on locations and monsoons. The result indicated that the reduction in ADWP did not greatly impact the retention rate.

The variations in the retention performances of rainfall events with similar rainfall depth and peak rainfall intensity were noticed between the monsoons. For example, the mean retention rates for events with rainfall depth greater than 40.0 mm were about 5.2% - 12.1% during the Northeast monsoon. Meanwhile, the mean retention rates of similar events were higher during the Southwest monsoon (16.0% in Kuching, 18.9% in Sibul, 15.2% in Miri). Most studies attribute the seasonal variations in retention performances to the changes in evapotranspiration rates between the seasons (Hoffman et al., 2010; Sims, 2015; Uhl & Schiedt, 2008). However, given that the PET rates between the monsoons in Sarawak were fairly consistent, it is unlikely that the variability in event retention

performances of similar events between the monsoons is due to the differences in evapotranspiration rate.

Carson (2014) attributes the seasonal variability observed in retention for the 10.0 mm - 40.0 mm events to the factors controlling the antecedent moisture content includes evapotranspiration rate and ADWP. The study suggested that the antecedent moisture content is important in determining the proportion of rainfall retained by the green roof for 10.0 mm - 40.0 mm events. By referring to the average ADWP between the monsoons, it is most likely that the reduced retention performance of similar rainfall events during the Northeast monsoon was due to the shorter ADWP. On average, the ADWP of the rainfall events during the Southwest monsoon (26.0 hours for Kuching, 27.0 hours for Sibu, 29.2 hours for Miri) were longer than Northeast monsoon (14.0 hours for Kuching, 15.4 hours for Sibu, 18.7 hours for Miri). Longer ADWP between the rainfall events provides more time for the evapotranspiration mechanism to restore the water storage capacity. In addition, the ADWP has stronger effect on the regeneration of the water storage capacity in Sarawak due to high evapotranspiration rate under hot-humid tropical climates. Hence, similar rainfall events will result in different retention rate due to variation in initial water storage capacity.

In an attempt to identify the salient meteorological factors that affects the event retention rate in Sarawak, correlation analysis was performed and the result is summarised in Table 4.4. It shows that the rainfall depth alone had the strongest negative correlations with retention rate for all green roof models. The result from correlation analysis indicated that the retention rate tends to decreases as the rainfall depth increases. The inverse relationship found between the variables generally consistent with the findings from previous studies (Carson et al., 2013; Prowell, 2006; Voyde, 2011). Similarly, the strong

negative correlation between retention rate and peak rainfall intensity indicated that the variables were inversely related. The result agrees with the reported findings of Musa et al. (2011) and Wai, Lam & Lau (2014). The significant influence of rainfall depth on retention rate is expected as it is the sole input to the green roof system (Wong & Jim, 2014). Since the water storage capacity of the green roof is finite, a large and intense event will quickly saturate the water storage and produce greater proportion of runoff compared to a light event. As a result, heavier event will retain smaller proportion of rainfall.

Table 4.4: Spearman's rank correlation coefficients between event retention rate and different meteorological factors in Sarawak during the Northeast monsoon (NE) and Southwest monsoon (SW)

Meteorological factor	Rainfall depth	Peak rainfall intensity	ADWP
Kuching – NE	-0.741*	-0.715*	0.160*
Kuching – SW	-0.759*	-0.741*	0.055
Sibu – NE	-0.742*	-0.704*	0.249*
Sibu – SW	-0.579*	-0.556*	0.186*
Miri – NE	-0.815*	-0.807*	0.226*
Miri - SW	-0.631*	-0.619*	0.281*

*Correlation is statistically significant with $p\text{-value} < 0.05$

Correlation analysis revealed that the rainfall depth and peak rainfall intensity of the analysed events were highly correlated ($r = 0.957$ during NE and $r = 0.983$ during SW for Kuching, $r = 0.979$ during NE and $r = 0.978$ during SW for Sibu, $r = 0.978$ during NE and $r = 0.981$ during SW for Miri). It is likely that most of the analysed events with higher rainfall depth were also associated with higher peak rainfall intensity. Thus, the strong correlation found between retention rate with rainfall depth and peak rainfall intensity must be interpreted with caution. Since the correlation coefficients were similar, it is reasonable to assume that the correlation between one of the meteorological factor with retention rate

can be misleading due to rainfall characteristic of analysed events.

Hui & Chu (2009) attribute the reduced retention performance during the high-intensity event to the decreased infiltration capacity of the green roof medium. Having considered that the modeling approach in the present study did not account the infiltration capability of the green roof model, it is appear that the strong correlations found between retention rate and peak rainfall intensity may not be able to provide meaningful data. Furthermore, the strength of correlations between retention rate and peak rainfall intensity were comparatively weaker than rainfall depth. For this reason, it is most probably that the correlation found between peak rainfall intensity and retention rate in the present study was driven by the directly related pattern between rainfall depth and peak rainfall intensity of analysed events.

The evapotranspiration rate and ADWP both plays important roles in determining the initial water storage capacity of the green roof. Since the local evapotranspiration rate is fairly stable, it is reasonable to expect that the ADWP will exert stronger effect on the water storage capacity as well as the event retention rate. Contrary to expectation, the result indicated that retention rate had very weak positive correlations with ADWP for all the green roof models. The poor correlations found between the variables were conflicted with the findings from the studies which suggested that retention performance is dependent upon the ADWP (Berghage et al., 2009; Qin, 2013; Stovin et al., 2007). On the other hand, the result concurs with the findings of Spengen (2010) and Voyde (2011) which has found a weak correlation between the variables.

There are several possible explanations for this result, for example, ADWP would not be in full effect if the ADWP was only reset by a small antecedent event after a long dry weather period (Spengen, 2010; Wong & Jim, 2014). The water storage capacity will

still remain high after a short ADWP as the small antecedent event did not cause a drastic change in the antecedent moisture content. Since the local rainfall events in Sarawak were dominated by light events, it is likely that most of the analysed event with short ADWP was reset by light event and thus resulted in higher retention rate. In addition, Stovin et al. (2012) has found that the retention rate tends to be low with short ADWP yet a long ADWP does not necessarily yield higher retention as the water storage capacity is finite. One of the examples for such event can be seen from a 103.5 mm rainfall event in Kuching on 7 March 2013 with retention rate of 17.6% only even though the recorded ADWP was very long (169 hours).

Table 4.5: Spearman's rank correlation coefficients between event retention rate and ADWP for analysed events organized by rainfall depth

Rainfall depth (mm)	<10	10-20	20-30	30-40	≥40
Kuching	0.413*	0.593*	0.525*	0.610*	0.706*
Sibu	0.522*	0.496*	0.469*	0.428	0.480
Miri	0.377*	0.653*	0.576*	0.405	0.299

*Correlation is statistically significant with $p\text{-value} < 0.05$

These shortcomings suggested that the unclear relationship between retention rate and ADWP could be partly due to the variations in event size. In order to examine whether the influences of ADWP towards retention rate is masked by the event size, Spearman's rank correlation analysis was performed to determine the associations between ADWP and retention rate of the analysed event according to rainfall depth. As expected, it was found that the strength of correlations between the ADWP and retention rate were more pronounced among the events with similar rainfall depth. In brief, there were moderate to strong positive correlations were found between the retention rate and ADWP, depending

on the event size (Table 4.5). The result indicated that the event retention rate of the rainfall events with similar rainfall depth tends to increase with longer ADWP. In addition, the correlations found between the retention rate and ADWP within the similar event size category are thought to explain the variations in retention rate within the rainfall depth category as shown in Figure 4.6.

Overall, there were substantial variations in the reported relationships between retention performances and various meteorological factors in the present study and the findings from other climates. The findings revealed that the influences of meteorological factors towards event retention rate are complex. The biggest contribution of meteorological factors to event retention is most likely through the influences of rainfall depth. However, depending on the event size, the influences of ADWP could be significant too and thus should not be neglected. A stepwise regression analysis was undertaken to attempt to identify combination of influencing meteorological factor towards retention and develop potentially useful equation that capable of predicting green roof retention from meteorological factor. Table 4.6 displays the optimal regression equation resulted from stepwise regression analysis in predicting the retention rate of each green roof models according to the location and monsoons. The t-statistics are presented in the same order as the parameter in the equation. Overall, rainfall depth is the most significant explanatory variable among the meteorological factors as it has the highest absolute value of regression coefficient in five out of six regression equations and it is concurred with result from correlation analysis.

Table 4.6 shows that the regression equation (4.5) and (4.9) correlates retention rate with all meteorological factors and exhibits a R^2 equal to 57.24% and 46.18% for the green roof model in Kuching (SW) and Miri (SW) respectively. However, the peak rainfall

intensity turns out to be less significant with $p\text{-value} = 0.019$ (Kuching-SW) and $p\text{-value} = 0.131$ (Miri-SW). Meanwhile, the rest of the regression equations correlate retention rate with ADWP and rainfall depth or peak rainfall intensity. These regression equations were statistically highly significant with $p\text{-value} < 0.01$. It is believed that the usefulness of adding extra meteorological factors (i or P) as predictors into the two-variable regression model (P-ADWP or i-ADWP) is minimal for these specified locations of green roof and monsoons. The result is likely due to the high correlation between the rainfall depth and peak rainfall intensity as discussed earlier. If two predictors are not independent and highly correlated, then neither will contribute much to the prediction above and beyond the other. Thus, adding an extra predictor that highly correlates with existing predictor in the regression model does not gives a significant increment in the R^2 .

Table 4.6: Multiple regression analysis for event retention data

Location/ Monsoon	Regression equation	R^2 (%)	t-statistic
Kuching/NE	Retention = 73.67 – 1.428 P + 0.394 ADWP (4.4)	38.55	-10.07*, 3.41*
Kuching/SW	Retention = 86.58 – 1.104 P – 0.738 i + 0.2245 ADWP (4.5)	57.24	-5.09*, -2.36**, 4.93*
Sibu/NE	Retention = 83.69 – 2.294 P + 0.3904 ADWP (4.6)	61.84	-15.55*, 4.72*
Sibu/SW	Retention = 93.43 – 1.671 P + 0.0916 ADWP (4.7)	58.20	-16.48*, 3.05*
Miri/NE	Retention = 80.94 – 2.356 i + 0.3799 ADWP (4.8)	54.82	-12.59*, 4.53*
Miri/SW	Retention = 83.18 – 1.002 P – 0.734 i + 0.1887 ADWP (4.9)	46.18	-3.83*, -1.52 ^{NS} , 4.53*

* $p\text{-value} < 0.01$, ** $p\text{-value} < 0.05$. NS – not significant

Based on the result from the stepwise multiple regression analysis, it is important not to misuse the result by claiming that it yields the best model in predicting the retention

of green roof in Sarawak. As can be seen from the result, the R^2 for most of the regression models were not high, accounts for 38.55% to 61.84% of the variance only, depending to the location of green roof model and monsoons. This relationship, although significant at the 5% significance level, is relatively weak. However, the result from stepwise regression analysis can acts as a screening tool and helps to eliminate the least significant meteorological factors towards the retention performance of the green roof according to location and monsoons. In order to improve the predictive capability of the regression model specifically under the climatic conditions in Sarawak, a multiple regression analysis with more meteorological factors that have not been included in the present study shall be conducted based on more detailed empirical evidence.

From the perspective of stormwater management, evaluating the retention performances under the events that potentially trigger the occurrence of flashflood will ultimately determine whether a green roof system is preferred for managing urban stormwater in Sarawak. According to DID Sarawak (n.d.), any convective rainfall event with total depth above 60.0 mm within two to four hours will potentially triggers the occurrence of the flash flood in Sarawak. Overall, there are total sixteen rainfall events were identified as significant event from three locations (Table 4.7). It was revealed that the retention performances of these events were considerably low with mean and median retention rate of 11.5% and 9.5% only. The highest retention rate (24.8%) was seen from an event in Kuching with total rainfall depth of 62.5 mm and ADWP of 142 hours while the lowest retention rate (2.4%) was seen from an event in Kuching too with total rainfall depth of 131.5 mm and ADWP of 10 hours only.

Table 4.7: Retention rate of the green roof during the identified significant events between November 2012 and October 2013

Location	Date	Rainfall depth (mm)	Peak intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (%)
Kuching	17-Feb-13	131.5	64.5	10.0	128.3	2.4
	25-Feb-13	62.5	41.5	18.0	55.2	11.7
	7-Mar-13	103.5	23.5	169.0	85.3	17.6
	24-Sep-13	62.5	56.5	142.0	47.0	24.8
	3-Oct-13	116.5	88.5	18.0	112.4	3.5
Sibu	10-Feb-13	61.0	30.5	8.0	57.1	6.4
	18-Mar-13	66.0	52.0	24.0	49.8	24.5
	19-Aug-13	84.5	37.0	23.0	78.2	7.5
Miri	4-Nov-12	108.5	37.5	8.0	102.9	5.2
	12-Nov-12	100.5	67.5	14.0	97.1	3.4
	15-Dec-12	61.0	27.0	36.0	54.0	11.5
	22-Dec-12	87.0	49.0	18.0	79.1	9.1
	10-Jan-13	98.0	55.5	16.0	88.2	10.0
	28-Jan-13	80.5	58.5	228.0	61.7	23.4
	1-Aug-13	77.0	29.5	33.0	65.9	14.4
	15-Sep-13	130.0	40.5	49.0	118.6	8.8

Having considered that the water storage capacity of the green roof is finite, the improvement in retention performance with longer ADWP could be minimal. For example, an event recorded in Kuching during 7 March 2013 managed to retains 18.2 mm of the rainfall due to the very long ADWP (169.0 hours) that helps to restore the water storage capacity prior to the event. Although the retention depth was considerably high, the retention rate was only 17.6% and huge amount of runoff (47.0 mm) was produced from the green roof. This is due to the extremely high amount of rainfall (103.5 mm) entered the green roof and exceeded the maximum water storage capacity (20.0 mm). The maximum water storage capacity will determine the amount of runoff produced from the green roof when the rainfall increases and exceeded the water storage capacity (Carson, 2014). It is

apparent that any event categorized as significant event by DID Sarawak will produce at least 40.0 mm runoff from the green roof models in the present study.

The retention performance of the green roof during the significant event can be improved with increased maximum water storage capacity, but will also result in higher construction cost and rooftop loading. In addition to stormwater retention, there are other hydrological benefits provided by the green roof towards urban stormwater management such as detention and peak flow reduction (Chen, 2011; Seattle Public Utilities, 2013; Voyde, 2011). Instead of increasing the maximum water storage capacity, the green roof should be designed to achieve the best balance between various hydrological benefits offered by the green roof based on the meteorological conditions, local rooftop loading restrictions and the budget.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Due to rapid urbanization, green roof is emerging as one of the BMP of sustainable urban stormwater management in developed countries. Runoff reduction or commonly known as retention is one of the hydrological benefits offered by the green roof. To date, most of the studies concerning the retention performance of the green roof are widely covered the region under the temperate climate. Meanwhile, available literatures concerning the retention performances in tropical region are scarce. It has been suggested that the high and stable evapotranspiration in tropical region is favorable for the retention of green roof. However, it is uncertain whether the characteristic of tropical rainfall will impact the expected retention performance. Existing literatures have revealed that the retention of a green roof is highly dependent on the local climate and the data is not transferrable from one climate to another. Thus, there is a need to investigate the influences of hot-humid tropical climate on the retention performance of green roof. By applying past climate data specific to Kuching, Sibul and Miri in Sarawak to the green roof water balance model, the retention performances of green roof models were estimated according to the continuous interaction between different meteorological factors from November 2012 to October 2013. The results are intended to provide data of the runoff reduction benefits contributed by the green roof alone under the hot-humid tropical climate.

The result from the field monitoring at the UNIMAS green roof prior to the modeling has demonstrated the capability of a typical extensive green roof in reducing the

runoff from the roof under the actual meteorological conditions in Sarawak. The green roof has retained 80.8% of the total rainfall depth with mean retention rate of 88.1% from seven monitored events. When the retention performances of the green roof under wide range of rainfall scenarios were further explored through modeling approach, it was found that the green roofs were effective in retention for most of the rainfall events in Sarawak with mean retention rates of 72.5%, 79.5% and 74.5% for Kuching, Sibul and Miri respectively. The result shown that the event retention rate in Sarawak varied from 1.9% - 100.0% in Kuching, 2.7% - 100.0% in Sibul and 2.4% - 100.0% in Miri. On event basis, the rainfall events with smaller rainfall depth and peak rainfall intensity were highly retained by the green roofs. The retention performance declined to a minimum when the rainfall depth exceeded 40.0 mm and peak rainfall intensity higher than 30.0 mm/hour. From the aspect of urban stormwater management, the retention performances of the green roof during the events that responsible for the flash flood were found to be less effective with mean retention rate of 11.5% only.

The correlation analysis revealed that, individually, event retention rate had strong and statistically significant negative correlations with rainfall depth and peak rainfall intensity. The results also show that ADWP, previously thought to play important role in determining the retention performance, account for little of the variance in retention rate with weak correlation found between the variables. However, the retention rate had moderate to strong positive correlations with the ADWP after the events were organized by rainfall depth, depending on the locations and event size. It was revealed that the ADWP have more pronounced effect on retention performance when rainfall depth is taken into account. In brief, it is clear that the event retention rate of the green roof in Sarawak has an inverse relationship with rainfall depth and peak rainfall intensity, while the direct

relationship between retention rate and ADWP is event size dependent. As has been noted from the strengths of correlation, it is suggested that the rainfall depth is the primary factor that affects the event retention rate of the green roof in Sarawak.

On monthly basis, the variations in the monthly retention rate were noted from the modeled result, ranging from 19.6% to 49.6% in Kuching, 25.5% to 76.6% in Sibü and 20.8% to 99.1% in Miri. The correlation analysis revealed that there were very strong and statistically significant negative correlation between the monthly retention rate and monthly rainfall depth for all locations, suggesting that the monthly retention rate is inversely related to monthly rainfall depth. In Miri, monthly retention rate also had strong positive correlation, individually, with mean ADWP and mean PET rate, indicating that the monthly retention rate tends to increase with higher mean ADWP and mean PET rate. All things considered, it is obvious that monthly rainfall depth is the key meteorological factor that has significant effects towards the monthly retention performance of the green roof in Sarawak.

With respect to long-term retention performance, the modeled result indicated that the overall cumulative retention rates over the twelve months study period in Kuching, Sibü and Miri were 34.6%, 41.0% and 31.5% respectively. The overall cumulative retention rates were comparable with the reported long-term retention performance from the green roofs under temperate climates with relatively smaller cumulative rainfall. It was revealed that the high and stable evapotranspiration rate from hot-humid tropical climate in Sarawak has moderate the unfavorable impact from high rainfall on the long-term retention performance. However, the improvement in long-term retention performance due to the high and stable evapotranspiration rate could be less pronounced when the cumulative rainfall under hot-humid tropical climates is significantly higher than other climates.

The study has revealed that the effectiveness of green roof in managing urban stormwater under the hot-humid tropical climate in Sarawak is conditional depending on the rainfall scenario. Although it is apparent that green roof alone is unable to significantly contribute to the runoff reduction during the significant events, it may well provide effective and practical contribution towards the urban stormwater management in the context of Sarawak's hot-humid tropical climate when it is associated with other sustainable BMPs in parcel scale. It is hope that the estimated retention performances of the green roof in the present study can be referred as the potential contribution of green roof alone in runoff reduction when it is incorporated with other BMPs in large scale modeling. In addition, knowing how the salient meteorological factors affect the retention on event-based and long-term retention performance will allow designer to enhance the retention capability of the green roof according to the characteristic of identified meteorological factors.

5.2 Limitations and Recommendations

It is important to note that the hydrological model in this study was implicitly developed to simulate the runoff data based on theoretical hydrologic mechanism within the green roof system. This model has not calibrated based on field rainfall-runoff data in Sarawak due to unavailability of instruments for continuous monitoring. Although this model has been applied in existing studies and proven to be performed well in estimating the runoff, it is suggested that the model could be calibrated according to climate condition in Sarawak to give a more accurate prediction of volumetric retention. Understanding on the potential deviation of simulated result from the actual performance could enhance the

reliability of the simulated result. Calibration of this model applying on other green roofs varies in design and configuration could also be a future research topic. The simulated results between different green roofs can be compared and analyzed to determine the design parameters that could optimize the retention performance in Sarawak.

In the present study, the green roof was assumed to be applied uniformly and runoff was directly drained from the roof. Under the actual condition, runoff is routed to the impervious or pervious area through drain and downspouts pipe. There will be delayed in time during runoff is generated within the green roof and entering the main drainage system. Thus, other important time-related hydrologic benefits towards stormwater management such as the detention of stormwater and peak flow reduction are not assessed. It is recommended that these hydrologic behaviors of the green roof can be incorporated into future simulation works. Shorter time step shall be used for simulation to closely monitor these time-related hydrological performances.

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APPENDICES

Appendix A

Hydrological Data and Retention Performance of UNIMAS Green Roof

Hydrological data and retention performance for event on 10 May 2014.

RAINFALL DETAILS	
Rainfall Event	1
Date	10 May 2014
Time Start	1704
Time End	1710
Mean Rainfall Intensity (mm/hr)	8.57
Total Rainfall (mm)	1.00
Total Runoff (Litre)	0.95
Total Runoff (mm)	0.012
Retention (mm)	0.988
Retention (%)	98.8

Hydrological data and retention performance for event on 31 May 2014

RAINFALL DETAILS	
Rainfall Event	2
Date	31 May 14
Time Start	1549
Time End	1701
Mean Rainfall Intensity (mm/hr)	12.32
Total Rainfall (mm)	15.00
Total Runoff (Litre)	29.10
Total Runoff (mm)	0.378
Retention (mm)	14.622
Retention (%)	97.5

Hydrological data and retention performance for event on 06 Jun 2014

RAINFALL DETAILS	
Rainfall Event	3
Date	6 Jun 14
Time Start	1409
Time End	1430
Mean Rainfall Intensity (mm/hr)	8.73
Total Rainfall (mm)	3.2
Total Runoff (Litre)	6.78
Total Runoff (mm)	0.088
Retention (mm)	3.112
Retention (%)	97.2

Hydrological data and retention performance for event on 13 July 2014

RAINFALL DETAILS	
Rainfall Event	4
Date	13 Jul 14
Time Start	1604
Time End	1619
Mean Rainfall Intensity (mm/hr)	7.5
Total Rainfall (mm)	2
Total Runoff (Litre)	2.73
Total Runoff (mm)	0.035
Retention (mm)	1.965
Retention (%)	98.2

Hydrological data and retention performance for event on 17 August 2014

RAINFALL DETAILS	
Rainfall Event	5
Date	17 Aug 14
Time Start	1524
Time End	1840
Mean Rainfall Intensity (mm/hr)	3.53
Total Rainfall (mm)	11.6
Total Runoff (Litre)	287.48
Total Runoff (mm)	3.732
Retention (mm)	7.868
Retention (%)	67.8

Hydrological data and retention performance for event on 24 August 2014

RAINFALL DETAILS	
Rainfall Event	6
Date	24 Aug 14
Time Start	1416
Time End	1441
Mean Rainfall Intensity (mm/hr)	11.08
Total Rainfall (mm)	4.8
Total Runoff (Litre)	30.55
Total Runoff (mm)	0.397
Retention (mm)	4.403
Retention (%)	91.7

Hydrological data and retention performance for event on 15 November 2014

RAINFALL DETAILS	
Rainfall Event	7
Date	15 Nov 14
Time Start	1512
Time End	1555
Mean Rainfall Intensity (mm/hr)	22.64
Total Rainfall (mm)	16.6
Total Runoff (Litre)	445.56
Total Runoff (mm)	5.783
Retention (mm)	10.817
Retention (%)	65.2

Appendix B

Measured Rainfall and Runoff Data from UNIMAS Green Roof

5-Minutes time scale rainfall and runoff volume from UNIMAS green roof during rainfall event on 10 May 2014

Time	Rainfall (mm)	Volume (Litre)	
		Rainfall	Runoff
1700	0	0.00	0.00
1705	0.4	30.82	0.00
1710	0.6	46.22	0.60
1715	0	0.00	0.22
1720	0	0.00	0.08
1725	0	0.00	0.04
1730	0	0.00	0.01
Total	1	77.04	0.95

5-Minutes time scale rainfall and runoff volume from UNIMAS green roof during rainfall event on 31 May 2014

Time	Rainfall (mm)	Volume (Litre)	
		Rainfall	Runoff
1545	0	0.00	0.00
1550	0.2	15.41	0.00
1555	0.6	46.22	0.00
1600	1	77.04	0.30
1605	0.6	46.22	1.05
1610	0.8	61.63	1.08
1615	3.6	277.34	2.10
1620	2	154.08	3.60
1625	1.8	138.67	2.85
1630	0.8	61.63	4.35
1635	0.6	46.22	4.20
1640	1.2	92.45	4.03
1645	0.8	61.63	2.15
1650	0.4	30.82	1.20
1655	0.2	15.41	0.85
1700	0.2	15.41	0.28
1705	0.2	15.41	0.25
1710	0	0.00	0.20
1715	0	0.00	0.15
1720	0	0.00	0.13
1725	0	0.00	0.10
1730	0	0.00	0.08
1735	0	0.00	0.05
1740	0	0.00	0.05
1745	0	0.00	0.05
Total	15	1155.60	29.10

5-Minutes time scale rainfall and runoff volume from UNIMAS green roof during rainfall event on 08 June 2014

Time	Rainfall (mm)	Volume (Litre)	
		Rainfall	Runoff
1405	0	0.00	0.00
1410	0.6	46.22	0.00
1415	0.2	15.41	0.15
1420	0.8	61.63	1.40
1425	1.4	107.86	1.20
1430	0.2	15.41	1.60
1435	0	0.00	0.80
1440	0	0.00	0.45
1445	0	0.00	0.30
1450	0	0.00	0.20
1455	0	0.00	0.20
1500	0	0.00	0.15
1505	0	0.00	0.10
1510	0	0.00	0.05
1515	0	0.00	0.05
1520	0	0.00	0.05
1525	0	0.00	0.05
1530	0	0.00	0.03
1535	0	0.00	0.00
Total	3.2	246.53	6.78

5-Minutes time scale rainfall and runoff volume from UNIMAS green roof during rainfall event on 13 July 2014

Time	Rainfall (mm)	Volume (Litre)	
		Rainfall	Runoff
1600	0	0.00	0.00
1605	0.2	15.41	0.00
1610	1.4	107.86	1.60
1615	0.2	15.41	0.40
1620	0.2	15.41	0.35
1625	0	0.00	0.17
1630	0	0.00	0.10
1635	0	0.00	0.05
1640	0	0.00	0.03
1645	0	0.00	0.03
1650	0	0.00	0.00
Total	2	154.08	2.73

5-Minutes time scale rainfall and runoff volume from UNIMAS green roof during rainfall event on 17 August 2014

Time	Rainfall (mm)	Volume (Litre)	
		Rainfall	Runoff
1520	0	0.00	0.00
1525	0.4	30.82	0.00
1530	0.6	46.22	0.27
1535	0.8	61.63	0.75
1540	0.4	30.82	0.40
1545	0.2	15.41	0.22
1550	0.4	30.82	0.38
1555	0.4	30.82	0.60
1600	1	77.04	2.20
1605	1.4	107.86	5.20
1610	0.8	61.63	4.60
1615	0.4	30.82	3.20
1620	1	77.04	3.90
1625	1	77.04	4.40
1630	0.8	61.63	19.00
1635	0	0.00	16.50
1640	0.2	15.41	15.50
1645	0.2	15.41	18.50
1650	0	0.00	16.50
1655	0.2	15.41	14.00
1700	0	0.00	12.40
1705	0	0.00	10.00
1710	0	0.00	9.00
1715	0.2	15.41	7.60
1720	0.2	15.41	6.40
1725	0	0.00	7.60
1730	0	0.00	7.60
1735	0.2	15.41	7.60
1740	0.2	15.41	6.00
1745	0	0.00	7.00
1750	0.2	15.41	7.00
1755	0	0.00	8.10
1800	0	0.00	7.00
1805	0	0.00	7.00

Time	Rainfall (mm)	Volume (Litre)	
		Rainfall	Runoff
1810	0	0.00	6.40
1815	0.2	15.41	3.60
1820	0	0.00	4.10
1825	0	0.00	3.40
1830	0	0.00	3.00
1835	0	0.00	3.50
1840	0.2	15.41	2.90
1845	0	0.00	3.50
1850	0	0.00	3.90
1855	0	0.00	4.00
1900	0	0.00	4.00
1905	0	0.00	3.00
1910	0	0.00	2.40
1915	0	0.00	1.70
1920	0	0.00	1.50
1925	0	0.00	0.08
1930	0	0.00	0.08
Total	11.6	893.66	287.48

5-Minutes time scale rainfall and runoff volume from UNIMAS green roof during rainfall event on 24 August 2014

Time	Rainfall (mm)	Volume (Litre)	
		Rainfall	Runoff
1415	0.0	0.00	0.00
1420	0.6	46.22	0.00
1425	1.2	92.45	0.00
1430	1.6	123.26	12.00
1435	0.8	61.63	8.20
1440	0.4	30.82	4.40
1445	0.2	15.41	2.50
1450	0.0	0.00	1.25
1455	0.0	0.00	0.80
1500	0.0	0.00	0.30
1505	0.0	0.00	0.24
1510	0.0	0.00	0.16
1515	0.0	0.00	0.14
1520	0.0	0.00	0.10
1525	0.0	0.00	0.08
1530	0.0	0.00	0.08
1535	0.0	0.00	0.05
1540	0.0	0.00	0.05
1545	0.0	0.00	0.05
1550	0.0	0.00	0.05
1555	0.0	0.00	0.05
1600	0.0	0.00	0.05
1605	0.0	0.00	0.00
1610	0.0	0.00	0.00
Total	4.8	369.79	30.55

5-Minutes time scale rainfall and runoff volume from UNIMAS green roof during rainfall event on 15 November 2014

Time	Rainfall (mm)	Volume (Litre)	
		Rainfall	Runoff
1510	0.0	0.00	0.00
1515	0.2	15.41	0.00
1520	0.6	46.22	0.05
1525	0.0	0.00	0.00
1530	1.0	77.04	0.30
1535	4.4	338.98	9.00
1540	4.4	338.98	9.00
1545	4.0	308.16	10.00
1550	1.6	123.26	10.00
1555	0.4	30.82	20.00
1600	0.0	0.00	20.00
1605	0.0	0.00	20.00
1610	0.0	0.00	50.00
1615	0.0	0.00	50.00
1620	0.0	0.00	40.00
1625	0.0	0.00	40.00
1630	0.0	0.00	30.00
1635	0.0	0.00	30.00
1640	0.0	0.00	25.00
1645	0.0	0.00	15.00
1650	0.0	0.00	10.00
1655	0.0	0.00	10.00
1700	0.0	0.00	7.50
1705	0.0	0.00	7.50
1710	0.0	0.00	5.00
1715	0.0	0.00	5.00
1720	0.0	0.00	5.00
1725	0.0	0.00	3.00
1730	0.0	0.00	3.00
1735	0.0	0.00	3.00
1740	0.0	0.00	1.50
1745	0.0	0.00	1.30

Time	Rainfall (mm)	Volume (Litre)	
		Rainfall	Runoff
1750	0.0	0.00	1.10
1755	0.0	0.00	1.00
1800	0.0	0.00	1.00
1805	0.0	0.00	1.00
1810	0.0	0.00	1.00
1815	0.0	0.00	0.08
1820	0.0	0.00	0.08
1825	0.0	0.00	0.08
1830	0.0	0.00	0.07
Total	16.6	1278.86	445.56

Appendix C

Example of Calculation Sheet for Potential Evapotranspiration Rate

Example

Location: Kuching

Month: January 2013

Latitude, $\phi = 1.483^\circ \text{ N}$ or 0.026 rad

Daily mean temperature, $T_m = 27.5^\circ \text{C}$

Daily maximum temperature, $T_{\max} = 30.9^\circ \text{C}$,

Daily minimum temperature, $T_{\min} = 24.0^\circ \text{C}$

Step 1: Determine the solar declination, δ

$$\delta = 0.409 \sin\left(\frac{2\pi}{365}J - 1.39\right)$$

$$= 0.409 \sin(0.0172J - 1.39)$$

Given;

Number of the day in the year (Increased by 15 days per month), $J = 15 \text{ days}$

$$\delta = 0.409 \sin[(0.0172 \times 15) - 1.39]$$

$$= 0.409 \sin\left[-1.132 \times \frac{180}{\pi}\right]$$

$$= -0.370 \text{ rad or } 338.786^\circ$$

Step 2: Determine the relative distance Earth – Sun, d_t

$$\begin{aligned}d_t &= 1 + 0.033 \cos\left(\frac{2\pi}{365}J\right) \\&= 1 + 0.033 \cos(0.0172J) \\&= 1 + 0.033 \cos(0.0172 \times 15) \\&= 1 + 0.033 \cos\left(0.258 \times \frac{180}{\pi}\right) \\&= 1.032 \text{ rad or } 59.124^\circ\end{aligned}$$

Step 3: Determine the sunset hour angle, ω_s

$$\begin{aligned}\omega_s &= \cos^{-1}(-\tan \varphi \tan \delta) \\&= \cos^{-1}[-\tan 1.483^\circ \tan 338.786^\circ] \\&= 89.424^\circ \text{ or } 1.561 \text{ rad}\end{aligned}$$

Step 4: Determine the daily extraterrestrial radiation, R_a

$$R_a = \frac{24(60)}{\pi} G_{SC} d_t (\omega_s \sin \varphi \sin \delta + \cos \varphi \cos \delta \sin \omega_s)$$

Given;

Solar constant, $G_{SC} = 0.0820 \text{ MJ m}^{-2} \text{ day}^{-1}$

$$\begin{aligned}R_a &= \frac{24(60)}{\pi} \times 0.0820 \times 1.032 \times [(1.561 \sin 1.483^\circ \sin 338.786^\circ) \\&\quad + (\cos 1.483^\circ \cos 338.786^\circ \sin 89.424^\circ)] \\&= 35.577 \text{ MJ m}^{-2} \text{ day}^{-1}\end{aligned}$$

**Step 5: Determine the Potential Evapotranspiration Rate by using
Hargreaves Equation**

$$\begin{aligned} PET_0 &= 0.0023(0.408R_a)(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} \\ &= 0.0023(0.408)(35.577)(27.5 + 17.8)(30.9 - 24.0)^{0.5} \\ &= 3.97 \text{ mm day}^{-1} \text{ or } 0.17 \text{ mm h}^{-1} \end{aligned}$$

APPENDIX D

Potential Evapotranspiration Rate

Inputs for calculation of Potential Evapotranspiration Rate in Kuching by using Hargreaves Equation

Year	2012		2013									
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
J (Days in Year)	319	349	15	46	74	105	135	166	196	227	258	288
d_t (rad)	1.023	1.032	1.032	1.023	1.010	0.992	0.977	0.968	0.968	0.976	0.991	1.008
δ (rad)	-0.335	-0.407	-0.370	-0.230	-0.047	0.166	0.329	0.407	0.375	0.239	0.037	-0.169
ω_s (rad)	1.562	1.560	1.561	1.565	1.570	1.575	1.580	1.582	1.581	1.577	1.572	1.566
R_a	35.795	34.975	35.577	37.073	37.821	37.022	35.241	34.001	34.388	35.991	37.272	37.076
T_{max} (°C)	32.0	31.8	30.9	31.0	32.3	32.9	32.7	33.7	32.8	33.0	32.5	32.6
T_{min} (°C)	23.6	23.7	24.0	23.7	24.2	24.0	24.1	23.9	23.3	23.3	23.5	23.4
T_m (°C)	27.8	27.8	27.5	27.4	28.3	28.5	28.4	28.8	28.1	28.2	28.0	28.0
PET (mm day ⁻¹)	4.44	4.25	3.97	4.24	4.65	4.79	4.48	4.65	4.56	4.83	4.81	4.83
PET (mm h ⁻¹)	0.18	0.18	0.17	0.18	0.19	0.20	0.19	0.19	0.19	0.20	0.20	0.20

*Latitude for Kuching is 1.483°N

Inputs for calculation of Potential Evapotranspiration Rate in Sibiu by using Hargreaves Equation

Year	2012		2013									
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
J (Days in Year)	319	349	15	46	74	105	135	166	196	227	258	288
d_t (rad)	1.023	1.032	1.032	1.023	1.010	0.992	0.977	0.968	0.968	0.976	0.991	1.008
δ (rad)	-0.335	-0.407	-0.370	-0.230	-0.047	0.166	0.329	0.407	0.375	0.239	0.037	-0.169
ω_s (rad)	1.557	1.554	1.556	1.562	1.569	1.577	1.584	1.588	1.586	1.580	1.572	1.564
R_a	35.515	34.640	35.268	36.873	37.766	37.136	35.477	34.292	34.655	36.159	37.285	36.926
T_{max} (°C)	32.0	32.2	31.8	31.7	33.1	32.8	33.2	34.0	32.9	33.3	32.5	32.7
T_{min} (°C)	23.7	23.6	23.7	23.7	23.9	23.8	24.2	24.2	23.2	23.3	23.6	23.1
T_m (°C)	27.9	27.9	27.8	27.7	28.5	28.3	28.7	29.1	28.1	28.3	28.1	27.9
PET (mm day ⁻¹)	4.38	4.36	4.29	4.45	4.98	4.82	4.64	4.72	4.64	4.95	4.79	4.91
PET (mm h ⁻¹)	0.18	0.18	0.18	0.19	0.21	0.20	0.19	0.20	0.19	0.21	0.20	0.20

*Latitude for Sibiu is 2.250° N

Inputs for calculation of Potential Evapotranspiration Rate in Miri by using Hargreaves Equation

Year	2012		2013									
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
J (Days in Year)	319	349	15	46	74	105	135	166	196	227	258	288
d_t (rad)	1.023	1.032	1.032	1.023	1.010	0.992	0.977	0.968	0.968	0.976	0.991	1.008
δ (rad)	-0.335	-0.407	-0.370	-0.230	-0.047	0.166	0.329	0.407	0.375	0.239	0.037	-0.169
ω_s (rad)	1.544	1.538	1.541	1.553	1.567	1.583	1.597	1.603	1.601	1.589	1.574	1.558
R_a	34.728	33.704	34.404	36.299	37.585	37.412	36.090	35.056	35.354	36.584	37.285	36.487
T_{max} (°C)	31.2	31.5	31.3	31.5	31.9	31.8	31.9	32.0	31.0	31.0	30.7	31.1
T_{min} (°C)	24.0	24.3	24.0	24.2	24.4	24.4	24.5	24.4	23.5	23.6	23.5	23.7
T_m (°C)	27.6	27.9	27.7	27.9	28.2	28.1	28.2	28.2	27.3	27.3	27.1	27.4
PET (mm day ⁻¹)	3.97	3.88	3.96	4.20	4.44	4.38	4.24	4.17	4.09	4.21	4.22	4.21
PET (mm h ⁻¹)	0.17	0.16	0.17	0.18	0.18	0.18	0.18	0.17	0.17	0.18	0.18	0.18

*Latitude for Miri is 4.333° N

Appendix E

Runoff Modeling Worksheet by using Microsoft Excel 2010

2. Runoff Modeling Worksheet - Microsoft Excel

Home Insert Page Layout Formulas Data Review View Add-Ins novaPDF

Clipboard Font Alignment Number Styles Cells Editing

F9 $=IF(G8<20,E9*G8/20,E9)$

	A	B	C	D	E	F	G	H	I
1									
2		Location		Kuching					
3		Smax (mm)		20.000					
4									
5									
6		Date	Time	Depth of Precipitation	Potential Evapo-transpiration	Evapo-transpiration	Substrate Moisture Content	Runoff Depth	
7		-	t (hour)	P (mm)	PET (mm)	ET (mm)	S (mm)	R (mm)	
8		0	0	-	-	-	10.0	-	
9	NOV	01/11/2012	1	0.0	0.18	0.09	9.9	0.0	
10			2	0.5	0.18	0.09	10.3	0.0	
11			3	0.0	0.18	0.09	10.2	0.0	
12			4	0.0	0.18	0.09	10.1	0.0	
13			5	0.0	0.18	0.09	10.0	0.0	
14			6	0.0	0.18	0.09	10.0	0.0	
15			7	0.0	0.18	0.09	9.9	0.0	
16			8	0.0	0.18	0.09	9.8	0.0	
17			9	0.0	0.18	0.09	9.7	0.0	
18			10	0.0	0.18	0.09	9.6	0.0	
19			11	0.0	0.18	0.09	9.5	0.0	
20			12	0.0	0.18	0.09	9.4	0.0	
21			13	0.0	0.18	0.08	9.3	0.0	
22			14	5.0	0.18	0.08	14.3	0.0	
23			15	3.0	0.18	0.13	17.1	0.0	
24			16	0.0	0.18	0.15	17.0	0.0	
25			17	2.0	0.18	0.15	18.8	0.0	
26			18	0.0	0.18	0.17	18.7	0.0	

KUCHING SIBU MIRI Sheet3

Ready 100%

Formula for continuous computation of evapotranspiration from the green roof

2. Runoff Modeling Worksheet - Microsoft Excel

Home

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Formulas

Data

Review

View

Add-Ins

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Font

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G9

$$=IF((G8+D9-F9)<20,G8+D9-F9,20)$$

	A	B	C	D	E	F	G	H	I
1									
2		Location		Kuching					
3		Smax (mm)		20.000					
4									
5									
6		Date	Time	Depth of Precipitation	Potential Evapo-transpiration	Evapo-transpiration	Substrate Moisture Content	Runoff Depth	
7		-	t (hour)	P (mm)	PET (mm)	ET (mm)	S (mm)	R (mm)	
8		0	0	-	-	-	10.0	-	
9	NOV	01/11/2012	1	0.0	0.18	0.09	9.9	0.0	
10	2		0.5	0.18	0.09	10.3	0.0		
11	3		0.0	0.18	0.09	10.2	0.0		
12	4		0.0	0.18	0.09	10.1	0.0		
13	5		0.0	0.18	0.09	10.0	0.0		
14	6		0.0	0.18	0.09	10.0	0.0		
15	7		0.0	0.18	0.09	9.9	0.0		
16	8		0.0	0.18	0.09	9.8	0.0		
17	9		0.0	0.18	0.09	9.7	0.0		
18	10		0.0	0.18	0.09	9.6	0.0		
19	11		0.0	0.18	0.09	9.5	0.0		
20	12		0.0	0.18	0.09	9.4	0.0		
21	13		0.0	0.18	0.08	9.3	0.0		
22	14		5.0	0.18	0.08	14.3	0.0		
23	15		3.0	0.18	0.13	17.1	0.0		
24	16		0.0	0.18	0.15	17.0	0.0		
25	17		2.0	0.18	0.15	18.8	0.0		
26	18		0.0	0.18	0.17	18.7	0.0		

KUCHINGSIBUMIRISheet3

Ready100%

Formula for continuous computation of substrate moisture content of the green roof

2. Runoff Modeling Worksheet - Microsoft Excel

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Clipboard Font Alignment Number Styles Cells Editing

H9 $=IF((G8+D9-F9)>20,G8+D9-F9-20,0)$

	A	B	C	D	E	F	G	H	I
1									
2		Location		Kuching					
3		Smax (mm)		20.000					
4									
5									
6		Date	Time	Depth of Precipitation	Potential Evapo-transpiration	Evapo-transpiration	Substrate Moisture Content	Runoff Depth	
7		-	t (hour)	P (mm)	PET (mm)	ET (mm)	S (mm)	R (mm)	
8		0	0	-	-	-	10.0	-	
9	NOV		1	0.0	0.18	0.09	9.9	0.0	
10			2	0.5	0.18	0.09	10.3	0.0	
11			3	0.0	0.18	0.09	10.2	0.0	
12			4	0.0	0.18	0.09	10.1	0.0	
13			5	0.0	0.18	0.09	10.0	0.0	
14			6	0.0	0.18	0.09	10.0	0.0	
15			7	0.0	0.18	0.09	9.9	0.0	
16			8	0.0	0.18	0.09	9.8	0.0	
17			9	0.0	0.18	0.09	9.7	0.0	
18			10	0.0	0.18	0.09	9.6	0.0	
19			11	0.0	0.18	0.09	9.5	0.0	
20		01/11/2012	12	0.0	0.18	0.09	9.4	0.0	
21			13	0.0	0.18	0.08	9.3	0.0	
22			14	5.0	0.18	0.08	14.3	0.0	
23			15	3.0	0.18	0.13	17.1	0.0	
24			16	0.0	0.18	0.15	17.0	0.0	
25			17	2.0	0.18	0.15	18.8	0.0	
26			18	0.0	0.18	0.17	18.7	0.0	

KUCHING SIBU MIRI Sheet3

Ready 100%

Formula for continuous computation of runoff generated from the green roof.

Appendix F

Event Retention Rate of the Green Roof Model in Kuching

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
1	1-Nov-12	0.5	0.5	1	0.0	0.5	100.0
2	1-Nov-12	8.0	5.0	11	0.0	8.0	100.0
3	1-Nov-12	2.0	2.0	1	0.0	2.0	100.0
4	2-Nov-12	0.5	0.5	17	0.0	0.5	100.0
5	2-Nov-12	1.0	0.5	12	0.0	1.0	100.0
6	3-Nov-12	16.0	4.0	1	10.0	6.0	37.5
7	4-Nov-12	1.0	0.5	21	0.0	1.0	100.0
8	5-Nov-12	8.0	3.5	17	2.1	5.9	73.8
9	5-Nov-12	3.5	3.5	8	1.9	1.6	45.7
10	5-Nov-12	6.5	2.5	8	4.6	1.9	29.2
11	6-Nov-12	0.5	0.5	1	0.1	0.4	80.0
12	6-Nov-12	3.0	3.0	8	1.4	1.6	53.3
13	7-Nov-12	11.5	8.0	29	6.6	4.9	42.6
14	9-Nov-12	59.0	20.5	37	52.8	6.2	10.5
15	10-Nov-12	14.0	12.0	25	9.5	4.5	32.1
16	11-Nov-12	4.5	4.0	28	0.0	4.5	100.0
17	12-Nov-12	14.0	11.0	4	12.3	1.7	12.1
18	12-Nov-12	0.5	0.5	1	0.1	0.4	80.0
19	12-Nov-12	1.0	1.0	1	0.6	0.4	40.0
20	12-Nov-12	2.5	1.0	1	1.8	0.7	28.0
21	13-Nov-12	1.0	0.5	24	0.0	1.0	100.0
22	13-Nov-12	0.5	0.5	1	0.0	0.5	100.0
23	14-Nov-12	7.5	2.5	29	0.0	7.5	100.0
24	16-Nov-12	2.5	1.0	22	0.0	2.5	100.0
25	16-Nov-12	8.0	6.5	18	3.3	4.7	58.8
26	17-Nov-12	2.5	1.0	2	1.6	0.9	36.0
27	17-Nov-12	0.5	0.5	2	0.0	0.5	100.0
28	19-Nov-12	30.0	23.0	54	22.0	8.0	26.7
29	19-Nov-12	2.5	1.5	3	1.6	0.9	36.0
30	20-Nov-12	26.5	14.0	18	22.6	3.9	14.7
31	20-Nov-12	0.5	0.5	1	0.1	0.4	80.0
32	21-Nov-12	0.5	0.5	11	0.0	0.5	100.0
33	23-Nov-12	6.5	6.5	50	0.0	6.5	100.0
34	23-Nov-12	3.5	3.5	2	1.1	2.4	68.6

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
35	24-Nov-12	13.5	6.0	25	8.3	5.2	38.5
36	25-Nov-12	0.5	0.5	15	0.0	0.5	100.0
37	27-Nov-12	8.0	5.0	34	0.5	7.5	93.8
38	28-Nov-12	6.0	5.0	32	0.7	5.3	88.3
39	29-Nov-12	26.0	16.5	24	21.8	4.2	16.2
40	30-Nov-12	0.5	0.5	11	0.0	0.5	100.0
41	1-Dec-12	0.5	0.5	37	0.0	0.5	100.0
42	1-Dec-12	10.0	4.5	1	2.8	7.2	72.0
43	2-Dec-12	1.0	1.0	19	0.0	1.0	100.0
44	2-Dec-12	4.0	1.5	1	1.0	3.0	75.0
45	3-Dec-12	5.5	2.5	11	3.1	2.4	43.6
46	3-Dec-12	1.0	1.0	2	0.5	0.5	50.0
47	4-Dec-12	0.5	0.5	6	0.0	0.5	100.0
48	4-Dec-12	3.0	2.0	14	0.0	3.0	100.0
49	5-Dec-12	29.5	29.0	20	25.4	4.1	13.9
50	5-Dec-12	6.5	2.5	1	5.2	1.3	20.0
51	6-Dec-12	3.0	3.0	18	0.0	3.0	100.0
52	7-Dec-12	7.0	5.5	23	2.8	4.2	60.0
53	8-Dec-12	0.5	0.5	7	0.0	0.5	100.0
54	8-Dec-12	0.5	0.5	7	0.0	0.5	100.0
55	8-Dec-12	1.0	1.0	1	0.0	1.0	100.0
56	9-Dec-12	0.5	0.5	11	0.0	0.5	100.0
57	9-Dec-12	10.5	10.5	13	5.9	4.6	43.8
58	9-Dec-12	0.5	0.5	1	0.1	0.4	80.0
59	9-Dec-12	8.5	7.0	1	8.0	0.5	5.9
60	10-Dec-12	18.0	17.0	16	14.8	3.2	17.8
61	10-Dec-12	0.5	0.5	5	0.0	0.5	100.0
62	14-Dec-12	13.0	3.5	77	2.1	10.9	83.8
63	14-Dec-12	0.5	0.5	1	0.1	0.4	80.0
64	15-Dec-12	6.5	3.0	18	2.8	3.7	56.9
65	15-Dec-12	0.5	0.5	3	0.0	0.5	100.0
66	16-Dec-12	1.0	0.5	14	0.0	1.0	100.0
67	16-Dec-12	0.5	0.5	5	0.0	0.5	100.0
68	17-Dec-12	9.5	6.5	18	3.9	5.6	58.9
69	17-Dec-12	0.5	0.5	3	0.0	0.5	100.0
70	18-Dec-12	0.5	0.5	24	0.0	0.5	100.0
71	19-Dec-12	0.5	0.5	25	0.0	0.5	100.0
72	22-Dec-12	1.0	0.5	60	0.0	1.0	100.0
73	22-Dec-12	0.5	0.5	3	0.0	0.5	100.0
74	22-Dec-12	3.0	2.5	8	0.0	3.0	100.0
75	23-Dec-12	5.5	4.5	21	0.0	5.5	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
76	23-Dec-12	51.0	19.5	2	44.0	7.0	13.7
77	24-Dec-12	6.5	4.5	19	2.9	3.6	55.4
78	25-Dec-12	0.5	0.5	3	0.0	0.5	100.0
79	29-Dec-12	1.5	1.0	104	0.0	1.5	100.0
80	29-Dec-12	6.5	2.5	5	0.0	6.5	100.0
81	30-Dec-12	0.5	0.5	18	0.0	0.5	100.0
82	30-Dec-12	3.5	2.0	4	0.0	3.5	100.0
83	31-Dec-12	2.5	2.0	17	0.0	2.5	100.0
84	31-Dec-12	4.0	1.5	1	0.0	4.0	100.0
85	1-Jan-13	0.5	0.5	4	0.0	0.5	100.0
86	2-Jan-13	0.5	0.5	39	0.0	0.5	100.0
87	3-Jan-13	1.5	1.0	5	0.0	1.5	100.0
88	3-Jan-13	6.0	6.0	10	0.0	6.0	100.0
89	3-Jan-13	9.5	2.5	8	6.3	3.2	33.7
90	4-Jan-13	2.0	2.0	6	0.8	1.2	60.0
91	4-Jan-13	1.0	1.0	9	0.0	1.0	100.0
92	5-Jan-13	1.0	0.5	2	0.0	1.0	100.0
93	5-Jan-13	1.0	1.0	4	0.0	1.0	100.0
94	5-Jan-13	0.5	0.5	5	0.0	0.5	100.0
95	9-Jan-13	7.0	4.5	96	0.0	7.0	100.0
96	9-Jan-13	0.5	0.5	1	0.0	0.5	100.0
97	9-Jan-13	5.5	5.5	5	0.3	5.2	94.5
98	10-Jan-13	35.0	11.0	1	33.6	1.4	4.0
99	11-Jan-13	35.5	12.0	16	31.8	3.7	10.4
100	11-Jan-13	10.0	4.5	3	8.8	1.2	12.0
101	11-Jan-13	1.5	1.5	2	1.0	0.5	33.3
102	11-Jan-13	8.0	6.0	1	7.5	0.5	6.3
103	12-Jan-13	0.5	0.5	9	0.0	0.5	100.0
104	12-Jan-13	1.0	1.0	1	0.0	1.0	100.0
105	13-Jan-13	1.0	1.0	17	0.0	1.0	100.0
106	13-Jan-13	2.0	1.0	1	0.0	2.0	100.0
107	13-Jan-13	0.5	0.5	1	0.0	0.5	100.0
108	13-Jan-13	2.0	1.0	2	0.8	1.2	60.0
109	13-Jan-13	3.0	3.0	9	1.4	1.6	53.3
110	13-Jan-13	10.0	5.5	1	9.5	0.5	5.0
111	14-Jan-13	0.5	0.5	3	0.0	0.5	100.0
112	18-Jan-13	57.5	33.5	102	45.1	12.4	21.6
113	18-Jan-13	2.5	1.0	1	1.7	0.8	32.0
114	19-Jan-13	0.5	0.5	6	0.0	0.5	100.0
115	19-Jan-13	1.5	1.0	4	0.0	1.5	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
116	19-Jan-13	9.0	3.5	7	6.9	2.1	23.3
117	19-Jan-13	5.5	4.5	2	4.8	0.7	12.7
118	21-Jan-13	19.5	18.0	36	13.9	5.6	28.7
119	21-Jan-13	3.5	2.0	5	2.2	1.3	37.1
120	22-Jan-13	6.0	3.0	7	4.5	1.5	25.0
121	22-Jan-13	12.5	3.0	15	8.9	3.6	28.8
122	23-Jan-13	52.0	32.0	2	51.0	1.0	1.9
123	23-Jan-13	4.0	3.5	1	3.5	0.5	12.5
124	24-Jan-13	0.5	0.5	15	0.0	0.5	100.0
125	28-Jan-13	3.5	2.5	92	0.0	3.5	100.0
126	28-Jan-13	16.0	9.0	6	6.3	9.7	60.6
127	29-Jan-13	1.5	1.0	14	0.0	1.5	100.0
128	31-Jan-13	42.0	20.5	40	34.8	7.2	17.1
129	31-Jan-13	5.5	4.5	17	2.3	3.2	58.2
130	1-Feb-13	35.0	16.5	1	33.9	1.1	3.1
131	3-Feb-13	2.0	2.0	44	0.0	2.0	100.0
132	3-Feb-13	6.5	6.5	1	1.5	5.0	76.9
133	3-Feb-13	0.5	0.5	7	0.0	0.5	100.0
134	4-Feb-13	1.0	1.0	12	0.0	1.0	100.0
135	4-Feb-13	1.0	1.0	3	0.0	1.0	100.0
136	4-Feb-13	15.0	3.0	17	9.2	5.8	38.7
137	5-Feb-13	60.5	22.5	1	59.1	1.4	2.3
138	5-Feb-13	0.5	0.5	2	0.0	0.5	100.0
139	6-Feb-13	3.0	3.0	25	0.0	3.0	100.0
140	6-Feb-13	16.0	5.0	2	13.6	2.4	15.0
141	7-Feb-13	0.5	0.5	3	0.0	0.5	100.0
142	9-Feb-13	3.0	1.0	61	0.0	3.0	100.0
143	10-Feb-13	21.5	18.5	17	13.3	8.2	38.1
144	10-Feb-13	11.0	2.5	2	9.2	1.8	16.4
145	12-Feb-13	12.5	3.5	22	7.9	4.6	36.8
146	12-Feb-13	0.5	0.5	3	0.0	0.5	100.0
147	13-Feb-13	7.0	7.0	28	2.2	4.8	68.6
148	13-Feb-13	5.5	3.0	2	4.4	1.1	20.0
149	14-Feb-13	14.5	12.0	17	11.3	3.2	22.1
150	15-Feb-13	14.0	4.0	6	11.5	2.5	17.9
151	15-Feb-13	7.0	4.0	1	6.3	0.7	10.0
152	17-Feb-13	25.0	13.5	35	18.6	6.4	25.6
153	17-Feb-13	2.0	1.5	1	1.5	0.5	25.0
154	17-Feb-13	131.5	64.5	10	128.3	3.2	2.4
155	20-Feb-13	14.5	5.5	47	6.8	7.7	53.1

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
156	20-Feb-13	13.5	7.0	4	11.9	1.6	11.9
157	20-Feb-13	2.0	2.0	4	1.1	0.9	45.0
158	20-Feb-13	0.5	0.5	1	0.1	0.4	80.0
159	21-Feb-13	2.5	2.5	5	1.4	1.1	44.0
160	21-Feb-13	0.5	0.5	1	0.1	0.4	80.0
161	21-Feb-13	6.5	5.5	5	5.3	1.2	18.5
162	21-Feb-13	0.5	0.5	8	0.0	0.5	100.0
163	24-Feb-13	6.5	3.0	53	0.0	6.5	100.0
164	24-Feb-13	0.5	0.5	14	0.0	0.5	100.0
165	25-Feb-13	62.5	41.5	18	55.2	7.3	11.7
166	26-Feb-13	0.5	0.5	1	0.1	0.4	80.0
167	26-Feb-13	13.0	10.5	14	10.3	2.7	20.8
168	27-Feb-13	1.5	1.5	24	0.0	1.5	100.0
169	28-Feb-13	7.0	6.5	21	1.1	5.9	84.3
170	28-Feb-13	0.5	0.5	1	0.1	0.4	80.0
171	7-Mar-13	103.5	23.5	169	85.3	18.2	17.6
172	12-Mar-13	0.5	0.5	106	0.0	0.5	100.0
173	14-Mar-13	3.5	2.0	31	0.0	3.5	100.0
174	15-Mar-13	17.0	17.0	24	4.1	12.9	75.9
175	16-Mar-13	21.0	9.5	20	16.4	4.6	21.9
176	16-Mar-13	1.0	1.0	1	0.6	0.4	40.0
177	16-Mar-13	0.5	0.5	11	0.0	0.5	100.0
178	18-Mar-13	4.0	2.5	39	0.0	4.0	100.0
179	19-Mar-13	32.0	32.0	24	24.9	7.1	22.2
180	19-Mar-13	0.5	0.5	1	0.1	0.4	80.0
181	20-Mar-13	14.0	12.0	20	10.2	3.8	27.1
182	22-Mar-13	13.5	13.0	36	7.4	6.1	45.2
183	22-Mar-13	4.0	4.0	4	3.1	0.9	22.5
184	25-Mar-13	0.5	0.5	82	0.0	0.5	100.0
185	26-Mar-13	19.5	7.5	3	7.9	11.6	59.5
186	28-Mar-13	9.5	7.5	46	1.9	7.6	80.0
187	31-Mar-13	47.0	34.5	76	36.2	10.8	23.0
188	31-Mar-13	1.0	1.0	1	0.6	0.4	40.0
189	1-Apr-13	0.5	0.5	15	0.0	0.5	100.0
190	3-Apr-13	7.5	7.5	50	0.0	7.5	100.0
191	4-Apr-13	0.5	0.5	11	0.0	0.5	100.0
192	4-Apr-13	1.0	0.5	22	0.0	1.0	100.0
193	5-Apr-13	0.5	0.5	2	0.0	0.5	100.0
194	5-Apr-13	32.0	17.0	13	23.8	8.2	25.6
195	6-Apr-13	46.5	17.5	19	41.7	4.8	10.3

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
196	7-Apr-13	4.5	2.5	16	1.0	3.5	77.8
197	7-Apr-13	10.5	3.5	1	9.1	1.4	13.3
198	8-Apr-13	0.5	0.5	1	0.1	0.4	80.0
199	8-Apr-13	19.0	18.0	11	16.5	2.5	13.2
200	8-Apr-13	0.5	0.5	4	0.0	0.5	100.0
201	9-Apr-13	0.5	0.5	22	0.0	0.5	100.0
202	10-Apr-13	7.5	3.0	7	1.7	5.8	77.3
203	10-Apr-13	24.0	22.0	9	21.9	2.1	8.8
204	11-Apr-13	0.5	0.5	16	0.0	0.5	100.0
205	11-Apr-13	0.5	0.5	3	0.0	0.5	100.0
206	11-Apr-13	1.5	1.0	3	0.0	1.5	100.0
207	11-Apr-13	0.5	0.5	4	0.0	0.5	100.0
208	13-Apr-13	0.5	0.5	30	0.0	0.5	100.0
209	13-Apr-13	2.5	2.5	10	0.0	2.5	100.0
210	13-Apr-13	0.5	0.5	1	0.0	0.5	100.0
211	14-Apr-13	4.0	4.0	25	0.0	4.0	100.0
212	14-Apr-13	8.5	2.5	1	2.5	6.0	70.6
213	18-Apr-13	3.0	2.5	78	0.0	3.0	100.0
214	19-Apr-13	22.0	20.0	30	10.5	11.5	52.3
215	22-Apr-13	1.0	1.0	57	0.0	1.0	100.0
216	24-Apr-13	47.5	46.5	56	34.2	13.3	28.0
217	25-Apr-13	2.0	1.0	24	0.0	2.0	100.0
218	27-Apr-13	11.0	11.0	41	2.3	8.7	79.1
219	29-Apr-13	8.0	8.0	47	0.3	7.7	96.3
220	30-Apr-13	0.5	0.5	22	0.0	0.5	100.0
221	30-Apr-13	0.5	0.5	4	0.0	0.5	100.0
222	1-May-13	0.5	0.5	17	0.0	0.5	100.0
223	1-May-13	0.5	0.5	3	0.0	0.5	100.0
224	6-May-13	0.5	0.5	118	0.0	0.5	100.0
225	8-May-13	3.0	3.0	48	0.0	3.0	100.0
226	8-May-13	3.5	2.5	1	0.0	3.5	100.0
227	9-May-13	2.0	2.0	14	0.0	2.0	100.0
228	9-May-13	48.0	25.5	7	36.9	11.1	23.1
229	10-May-13	21.5	20.0	18	18.0	3.5	16.3
230	11-May-13	0.5	0.5	9	0.0	0.5	100.0
231	11-May-13	0.5	0.5	17	0.0	0.5	100.0
232	12-May-13	0.5	0.5	8	0.0	0.5	100.0
233	15-May-13	4.0	2.5	84	0.0	4.0	100.0
234	16-May-13	34.0	15.5	19	22.0	12.0	35.3
235	16-May-13	0.5	0.5	1	0.1	0.4	80.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
236	18-May-13	11.0	6.0	42	3.9	7.1	64.5
237	20-May-13	0.5	0.5	36	0.0	0.5	100.0
238	20-May-13	7.5	7.5	3	1.5	6.0	80.0
239	22-May-13	4.0	2.5	50	0.0	4.0	100.0
240	23-May-13	0.5	0.5	8	0.0	0.5	100.0
241	23-May-13	9.5	6.0	12	2.7	6.8	71.6
242	24-May-13	0.5	0.5	8	0.0	0.5	100.0
243	24-May-13	18.5	10.0	14	14.3	4.2	22.7
244	25-May-13	11.0	7.0	18	7.3	3.7	33.6
245	25-May-13	0.5	0.5	2	0.0	0.5	100.0
246	26-May-13	10.5	4.0	16	6.5	4.0	38.1
247	28-May-13	35.5	35.0	45	28.2	7.3	20.6
248	29-May-13	4.5	3.0	21	0.5	4.0	88.9
249	29-May-13	0.5	0.5	4	0.0	0.5	100.0
250	30-May-13	1.5	1.0	4	0.0	1.5	100.0
251	30-May-13	0.5	0.5	2	0.0	0.5	100.0
252	31-May-13	12.5	12.5	33	6.9	5.6	44.8
253	31-May-13	0.5	0.5	1	0.1	0.4	80.0
254	1-Jun-13	0.5	0.5	22	0.0	0.5	100.0
255	2-Jun-13	0.5	0.5	24	0.0	0.5	100.0
256	4-Jun-13	8.0	3.0	48	0.0	8.0	100.0
257	5-Jun-13	0.5	0.5	20	0.0	0.5	100.0
258	7-Jun-13	26.5	24.5	47	14.9	11.6	43.8
259	8-Jun-13	0.5	0.5	20	0.0	0.5	100.0
260	8-Jun-13	1.0	0.5	1	0.0	1.0	100.0
261	8-Jun-13	2.0	1.5	1	0.0	2.0	100.0
262	9-Jun-13	10.0	7.5	14	6.2	3.8	38.0
263	9-Jun-13	2.0	1.5	2	1.2	0.8	40.0
264	9-Jun-13	3.0	3.0	2	2.4	0.6	20.0
265	11-Jun-13	5.0	4.0	41	0.0	5.0	100.0
266	11-Jun-13	43.5	41.5	1	41.2	2.3	5.3
267	12-Jun-13	5.5	2.5	15	2.3	3.2	58.2
268	14-Jun-13	0.5	0.5	52	0.0	0.5	100.0
269	16-Jun-13	3.0	3.0	47	0.0	3.0	100.0
270	25-Jun-13	13.0	9.0	201	0.0	13.0	100.0
271	26-Jun-13	3.5	3.5	28	0.0	3.5	100.0
272	27-Jun-13	2.5	2.0	28	0.0	2.5	100.0
273	28-Jun-13	3.0	2.0	20	0.0	3.0	100.0
274	29-Jun-13	0.5	0.5	25	0.0	0.5	100.0
275	30-Jun-13	23.5	19.5	21	12.1	11.4	48.5

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
276	1-Jul-13	12.5	12.0	21	8.5	4.0	32.0
277	3-Jul-13	0.5	0.5	44	0.0	0.5	100.0
278	5-Jul-13	3.5	2.0	31	0.0	3.5	100.0
279	5-Jul-13	64.5	26.5	13	54.3	10.2	15.8
280	14-Jul-13	0.5	0.5	193	0.0	0.5	100.0
281	14-Jul-13	10.5	10.0	12	0.0	10.5	100.0
282	14-Jul-13	0.5	0.5	1	0.0	0.5	100.0
283	15-Jul-13	2.5	2.5	17	0.0	2.5	100.0
284	17-Jul-13	33.0	21.5	50	20.9	12.1	36.7
285	18-Jul-13	20.5	13.5	16	16.7	3.8	18.5
286	27-Jul-13	16.5	16.5	197	0.0	16.5	100.0
287	27-Jul-13	0.5	0.5	5	0.0	0.5	100.0
288	28-Jul-13	17.0	13.0	36	9.9	7.1	41.8
289	29-Jul-13	0.5	0.5	2	0.0	0.5	100.0
290	29-Jul-13	2.0	1.0	18	0.0	2.0	100.0
291	30-Jul-13	18.0	12.5	19	13.1	4.9	27.2
292	3-Aug-13	0.5	0.5	90	0.0	0.5	100.0
293	3-Aug-13	10.0	9.0	4	0.0	10.0	100.0
294	3-Aug-13	0.5	0.5	1	0.0	0.5	100.0
295	4-Aug-13	4.0	4.0	23	0.0	4.0	100.0
296	4-Aug-13	2.5	2.5	1	0.4	2.1	84.0
297	5-Aug-13	0.5	0.5	17	0.0	0.5	100.0
298	7-Aug-13	1.0	0.5	32	0.0	1.0	100.0
299	7-Aug-13	0.5	0.5	2	0.0	0.5	100.0
300	7-Aug-13	18.5	11.5	9	10.3	8.2	44.3
301	8-Aug-13	1.5	1.5	20	0.0	1.5	100.0
302	8-Aug-13	0.5	0.5	6	0.0	0.5	100.0
303	10-Aug-13	13.5	5.5	41	3.9	9.6	71.1
304	11-Aug-13	20.0	17.5	19	16.2	3.8	19.0
305	11-Aug-13	0.5	0.5	3	0.0	0.5	100.0
306	16-Aug-13	1.5	0.5	109	0.0	1.5	100.0
307	17-Aug-13	8.5	8.0	29	0.0	8.5	100.0
308	19-Aug-13	2.0	1.0	46	0.0	2.0	100.0
309	20-Aug-13	0.5	0.5	7	0.0	0.5	100.0
310	20-Aug-13	0.5	0.5	12	0.0	0.5	100.0
311	21-Aug-13	1.5	1.5	23	0.0	1.5	100.0
312	22-Aug-13	32.5	31.5	22	19.5	13.0	40.0
313	26-Aug-13	10.0	5.5	93	0.0	10.0	100.0
314	27-Aug-13	19.0	19.0	31	11.8	7.2	37.9
315	28-Aug-13	59.5	21.5	1	57.5	2.0	3.4

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
316	29-Aug-13	9.5	4.0	17	5.6	3.9	41.1
317	30-Aug-13	39.0	23.0	19	35.0	4.0	10.3
318	30-Aug-13	12.0	9.0	2	11.0	1.0	8.3
319	30-Aug-13	0.5	0.5	13	0.0	0.5	100.0
320	31-Aug-13	5.5	3.0	1	2.6	2.9	52.7
321	1-Sep-13	15.0	9.5	28	9.2	5.8	38.7
322	2-Sep-13	2.0	1.0	19	0.0	2.0	100.0
323	3-Sep-13	2.5	2.0	31	0.0	2.5	100.0
324	4-Sep-13	4.0	3.5	11	0.0	4.0	100.0
325	4-Sep-13	5.0	4.0	4	1.4	3.6	72.0
326	6-Sep-13	0.5	0.5	38	0.0	0.5	100.0
327	7-Sep-13	5.5	3.0	35	0.0	5.5	100.0
328	8-Sep-13	41.0	36.0	21	32.5	8.5	20.7
329	9-Sep-13	17.5	14.0	18	13.6	3.9	22.3
330	10-Sep-13	1.5	1.0	12	0.0	1.5	100.0
331	10-Sep-13	0.5	0.5	5	0.0	0.5	100.0
332	10-Sep-13	4.0	3.5	1	1.7	2.3	57.5
333	11-Sep-13	33.0	28.5	24	28.4	4.6	13.9
334	12-Sep-13	6.5	2.0	7	4.0	2.5	38.5
335	13-Sep-13	12.5	5.5	22	7.8	4.7	37.6
336	13-Sep-13	0.5	0.5	2	0.0	0.5	100.0
337	15-Sep-13	16.0	5.5	53	6.6	9.4	58.8
338	16-Sep-13	0.5	0.5	5	0.0	0.5	100.0
339	17-Sep-13	2.0	1.5	41	0.0	2.0	100.0
340	18-Sep-13	20.5	18.0	16	12.5	8.0	39.0
341	24-Sep-13	62.5	56.5	142	47.0	15.5	24.8
342	25-Sep-13	8.0	6.0	22	3.7	4.3	53.8
343	27-Sep-13	0.5	0.5	32	0.0	0.5	100.0
344	27-Sep-13	0.5	0.5	2	0.0	0.5	100.0
345	27-Sep-13	2.5	2.0	9	0.0	2.5	100.0
346	28-Sep-13	3.0	3.0	23	0.0	3.0	100.0
347	28-Sep-13	0.5	0.5	1	0.0	0.5	100.0
348	29-Sep-13	1.0	1.0	26	0.0	1.0	100.0
349	30-Sep-13	1.0	1.0	11	0.0	1.0	100.0
350	2-Oct-13	15.0	15.0	52	2.3	12.7	84.7
351	2-Oct-13	2.0	2.0	1	1.6	0.4	20.0
352	2-Oct-13	0.5	0.5	1	0.1	0.4	80.0
353	3-Oct-13	116.5	88.5	18	112.4	4.1	3.5
354	4-Oct-13	1.5	1.0	24	0.0	1.5	100.0
355	5-Oct-13	2.0	2.0	20	0.0	2.0	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
356	6-Oct-13	2.5	2.0	22	0.0	2.5	100.0
357	7-Oct-13	5.5	4.0	21	0.0	5.5	100.0
358	9-Oct-13	2.5	2.5	48	0.0	2.5	100.0
359	11-Oct-13	7.0	7.0	46	0.0	7.0	100.0
360	12-Oct-13	4.5	4.0	24	0.0	4.5	100.0
361	13-Oct-13	0.5	0.5	19	0.0	0.5	100.0
362	13-Oct-13	0.5	0.5	1	0.0	0.5	100.0
363	13-Oct-13	3.5	3.5	1	0.0	3.5	100.0
364	13-Oct-13	0.5	0.5	1	0.0	0.5	100.0
365	19-Oct-13	16.0	9.5	136	0.2	15.8	98.8
366	19-Oct-13	0.5	0.5	2	0.0	0.5	100.0
367	20-Oct-13	34.0	25.0	21	29.8	4.2	12.4
368	20-Oct-13	0.5	0.5	2	0.0	0.5	100.0
369	21-Oct-13	0.5	0.5	9	0.0	0.5	100.0
370	21-Oct-13	6.0	5.5	13	1.9	4.1	68.3
371	21-Oct-13	0.5	0.5	2	0.0	0.5	100.0
372	22-Oct-13	0.5	0.5	4	0.0	0.5	100.0
373	22-Oct-13	20.5	16.5	11	17.1	3.4	16.6
374	23-Oct-13	1.5	1.5	19	0.0	1.5	100.0
375	23-Oct-13	0.5	0.5	3	0.0	0.5	100.0
376	25-Oct-13	0.5	0.5	29	0.0	0.5	100.0
377	25-Oct-13	4.5	2.0	3	0.0	4.5	100.0
378	28-Oct-13	29.5	22.5	74	17.3	12.2	41.4
379	30-Oct-13	8.0	7.5	53	0.0	8.0	100.0
380	31-Oct-13	4.5	3.5	21	0.0	4.5	100.0

Appendix G

Event Retention Rate of the Green Roof Model in Sibuh

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
1	1-Nov-12	2.0	1.5	8	0.0	2.0	100.0
2	1-Nov-12	0.5	0.5	1	0.0	0.5	100.0
3	1-Nov-12	29.5	16.0	2	19.9	9.6	32.5
4	1-Nov-12	0.5	0.5	1	0.1	0.4	80.0
5	2-Nov-12	3.0	2.0	19	0.0	3.0	100.0
6	2-Nov-12	0.5	0.5	2	0.0	0.5	100.0
7	2-Nov-12	11.0	4.0	1	9.1	1.9	17.3
8	3-Nov-12	0.5	0.5	6	0.0	0.5	100.0
9	4-Nov-12	39.5	12.0	16	34.4	5.1	12.9
10	6-Nov-12	18.0	8.5	36	12.0	6.0	33.3
11	6-Nov-12	0.5	0.5	3	0.0	0.5	100.0
12	6-Nov-12	0.5	0.5	1	0.0	0.5	100.0
13	7-Nov-12	1.0	1.0	25	0.0	1.0	100.0
14	8-Nov-12	1.0	1.0	29	0.0	1.0	100.0
15	9-Nov-12	0.5	0.5	19	0.0	0.5	100.0
16	9-Nov-12	1.0	1.0	3	0.0	1.0	100.0
17	9-Nov-12	22.0	20.5	2	14.1	7.9	35.9
18	10-Nov-12	0.5	0.5	17	0.0	0.5	100.0
19	11-Nov-12	0.5	0.5	18	0.0	0.5	100.0
20	11-Nov-12	2.0	2.0	3	0.0	2.0	100.0
21	12-Nov-12	3.5	3.0	12	0.0	3.5	100.0
22	12-Nov-12	10.0	8.0	1	7.7	2.3	23.0
23	13-Nov-12	5.0	3.0	16	1.8	3.2	64.0
24	13-Nov-12	0.5	0.5	1	0.1	0.4	80.0
25	14-Nov-12	10.5	10.0	41	4.1	6.4	61.0
26	14-Nov-12	0.5	0.5	8	0.0	0.5	100.0
27	17-Nov-12	1.0	0.5	44	0.0	1.0	100.0
28	18-Nov-17	1.0	1.0	29	0.0	1.0	100.0
29	19-Nov-17	0.5	0.5	20	0.0	0.5	100.0
30	21-Nov-17	0.5	0.5	49	0.0	0.5	100.0
31	24-Nov-12	3.0	2.5	72	0.0	3.0	100.0
32	24-Nov-12	18.5	14.5	1	4.4	14.1	76.2
33	25-Nov-12	0.5	0.5	13	0.0	0.5	100.0
34	25-Nov-12	5.5	5.5	11	1.8	3.7	67.3

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
35	26-Nov-12	0.5	0.5	6	0.0	0.5	100.0
36	26-Nov-12	9.0	9.0	10	6.4	2.6	28.9
37	26-Nov-12	1.0	1.0	4	0.1	0.9	90.0
38	27-Nov-12	6.5	6.0	3	5.6	0.9	13.8
39	28-Nov-12	16.5	9.0	23	11.9	4.6	27.9
40	29-Nov-12	10.0	7.5	36	3.8	6.2	62.0
41	30-Nov-12	0.5	0.5	8	0.0	0.5	100.0
42	30-Nov-12	0.5	0.5	6	0.0	0.5	100.0
43	30-Nov-12	1.5	1.5	4	0.0	1.5	100.0
44	1-Dec-12	3.5	2.5	19	0.0	3.5	100.0
45	3-Dec-12	9.0	6.0	35	2.4	6.6	73.3
46	3-Dec-12	9.5	8.0	4	8.4	1.1	11.6
47	3-Dec-12	0.5	0.5	1	0.1	0.4	80.0
48	3-Dec-12	11.5	6.5	2	10.8	0.7	6.1
49	5-Dec-12	3.0	1.5	50	0.0	3.0	100.0
50	7-Dec-12	0.5	0.5	45	0.0	0.5	100.0
51	7-Dec-12	6.0	4.5	1	0.0	6.0	100.0
52	8-Dec-12	34.5	13.0	6	28.7	5.8	16.8
53	10-Dec-12	0.5	0.5	37	0.0	0.5	100.0
54	10-Dec-12	9.5	6.5	5	2.9	6.6	69.5
55	12-Dec-12	4.0	4.0	51	0.0	4.0	100.0
56	13-Dec-12	10.0	5.0	15	4.0	6.0	60.0
57	14-Dec-12	12.5	5.5	13	9.8	2.7	21.6
58	15-Dec-12	35.5	34.0	25	31.1	4.4	12.4
59	15-Dec-12	1.0	1.0	15	0.0	1.0	100.0
60	17-Dec-12	9.0	4.5	28	2.8	6.2	68.9
61	17-Dec-12	0.5	0.5	10	0.0	0.5	100.0
62	18-Dec-12	0.5	0.5	19	0.0	0.5	100.0
63	18-Dec-12	4.0	4.0	3	0.0	4.0	100.0
64	19-Dec-12	7.0	4.0	11	4.1	2.9	41.4
65	20-Dec-12	1.5	1.0	40	0.0	1.5	100.0
66	21-Dec-12	0.5	0.5	17	0.0	0.5	100.0
67	22-Dec-12	38.0	24.5	23	27.8	10.2	26.8
68	23-Dec-12	0.5	0.5	1	0.1	0.4	80.0
69	23-Dec-12	58.5	53.0	16	55.3	3.2	5.5
70	23-Dec-12	1.0	0.5	1	0.5	0.5	50.0
71	24-Dec-12	33.5	19.0	1	32.6	0.9	2.7
72	24-Dec-12	19.0	17.5	11	16.6	2.4	12.6
73	26-Dec-12	1.5	1.0	37	0.0	1.5	100.0
74	26-Dec-12	0.5	0.5	4	0.0	0.5	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
75	28-Dec-12	10.5	10.5	51	0.1	10.4	99.0
76	28-Dec-12	0.5	0.5	4	0.0	0.5	100.0
77	29-Dec-12	3.5	1.5	21	0.0	3.5	100.0
78	30-Dec-12	0.5	0.5	6	0.0	0.5	100.0
79	31-Dec-12	20.5	13.5	33	13.8	6.7	32.7
80	1-Jan-13	2.5	1.0	12	0.0	2.5	100.0
81	1-Jan-13	0.5	0.5	3	0.0	0.5	100.0
82	2-Jan-13	15.5	7.0	31	9.4	6.1	39.4
83	4-Jan-13	2.0	2.0	33	0.0	2.0	100.0
84	4-Jan-13	10.0	10.0	2	6.3	3.7	37.0
85	4-Jan-13	22.5	9.0	6	20.0	2.5	11.1
86	5-Jan-13	3.5	3.5	7	2.1	1.4	40.0
87	8-Jan-13	2.0	2.0	64	0.0	2.0	100.0
88	8-Jan-13	2.5	2.5	6	0.0	2.5	100.0
89	8-Jan-13	0.5	0.5	2	0.0	0.5	100.0
90	9-Jan-13	0.5	0.5	14	0.0	0.5	100.0
91	9-Jan-13	26.0	25.5	4	18.8	7.2	27.7
92	9-Jan-13	1.0	0.5	1	0.5	0.5	50.0
93	9-Jan-13	0.5	0.5	5	0.0	0.5	100.0
94	10-Jan-13	4.0	2.5	5	1.9	2.1	52.5
95	10-Jan-13	0.5	0.5	1	0.1	0.4	80.0
96	10-Jan-13	2.0	1.5	2	1.3	0.7	35.0
97	11-Jan-13	2.5	2.5	10	0.6	1.9	76.0
98	11-Jan-13	0.5	0.5	1	0.1	0.4	80.0
99	11-Jan-13	0.5	0.5	2	0.0	0.5	100.0
100	11-Jan-13	10.5	4.5	2	9.4	1.1	10.5
101	11-Jan-13	2.0	2.0	8	0.4	1.6	80.0
102	12-Jan-13	0.5	0.5	4	0.0	0.5	100.0
103	12-Jan-13	8.0	7.5	1	7.1	0.9	11.3
104	12-Jan-13	0.5	0.5	1	0.1	0.4	80.0
105	13-Jan-13	0.5	0.5	31	0.0	0.5	100.0
106	18-Jan-13	5.0	5.0	119	0.0	5.0	100.0
107	18-Jan-13	0.5	0.5	5	0.0	0.5	100.0
108	18-Jan-13	7.5	5.0	2	0.0	7.5	100.0
109	19-Jan-13	20.0	13.5	13	14.2	5.8	29.0
110	20-Jan-13	0.5	0.5	18	0.0	0.5	100.0
111	22-Jan-13	0.5	0.5	36	0.0	0.5	100.0
112	22-Jan-13	3.0	1.0	12	0.0	3.0	100.0
113	28-Jan-13	10.5	7.0	138	0.0	10.5	100.0
114	30-Jan-13	7.0	7.0	45	0.0	7.0	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
115	31-Jan-13	0.5	0.5	23	0.0	0.5	100.0
116	1-Feb-13	3.0	2.5	22	0.0	3.0	100.0
117	2-Feb-13	2.0	2.0	28	0.0	2.0	100.0
118	3-Feb-13	0.5	0.5	4	0.0	0.5	100.0
119	3-Feb-13	0.5	0.5	6	0.0	0.5	100.0
120	4-Feb-13	32.5	18.0	36	20.5	12.0	36.9
121	5-Feb-13	13.5	4.5	1	12.4	1.1	8.1
122	5-Feb-13	1.5	1.0	2	0.7	0.8	53.3
123	5-Feb-13	26.5	16.0	3	25.4	1.1	4.2
124	5-Feb-13	0.5	0.5	3	0.0	0.5	100.0
125	5-Feb-13	0.5	0.5	1	0.0	0.5	100.0
126	6-Feb-13	1.0	1.0	2	0.3	0.7	70.0
127	6-Feb-13	0.5	0.5	15	0.0	0.5	100.0
128	6-Feb-13	4.5	2.5	4	0.8	3.7	82.2
129	7-Feb-13	15.5	12.0	1	14.7	0.8	5.2
130	7-Feb-13	40.5	21.5	2	39.0	1.5	3.7
131	8-Feb-13	7.5	7.5	27	2.8	4.7	62.7
132	8-Feb-13	1.0	1.0	2	0.4	0.6	60.0
133	8-Feb-13	0.5	0.5	1	0.1	0.4	80.0
134	9-Feb-13	2.0	2.0	10	0.0	2.0	100.0
135	9-Feb-13	27.5	25.5	3	26.6	0.9	3.3
136	9-Feb-13	1.5	1.0	4	0.4	1.1	73.3
137	10-Feb-13	0.5	0.5	13	0.0	0.5	100.0
138	10-Feb-13	61.0	30.5	8	57.1	3.9	6.4
139	10-Feb-13	0.5	0.5	1	0.1	0.4	80.0
140	11-Feb-13	18.0	11.0	17	14.1	3.9	21.7
141	12-Feb-13	4.0	2.0	5	2.5	1.5	37.5
142	12-Feb-13	17.5	17.0	8	15.7	1.8	10.3
143	13-Feb-13	2.0	1.5	24	0.0	2.0	100.0
144	13-Feb-13	0.5	0.5	1	0.0	0.5	100.0
145	14-Feb-13	5.5	4.0	6	1.8	3.7	67.3
146	14-Feb-13	0.5	0.5	2	0.0	0.5	100.0
147	14-Feb-13	0.5	0.5	14	0.0	0.5	100.0
148	14-Feb-13	2.0	1.0	1	0.0	2.0	100.0
149	15-Feb-13	0.5	0.5	1	0.0	0.5	100.0
150	15-Feb-13	1.5	1.0	1	0.2	1.3	86.7
151	16-Feb-13	0.5	0.5	33	0.0	0.5	100.0
152	18-Feb-13	36.0	19.5	32	26.0	10.0	27.8
153	20-Feb-13	0.5	0.5	50	0.0	0.5	100.0
154	20-Feb-13	26.0	13.0	3	17.6	8.4	32.3

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
155	20-Feb-13	1.0	0.5	1	0.4	0.6	60.0
156	20-Feb-13	1.0	0.5	1	0.4	0.6	60.0
157	21-Feb-13	19.0	16.5	15	16.0	3.0	15.8
158	24-Feb-13	0.5	0.5	68	0.0	0.5	100.0
159	25-Feb-13	0.5	0.5	13	0.0	0.5	100.0
160	25-Feb-13	0.5	0.5	8	0.0	0.5	100.0
161	25-Feb-13	3.5	2.0	1	0.0	3.5	100.0
162	27-Feb-13	24.5	9.5	54	11.1	13.4	54.7
163	28-Feb-13	1.0	0.5	1	0.4	0.6	60.0
164	28-Feb-13	0.5	0.5	14	0.0	0.5	100.0
165	1-Mar-13	0.5	0.5	5	0.0	0.5	100.0
166	1-Mar-13	2.5	1.5	13	0.0	2.5	100.0
167	2-Mar-13	0.5	0.5	16	0.0	0.5	100.0
168	2-Mar-13	5.0	5.0	10	0.0	5.0	100.0
169	4-Mar-13	5.0	2.5	36	0.0	5.0	100.0
170	6-Mar-13	9.0	9.0	52	0.0	9.0	100.0
171	7-Mar-13	0.5	0.5	13	0.0	0.5	100.0
172	7-Mar-13	47.5	21.0	2	42.6	4.9	10.3
173	8-Mar-13	6.0	6.0	21	1.9	4.1	68.3
174	9-Mar-13	0.5	0.5	19	0.0	0.5	100.0
175	15-Mar-13	0.5	0.5	129	0.0	0.5	100.0
176	17-Mar-13	3.0	2.5	65	0.0	3.0	100.0
177	18-Mar-13	66.0	52.0	24	49.8	16.2	24.5
178	18-Mar-13	0.5	0.5	2	0.0	0.5	100.0
179	19-Mar-13	36.5	28.0	16	32.9	3.6	9.9
180	20-Mar-13	1.0	0.5	24	0.0	1.0	100.0
181	22-Mar-13	2.5	1.0	46	0.0	2.5	100.0
182	23-Mar-13	0.5	0.5	14	0.0	0.5	100.0
183	24-Mar-13	1.5	1.5	29	0.0	1.5	100.0
184	24-Mar-13	0.5	0.5	1	0.0	0.5	100.0
185	25-Mar-13	16.0	13.0	21	3.4	12.6	78.8
186	25-Mar-13	0.5	0.5	1	0.1	0.4	80.0
187	26-Mar-13	11.0	2.5	8	7.9	3.1	28.2
188	27-Mar-13	0.5	0.5	19	0.0	0.5	100.0
189	31-Mar-13	53.0	35.0	102	38.1	14.9	28.1
190	1-Apr-13	0.5	0.5	9	0.0	0.5	100.0
191	1-Apr-13	0.5	0.5	1	0.0	0.5	100.0
192	1-Apr-13	0.5	0.5	3	0.0	0.5	100.0
193	2-Apr-13	42.0	18.5	29	35.2	6.8	16.2
194	2-Apr-13	0.5	0.5	2	0.0	0.5	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
195	4-Apr-13	19.0	17.0	45	11.1	7.9	41.6
196	5-Apr-13	0.5	0.5	6	0.0	0.5	100.0
197	5-Apr-13	1.5	1.5	13	0.0	1.5	100.0
198	5-Apr-13	0.5	0.5	5	0.0	0.5	100.0
199	6-Apr-13	0.5	0.5	16	0.0	0.5	100.0
200	7-Apr-13	1.0	1.0	23	0.0	1.0	100.0
201	7-Apr-13	1.0	0.5	2	0.0	1.0	100.0
202	8-Apr-13	17.0	11.5	4	9.6	7.4	43.5
203	8-Apr-13	0.5	0.5	1	0.1	0.4	80.0
204	9-Apr-13	17.5	14.0	23	12.8	4.7	26.9
205	9-Apr-13	0.5	0.5	1	0.1	0.4	80.0
206	10-Apr-13	2.0	1.5	26	0.0	2.0	100.0
207	10-Apr-13	22.5	19.5	6	18.0	4.5	20.0
208	10-Apr-13	0.5	0.5	1	0.1	0.4	80.0
209	11-Apr-13	4.5	1.5	1	3.5	1.0	22.2
210	11-Apr-13	0.5	0.5	8	0.0	0.5	100.0
211	11-Apr-13	4.5	3.5	7	1.4	3.1	68.9
212	12-Apr-13	0.5	0.5	1	0.1	0.4	80.0
213	13-Apr-13	3.0	3.0	27	0.0	3.0	100.0
214	13-Apr-13	0.5	0.5	6	0.0	0.5	100.0
215	13-Apr-13	3.5	3.5	3	0.2	3.3	94.3
216	15-Apr-13	41.5	19.5	31	34.6	6.9	16.6
217	18-Apr-13	6.5	3.5	72	0.0	6.5	100.0
218	18-Apr-13	11.0	11.0	3	6.1	4.9	44.5
219	18-Apr-13	0.5	0.5	1	0.1	0.4	80.0
220	19-Apr-13	1.0	0.5	28	0.0	1.0	100.0
221	20-Apr-13	0.5	0.5	2	0.0	0.5	100.0
222	21-Apr-13	1.0	1.0	36	0.0	1.0	100.0
223	25-Apr-13	0.5	0.5	90	0.0	0.5	100.0
224	25-Apr-13	57.0	31.5	5	40.6	16.4	28.8
225	26-Apr-13	0.5	0.5	10	0.0	0.5	100.0
226	29-Apr-13	1.5	1.5	73	0.0	1.5	100.0
227	30-Apr-13	0.5	0.5	17	0.0	0.5	100.0
228	1-May-13	2.0	2.0	32	0.0	2.0	100.0
229	1-May-13	0.5	0.5	2	0.0	0.5	100.0
230	2-May-13	14.0	14.0	8	2.1	11.9	85.0
231	2-May-13	0.5	0.5	3	0.0	0.5	100.0
232	2-May-13	1.5	1.5	7	0.0	1.5	100.0
233	3-May-13	2.5	2.5	25	0.0	2.5	100.0
234	3-May-13	0.5	0.5	3	0.0	0.5	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
235	4-May-13	4.0	4.0	19	0.0	4.0	100.0
236	5-May-13	0.5	0.5	11	0.0	0.5	100.0
237	5-May-13	3.5	3.5	11	0.0	3.5	100.0
238	7-May-13	10.5	6.5	31	3.6	6.9	65.7
239	7-May-13	1.5	1.0	2	0.7	0.8	53.3
240	8-May-13	4.5	4.0	30	0.0	4.5	100.0
241	10-May-13	15.0	8.0	42	7.2	7.8	52.0
242	10-May-13	0.5	0.5	3	0.0	0.5	100.0
243	11-May-13	0.5	0.5	23	0.0	0.5	100.0
244	16-May-13	0.5	0.5	118	0.0	0.5	100.0
245	17-May-13	1.0	1.0	21	0.0	1.0	100.0
246	17-May-13	0.5	0.5	3	0.0	0.5	100.0
247	18-May-13	3.0	2.5	17	0.0	3.0	100.0
248	19-May-13	0.5	0.5	9	0.0	0.5	100.0
249	19-May-13	0.5	0.5	2	0.0	0.5	100.0
250	19-May-13	0.5	0.5	4	0.0	0.5	100.0
251	23-May-13	1.5	1.0	91	0.0	1.5	100.0
252	23-May-13	5.5	4.0	14	0.0	5.5	100.0
253	24-May-13	2.0	1.5	2	0.0	2.0	100.0
254	24-May-13	1.5	1.5	15	0.0	1.5	100.0
255	24-May-13	1.5	1.0	2	0.0	1.5	100.0
256	25-May-13	14.0	13.5	17	4.1	9.9	70.7
257	25-May-13	1.0	0.5	3	0.1	0.9	90.0
258	26-May-13	1.0	1.0	6	0.0	1.0	100.0
259	29-May-13	20.5	20.5	71	10.4	10.1	49.3
260	29-May-13	0.5	0.5	1	0.1	0.4	80.0
261	31-May-13	1.5	1.5	57	0.0	1.5	100.0
262	31-May-13	2.5	1.5	4	0.0	2.5	100.0
263	1-Jun-13	0.5	0.5	1	0.0	0.5	100.0
264	3-Jun-13	3.0	3.0	68	0.0	3.0	100.0
265	4-Jun-13	19.0	17.0	9	8.2	10.8	56.8
266	4-Jun-13	0.5	0.5	1	0.1	0.4	80.0
267	9-Jun-13	0.5	0.5	107	0.0	0.5	100.0
268	25-Jun-13	0.5	0.5	393	0.0	0.5	100.0
269	26-Jun-13	0.5	0.5	29	0.0	0.5	100.0
270	28-Jun-13	23.5	20.5	31	3.6	19.9	84.7
271	28-Jun-13	0.5	0.5	1	0.1	0.4	80.0
272	29-Jun-13	0.5	0.5	32	0.0	0.5	100.0
273	30-Jun-13	17.0	15.5	25	8.0	9.0	52.9
274	2-Jul-13	17.0	16.5	44	9.8	7.2	42.4

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
275	3-Jul-13	0.5	0.5	17	0.0	0.5	100.0
276	3-Jul-13	2.0	1.0	5	0.0	2.0	100.0
277	4-Jul-13	4.0	2.5	22	0.0	4.0	100.0
278	5-Jul-13	25.5	24.0	17	20.6	4.9	19.2
279	5-Jul-13	2.5	1.0	1	1.7	0.8	32.0
280	6-Jul-13	0.5	0.5	7	0.0	0.5	100.0
281	6-Jul-13	7.0	3.5	1	4.9	2.1	30.0
282	6-Jul-13	0.5	0.5	1	0.1	0.4	80.0
283	6-Jul-13	1.0	1.0	1	0.6	0.4	40.0
284	9-Jul-13	2.5	2.0	74	0.0	2.5	100.0
285	10-Jul-13	2.0	2.0	16	0.0	2.0	100.0
286	12-Jul-13	2.0	2.0	53	0.0	2.0	100.0
287	13-Jul-13	0.5	0.5	24	0.0	0.5	100.0
288	13-Jul-13	5.5	4.5	2	0.0	5.5	100.0
289	14-Jul-13	0.5	0.5	2	0.0	0.5	100.0
290	14-Jul-13	0.5	0.5	10	0.0	0.5	100.0
291	16-Jul-13	1.0	0.5	54	0.0	1.0	100.0
292	16-Jul-13	4.5	1.5	1	0.0	4.5	100.0
293	17-Jul-13	1.0	1.0	1	0.0	1.0	100.0
294	17-Jul-13	11.0	10.0	18	1.7	9.3	84.5
295	18-Jul-13	0.5	0.5	1	0.1	0.4	80.0
296	18-Jul-13	16.0	7.5	14	12.4	3.6	22.5
297	19-Jul-13	0.5	0.5	14	0.0	0.5	100.0
298	27-Jul-13	5.5	5.5	191	0.0	5.5	100.0
299	28-Jul-13	8.5	7.0	28	0.0	8.5	100.0
300	1-Aug-13	2.0	2.0	78	0.0	2.0	100.0
301	1-Aug-13	12.5	4.0	20	0.0	12.5	100.0
302	2-Aug-13	0.5	0.5	17	0.0	0.5	100.0
303	7-Aug-13	0.5	0.5	102	0.0	0.5	100.0
304	8-Aug-13	17.0	13.5	34	0.9	16.1	94.7
305	8-Aug-13	0.5	0.5	3	0.0	0.5	100.0
306	10-Aug-13	6.5	4.0	35	0.0	6.5	100.0
307	11-Aug-13	0.5	0.5	24	0.0	0.5	100.0
308	18-Aug-13	25.5	25.5	173	8.0	17.5	68.6
309	18-Aug-13	0.5	0.5	4	0.0	0.5	100.0
310	19-Aug-13	84.5	37.0	23	78.2	6.3	7.5
311	20-Aug-13	19.0	6.5	1	18.0	1.0	5.3
312	27-Aug-13	0.5	0.5	78	0.0	0.5	100.0
313	28-Aug-13	9.0	8.5	107	0.0	9.0	100.0
314	28-Aug-13	31.0	25.5	16	20.3	10.7	34.5

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
315	30-Aug-13	2.0	1.0	27	0.0	2.0	100.0
316	30-Aug-13	26.0	10.5	9	19.8	6.2	23.8
317	1-Sep-13	21.5	11.0	27	15.6	5.9	27.4
318	1-Sep-13	0.5	0.5	7	0.0	0.5	100.0
319	2-Sep-13	9.5	5.0	16	5.1	4.4	46.3
320	3-Sep-13	0.5	0.5	18	0.0	0.5	100.0
321	5-Sep-13	9.0	5.0	56	0.0	9.0	100.0
322	6-Sep-13	0.5	0.5	7	0.0	0.5	100.0
323	7-Sep-13	0.5	0.5	38	0.0	0.5	100.0
324	8-Sep-13	0.5	0.5	29	0.0	0.5	100.0
325	9-Sep-13	1.0	1.0	10	0.0	1.0	100.0
326	11-Sep-13	0.5	0.5	44	0.0	0.5	100.0
327	11-Sep-13	38.0	18.0	12	22.6	15.4	40.5
328	12-Sep-13	4.0	2.5	1	3.2	0.8	20.0
329	12-Sep-13	29.0	12.0	17	23.9	5.1	17.6
330	14-Sep-13	2.5	2.0	28	0.0	2.5	100.0
331	14-Sep-13	1.0	0.5	2	0.0	1.0	100.0
332	15-Sep-13	8.5	7.5	18	2.7	5.8	68.2
333	16-Sep-13	7.0	2.0	11	3.9	3.1	44.3
334	16-Sep-13	0.5	0.5	1	0.1	0.4	80.0
335	21-Sep-13	0.5	0.5	117	0.0	0.5	100.0
336	24-Sep-13	0.5	0.5	83	0.0	0.5	100.0
337	29-Sep-13	1.0	1.0	116	0.0	1.0	100.0
338	30-Sep-13	0.5	0.5	17	0.0	0.5	100.0
339	2-Oct-13	0.5	0.5	54	0.0	0.5	100.0
340	2-Oct-13	12.0	9.5	1	0.0	12.0	100.0
341	3-Oct-13	0.5	0.5	3	0.0	0.5	100.0
342	3-Oct-13	10.0	5.0	16	0.8	9.2	92.0
343	4-Oct-13	0.5	0.5	4	0.0	0.5	100.0
344	7-Oct-13	9.5	7.5	86	0.0	9.5	100.0
345	7-Oct-13	0.5	0.5	1	0.0	0.5	100.0
346	8-Oct-13	0.5	0.5	2	0.0	0.5	100.0
347	10-Oct-13	1.5	1.0	59	0.0	1.5	100.0
348	11-Oct-13	0.5	0.5	22	0.0	0.5	100.0
349	13-Oct-13	2.0	2.0	55	0.0	2.0	100.0
350	18-Oct-13	0.5	0.5	112	0.0	0.5	100.0
351	19-Oct-13	8.5	6.5	14	0.0	8.5	100.0
352	19-Oct-13	2.5	1.5	1	0.0	2.5	100.0
353	20-Oct-13	1.0	1.0	28	0.0	1.0	100.0
354	20-Oct-13	4.0	1.5	1	0.0	4.0	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
355	21-Oct-13	4.5	4.0	17	0.0	4.5	100.0
356	21-Oct-13	0.5	0.5	3	0.0	0.5	100.0
357	22-Oct-13	1.0	1.0	9	0.0	1.0	100.0
358	22-Oct-13	0.5	0.5	1	0.0	0.5	100.0
359	22-Oct-13	0.5	0.5	6	0.0	0.5	100.0
360	22-Oct-13	1.0	0.5	1	0.0	1.0	100.0
361	22-Oct-13	8.0	5.0	5	2.3	5.7	71.3
362	23-Oct-13	0.5	0.5	9	0.0	0.5	100.0
363	24-Oct-13	6.0	5.5	27	0.0	6.0	100.0
364	25-Oct-13	37.0	16.0	12	33.8	3.2	8.6
365	25-Oct-13	0.5	0.5	1	0.1	0.4	80.0
366	28-Oct-13	0.5	0.5	75	0.0	0.5	100.0
367	31-Oct-13	11.0	10.5	74	0.0	11.0	100.0

Appendix H

Event Retention Rate of the Green Roof Model in Miri

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
1	1-Nov-12	55.5	25.5	20	43.0	12.5	22.5
2	2-Nov-12	22.5	12.5	16	19.3	3.2	14.2
3	3-Nov-12	0.5	0.5	11	0.0	0.5	100.0
4	4-Nov-12	1.5	1.5	16	0.0	1.5	100.0
5	4-Nov-12	108.5	37.5	8	102.9	5.6	5.2
6	5-Nov-12	4.5	1.0	18	0.9	3.6	80.0
7	6-Nov-12	0.5	0.5	3	0.0	0.5	100.0
8	7-Nov-12	4.0	4.0	22	0.3	3.7	92.5
9	9-Nov-12	5.0	3.5	46	0.0	5.0	100.0
10	9-Nov-12	1.0	0.5	17	0.0	1.0	100.0
11	10-Nov-12	0.5	0.5	8	0.0	0.5	100.0
12	11-Nov-12	3.0	2.0	16	0.0	3.0	100.0
13	11-Nov-12	6.5	6.5	4	2.2	4.3	66.2
14	12-Nov-12	24.5	18.0	20	20.7	3.8	15.5
15	12-Nov-12	100.5	67.5	14	97.1	3.4	3.4
16	13-Nov-12	1.0	1.0	8	0.0	1.0	100.0
17	14-Nov-12	4.5	4.5	11	2.1	2.4	53.3
18	14-Nov-12	16.5	7.0	21	12.1	4.4	26.7
19	16-Nov-12	1.0	0.5	20	0.0	1.0	100.0
20	17-Nov-12	0.5	0.5	42	0.0	0.5	100.0
21	19-Nov-12	6.5	4.0	30	0.0	6.5	100.0
22	19-Nov-12	0.5	0.5	12	0.0	0.5	100.0
23	20-Nov-12	12.5	4.5	4	6.1	6.4	51.2
24	20-Nov-12	27.0	14.5	18	23.0	4.0	14.8
25	23-Nov-12	1.5	1.0	62	0.0	1.5	100.0
26	24-Nov-12	0.5	0.5	9	0.0	0.5	100.0
27	24-Nov-12	2.0	1.5	4	0.0	2.0	100.0
28	24-Nov-12	20.5	10.0	3	13.1	7.4	36.1
29	26-Nov-12	1.0	1.0	38	0.0	1.0	100.0
30	26-Nov-12	0.5	0.5	2	0.0	0.5	100.0
31	27-Nov-12	9.5	7.5	20	2.2	7.3	76.8
32	27-Nov-12	27.5	18.0	5	26.0	1.5	5.5
33	28-Nov-12	1.0	1.0	18	0.0	1.0	100.0
34	29-Nov-12	40.5	40.5	18	35.8	4.7	11.6

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
35	29-Nov-12	0.5	0.5	4	0.0	0.5	100.0
36	1-Dec-12	14.0	14.0	42	7.7	6.3	45.0
37	2-Dec-12	0.5	0.5	11	0.0	0.5	100.0
38	2-Dec-12	0.5	0.5	10	0.0	0.5	100.0
39	2-Dec-12	1.0	1.0	8	0.0	1.0	100.0
40	2-Dec-12	3.0	3.0	1	0.1	2.9	96.7
41	3-Dec-12	14.0	13.0	1	13.5	0.5	3.6
42	3-Dec-12	21.0	15.0	1	20.5	0.5	2.4
43	3-Dec-12	1.5	1.5	1	1.2	0.3	20.0
44	3-Dec-12	1.0	1.0	5	0.1	0.9	90.0
45	4-Dec-12	36.0	13.0	12	33.2	2.8	7.8
46	6-Dec-12	15.0	9.5	43	8.7	6.3	42.0
47	6-Dec-12	0.5	0.5	3	0.0	0.5	100.0
48	8-Dec-12	7.5	3.0	39	1.6	5.9	78.7
49	8-Dec-12	0.5	0.5	12	0.0	0.5	100.0
50	8-Dec-12	0.5	0.5	2	0.0	0.5	100.0
51	8-Dec-12	0.5	0.5	2	0.0	0.5	100.0
52	10-Dec-12	7.0	7.0	37	0.7	6.3	90.0
53	10-Dec-12	0.5	0.5	4	0.0	0.5	100.0
54	12-Dec-12	0.5	0.5	40	0.0	0.5	100.0
55	12-Dec-12	0.5	0.5	4	0.0	0.5	100.0
56	12-Dec-12	0.5	0.5	7	0.0	0.5	100.0
57	13-Dec-12	11.0	9.0	2	4.5	6.5	59.1
58	13-Dec-12	1.0	0.5	17	0.0	1.0	100.0
59	15-Dec-12	61.0	27.0	36	54.0	7.0	11.5
60	15-Dec-12	20.5	14.0	1	20.0	0.5	2.4
61	18-Dec-12	2.5	2.5	76	0.0	2.5	100.0
62	19-Dec-12	38.5	25.5	13	30.0	8.5	22.1
63	19-Dec-12	0.5	0.5	3	0.0	0.5	100.0
64	21-Dec-12	1.0	1.0	43	0.0	1.0	100.0
65	21-Dec-12	0.5	0.5	1	0.0	0.5	100.0
66	22-Dec-12	87.0	49.0	18	79.1	7.9	9.1
67	23-Dec-12	0.5	0.5	25	0.0	0.5	100.0
68	24-Dec-12	0.5	0.5	11	0.0	0.5	100.0
69	25-Dec-12	29.5	17.5	18	22.8	6.7	22.7
70	25-Dec-12	2.0	1.0	2	1.2	0.8	40.0
71	26-Dec-12	21.0	10.0	20	17.4	3.6	17.1
72	26-Dec-12	0.5	0.5	4	0.0	0.5	100.0
73	28-Dec-12	0.5	0.5	49	0.0	0.5	100.0
74	29-Dec-12	6.5	3.0	19	0.0	6.5	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
75	29-Dec-12	3.0	2.0	4	0.0	3.0	100.0
76	29-Dec-12	7.0	6.0	1	6.5	0.5	7.1
77	30-Dec-12	3.5	3.0	22	0.0	3.5	100.0
78	31-Dec-12	3.0	2.5	12	0.8	2.2	73.3
79	3-Jan-13	2.5	2.5	67	0.0	2.5	100.0
80	4-Jan-13	2.0	1.0	13	0.0	2.0	100.0
81	4-Jan-13	1.5	1.0	1	0.0	1.5	100.0
82	4-Jan-13	10.0	6.5	1	4.6	5.4	54.0
83	4-Jan-13	2.5	2.0	11	0.4	2.1	84.0
84	5-Jan-13	4.0	4.0	20	0.7	3.3	82.5
85	5-Jan-13	0.5	0.5	1	0.2	0.3	60.0
86	5-Jan-13	11.0	11.0	2	10.5	0.5	4.5
87	8-Jan-13	3.5	3.5	59	0.0	3.5	100.0
88	9-Jan-13	2.5	1.0	35	0.0	2.5	100.0
89	10-Jan-13	98.0	55.5	16	88.2	9.8	10.0
90	11-Jan-13	0.5	0.5	2	0.0	0.5	100.0
91	11-Jan-13	6.5	6.5	14	4.1	2.4	36.9
92	12-Jan-13	1.5	0.5	3	0.5	1.0	66.7
93	13-Jan-13	3.0	3.0	30	0.0	3.0	100.0
94	13-Jan-13	4.0	2.5	7	0.8	3.2	80.0
95	14-Jan-13	4.5	2.0	16	1.3	3.2	71.1
96	14-Jan-13	35.0	26.5	4	34.0	1.0	2.9
97	15-Jan-13	0.5	0.5	4	0.0	0.5	100.0
98	15-Jan-13	0.5	0.5	7	0.0	0.5	100.0
99	18-Jan-13	0.5	0.5	59	0.0	0.5	100.0
100	18-Jan-13	1.0	1.0	1	0.0	1.0	100.0
101	18-Jan-13	1.0	1.0	8	0.0	1.0	100.0
102	18-Jan-13	0.5	0.5	10	0.0	0.5	100.0
103	28-Jan-13	80.5	58.5	228	61.7	18.8	23.4
104	31-Jan-13	0.5	0.5	59	0.0	0.5	100.0
105	31-Jan-13	0.5	0.5	1	0.0	0.5	100.0
106	31-Jan-13	0.5	0.5	10	0.0	0.5	100.0
107	1-Feb-13	0.5	0.5	24	0.0	0.5	100.0
108	1-Feb-13	20.0	5.0	2	9.2	10.8	54.0
109	5-Feb-13	0.5	0.5	84	0.0	0.5	100.0
110	5-Feb-13	13.0	5.0	5	1.6	11.4	87.7
111	6-Feb-13	0.5	0.5	1	0.1	0.4	80.0
112	7-Feb-13	3.5	2.0	32	0.0	3.5	100.0
113	7-Feb-13	21.0	6.0	4	17.5	3.5	16.7
114	9-Feb-13	1.0	1.0	28	0.0	1.0	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
115	9-Feb-13	7.0	4.5	3	2.6	4.4	62.9
116	9-Feb-13	25.5	24.5	4	24.3	1.2	4.7
117	9-Feb-13	3.0	2.0	3	2.1	0.9	30.0
118	10-Feb-13	0.5	0.5	14	0.0	0.5	100.0
119	10-Feb-13	15.0	9.0	2	12.1	2.9	19.3
120	11-Feb-13	21.5	11.0	20	17.7	3.8	17.7
121	11-Feb-13	10.0	7.0	7	8.1	1.9	19.0
122	12-Feb-13	1.5	1.5	1	1.1	0.4	26.7
123	14-Feb-13	0.5	0.5	63	0.0	0.5	100.0
124	15-Feb-13	19.0	16.0	5	9.6	9.4	49.5
125	17-Feb-13	0.5	0.5	46	0.0	0.5	100.0
126	18-Feb-13	1.5	1.5	24	0.0	1.5	100.0
127	18-Feb-13	2.5	2.5	6	0.0	2.5	100.0
128	18-Feb-13	2.5	2.5	1	0.0	2.5	100.0
129	18-Feb-13	1.5	1.0	5	0.0	1.5	100.0
130	19-Feb-13	0.5	0.5	12	0.0	0.5	100.0
131	23-Feb-13	4.5	2.0	86	0.0	4.5	100.0
132	25-Feb-13	6.0	5.0	49	0.0	6.0	100.0
133	25-Feb-13	0.5	0.5	3	0.0	0.5	100.0
134	25-Feb-13	21.0	10.0	2	13.2	7.8	37.1
135	26-Feb-13	0.5	0.5	19	0.0	0.5	100.0
136	27-Feb-13	1.0	1.0	29	0.0	1.0	100.0
137	1-Mar-13	0.5	0.5	27	0.0	0.5	100.0
138	2-Mar-13	3.5	3.0	35	0.0	3.5	100.0
139	5-Mar-13	2.5	1.5	67	0.0	2.5	100.0
140	6-Mar-13	0.5	0.5	26	0.0	0.5	100.0
141	6-Mar-13	0.5	0.5	1	0.0	0.5	100.0
142	6-Mar-13	2.5	1.5	1	0.0	2.5	100.0
143	6-Mar-13	2.5	1.5	2	0.0	2.5	100.0
144	8-Mar-13	0.5	0.5	24	0.0	0.5	100.0
145	8-Mar-13	0.5	0.5	10	0.0	0.5	100.0
146	14-Mar-13	13.5	10.0	144	0.0	13.5	100.0
147	17-Mar-13	10.0	8.0	68	0.0	10.0	100.0
148	18-Mar-13	0.5	0.5	17	0.0	0.5	100.0
149	18-Mar-13	5.0	4.0	2	0.5	4.5	90.0
150	19-Mar-13	1.5	1.5	20	0.0	1.5	100.0
151	26-Mar-13	2.0	1.5	177	0.0	2.0	100.0
152	30-Mar-13	6.5	6.5	90	0.0	6.5	100.0
153	31-Mar-13	0.5	0.5	19	0.0	0.5	100.0
154	1-Apr-13	59.0	53.0	14	45.2	13.8	23.4

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
155	1-Apr-13	0.5	0.5	1	0.1	0.4	80.0
156	1-Apr-13	0.5	0.5	2	0.0	0.5	100.0
157	2-Apr-13	0.5	0.5	20	0.0	0.5	100.0
158	4-Apr-13	0.5	0.5	57	0.0	0.5	100.0
159	6-Apr-13	3.0	3.0	37	0.0	3.0	100.0
160	6-Apr-13	2.5	2.5	1	0.0	2.5	100.0
161	6-Apr-13	0.5	0.5	5	0.0	0.5	100.0
162	7-Apr-13	3.5	3.0	28	0.0	3.5	100.0
163	8-Apr-13	1.0	0.5	22	0.0	1.0	100.0
164	9-Apr-13	0.5	0.5	15	0.0	0.5	100.0
165	9-Apr-13	1.0	1.0	7	0.0	1.0	100.0
166	10-Apr-13	0.5	0.5	19	0.0	0.5	100.0
167	11-Apr-13	1.0	1.0	13	0.0	1.0	100.0
168	12-Apr-13	58.0	46.0	20	45.0	13.0	22.4
169	12-Apr-13	0.5	0.5	1	0.1	0.4	80.0
170	14-Apr-13	0.5	0.5	44	0.0	0.5	100.0
171	15-Apr-13	8.0	4.5	22	0.0	8.0	100.0
172	18-Apr-13	3.5	3.5	74	0.0	3.5	100.0
173	19-Apr-13	3.0	1.5	32	0.0	3.0	100.0
174	21-Apr-13	2.5	2.5	25	0.0	2.5	100.0
175	21-Apr-13	53.0	37.5	3	44.2	8.8	16.6
176	24-Apr-13	2.5	1.0	83	0.0	2.5	100.0
177	25-Apr-13	0.5	0.5	2	0.0	0.5	100.0
178	25-Apr-13	3.0	2.0	21	0.0	3.0	100.0
179	29-Apr-13	24.5	13.5	73	10.6	13.9	56.7
180	1-May-13	2.0	0.5	52	0.0	2.0	100.0
181	5-May-13	1.5	1.0	86	0.0	1.5	100.0
182	7-May-13	5.0	4.5	44	0.0	5.0	100.0
183	8-May-13	57.5	26.0	21	44.8	12.7	22.1
184	8-May-13	0.5	0.5	1	0.1	0.4	80.0
185	10-May-13	18.5	14.0	40	11.8	6.7	36.2
186	10-May-13	9.0	4.5	1	8.1	0.9	10.0
187	11-May-13	21.5	7.5	36	14.7	6.8	31.6
188	16-May-13	3.5	1.5	110	0.0	3.5	100.0
189	18-May-13	4.5	2.5	42	0.0	4.5	100.0
190	22-May-13	2.5	2.5	95	0.0	2.5	100.0
191	23-May-13	5.0	2.5	2	0.0	5.0	100.0
192	23-May-13	1.0	1.0	8	0.0	1.0	100.0
193	23-May-13	0.5	0.5	8	0.0	0.5	100.0
194	23-May-13	4.5	2.0	1	0.0	4.5	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
195	25-May-13	7.5	7.5	26	0.0	7.5	100.0
196	28-May-13	1.0	1.0	80	0.0	1.0	100.0
197	28-May-13	0.5	0.5	2	0.0	0.5	100.0
198	29-May-13	0.5	0.5	19	0.0	0.5	100.0
199	29-May-13	0.5	0.5	2	0.0	0.5	100.0
200	29-May-13	10.5	9.5	7	0.0	10.5	100.0
201	1-Jun-13	14.0	8.5	48	5.9	8.1	57.9
202	2-Jun-13	35.5	20.5	33	30.1	5.4	15.2
203	10-Jun-13	2.5	2.5	180	0.0	2.5	100.0
204	10-Jun-13	4.0	4.0	16	0.0	4.0	100.0
205	11-Jun-13	0.5	0.5	2	0.0	0.5	100.0
206	11-Jun-13	33.5	20.5	1	22.8	10.7	31.9
207	14-Jun-13	9.0	9.0	70	0.0	9.0	100.0
208	14-Jun-13	0.5	0.5	1	0.1	0.4	80.0
209	24-Jun-13	0.5	0.5	245	0.0	0.5	100.0
210	25-Jun-13	1.0	1.0	13	0.0	1.0	100.0
211	26-Jun-13	0.5	0.5	33	0.0	0.5	100.0
212	26-Jun-13	0.5	0.5	1	0.0	0.5	100.0
213	1-Jul-13	0.5	0.5	105	0.0	0.5	100.0
214	4-Jul-13	9.0	8.5	93	0.0	9.0	100.0
215	5-Jul-13	1.0	1.0	13	0.0	1.0	100.0
216	5-Jul-13	60.0	46.0	5	48.0	12.0	20.0
217	6-Jul-13	1.0	0.5	6	0.0	1.0	100.0
218	13-Jul-13	13.0	6.0	176	0.0	13.0	100.0
219	14-Jul-13	19.0	8.5	17	12.7	6.3	33.2
220	15-Jul-13	18.0	12.0	8	16.4	1.6	8.9
221	15-Jul-13	6.5	6.0	1	6.0	0.5	7.7
222	17-Jul-13	11.0	6.5	56	3.1	7.9	71.8
223	18-Jul-13	0.5	0.5	1	0.2	0.3	60.0
224	18-Jul-13	3.5	3.5	4	2.7	0.8	22.9
225	18-Jul-13	4.5	4.5	13	2.2	2.3	51.1
226	19-Jul-13	35.5	18.5	2	34.5	1.0	2.8
227	20-Jul-13	0.5	0.5	42	0.0	0.5	100.0
228	29-Jul-13	0.5	0.5	203	0.0	0.5	100.0
229	31-Jul-13	11.5	11.0	45	0.0	11.5	100.0
230	31-Jul-13	0.5	0.5	3	0.0	0.5	100.0
231	1-Aug-13	77.0	29.5	33	65.9	11.1	14.4
232	2-Aug-13	11.0	10.5	13	8.5	2.5	22.7
233	3-Aug-13	0.5	0.5	13	0.0	0.5	100.0
234	6-Aug-13	4.5	4.5	62	0.0	4.5	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
235	6-Aug-13	1.0	1.0	2	0.0	1.0	100.0
236	6-Aug-13	0.5	0.5	1	0.0	0.5	100.0
237	7-Aug-13	8.5	4.0	40	0.0	8.5	100.0
238	9-Aug-13	13.5	8.5	24	8.2	5.3	39.3
239	9-Aug-13	9.0	6.0	4	7.9	1.1	12.2
240	10-Aug-13	4.0	4.0	12	1.8	2.2	55.0
241	10-Aug-13	2.0	2.0	1	1.6	0.4	20.0
242	10-Aug-13	0.5	0.5	1	0.1	0.4	80.0
243	10-Aug-13	11.5	9.0	6	9.7	1.8	15.7
244	11-Aug-13	5.0	4.5	17	1.8	3.2	64.0
245	11-Aug-13	9.0	7.0	13	6.1	2.9	32.2
246	12-Aug-13	2.0	1.0	1	1.5	0.5	25.0
247	12-Aug-13	0.5	0.5	8	0.0	0.5	100.0
248	19-Aug-13	20.5	20.0	154	5.0	15.5	75.6
249	19-Aug-13	31.5	9.5	19	26.4	5.1	16.2
250	28-Aug-13	13.5	6.0	183	0.0	13.5	100.0
251	29-Aug-13	0.5	0.5	37	0.0	0.5	100.0
252	30-Aug-13	0.5	0.5	6	0.0	0.5	100.0
253	30-Aug-13	0.5	0.5	8	0.0	0.5	100.0
254	30-Aug-13	3.5	3.5	1	0.0	3.5	100.0
255	30-Aug-13	23.5	6.5	2	17.3	6.2	26.4
256	30-Aug-13	0.5	0.5	1	0.1	0.4	80.0
257	31-Aug-13	0.5	0.5	13	0.0	0.5	100.0
258	1-Sep-13	6.5	6.5	30	0.2	6.3	96.9
259	2-Sep-13	0.5	0.5	22	0.0	0.5	100.0
260	3-Sep-13	0.5	0.5	15	0.0	0.5	100.0
261	4-Sep-13	4.5	2.5	17	0.0	4.5	100.0
262	5-Sep-13	14.5	6.5	22	7.9	6.6	45.5
263	5-Sep-13	0.5	0.5	3	0.0	0.5	100.0
264	7-Sep-13	1.5	1.5	38	0.0	1.5	100.0
265	7-Sep-13	0.5	0.5	3	0.0	0.5	100.0
266	7-Sep-13	1.0	1.0	1	0.0	1.0	100.0
267	7-Sep-13	0.5	0.5	4	0.0	0.5	100.0
268	7-Sep-13	51.0	39.0	6	45.4	5.6	11.0
269	8-Sep-13	43.0	16.0	3	41.2	1.8	4.2
270	8-Sep-13	4.0	3.5	10	1.9	2.1	52.5
271	11-Sep-13	21.0	9.0	51	13.0	8.0	38.1
272	11-Sep-13	3.0	1.5	14	0.0	3.0	100.0
273	11-Sep-13	0.5	0.5	1	0.1	0.4	80.0
274	13-Sep-13	0.5	0.5	38	0.0	0.5	100.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
275	13-Sep-13	1.5	1.0	3	0.0	1.5	100.0
276	15-Sep-13	130.0	40.5	49	118.6	11.4	8.8
277	16-Sep-13	1.0	1.0	5	0.0	1.0	100.0
278	16-Sep-13	27.0	15.5	1	25.9	1.1	4.1
279	27-Sep-13	14.0	8.0	257	0.0	14.0	100.0
280	27-Sep-13	2.5	2.5	2	0.0	2.5	100.0
281	28-Sep-13	0.5	0.5	17	0.0	0.5	100.0
282	29-Sep-13	5.0	4.5	13	0.0	5.0	100.0
283	29-Sep-13	2.5	1.5	6	0.0	2.5	100.0
284	30-Sep-13	9.5	8.0	36	3.5	6.0	63.2
285	1-Oct-13	0.5	0.5	1	0.1	0.4	80.0
286	3-Oct-13	2.5	2.5	46	0.0	2.5	100.0
287	3-Oct-13	0.5	0.5	2	0.0	0.5	100.0
288	5-Oct-13	24.0	12.5	48	13.6	10.4	43.3
289	5-Oct-13	0.5	0.5	7	0.0	0.5	100.0
290	7-Oct-13	6.0	5.0	35	0.0	6.0	100.0
291	7-Oct-13	8.0	7.5	2	6.9	1.1	13.8
292	7-Oct-13	12.5	7.0	1	11.4	1.1	8.8
293	7-Oct-13	5.0	4.0	7	3.4	1.6	32.0
294	8-Oct-13	0.5	0.5	14	0.0	0.5	100.0
295	9-Oct-13	1.0	1.0	32	0.0	1.0	100.0
296	10-Oct-13	7.0	2.5	1	0.6	6.4	91.4
297	10-Oct-13	1.5	1.5	1	1.1	0.4	26.7
298	10-Oct-13	3.5	2.5	1	3.0	0.5	14.3
299	10-Oct-13	0.5	0.5	2	0.0	0.5	100.0
300	11-Oct-13	6.5	4.5	17	3.1	3.4	52.3
301	11-Oct-13	7.5	6.5	2	6.6	0.9	12.0
302	11-Oct-13	0.5	0.5	1	0.1	0.4	80.0
303	11-Oct-13	0.5	0.5	6	0.0	0.5	100.0
304	12-Oct-13	27.5	8.5	2	24.3	3.2	11.6
305	12-Oct-13	3.0	3.0	8	1.4	1.6	53.3
306	13-Oct-13	17.0	7.0	2	15.9	1.1	6.5
307	13-Oct-13	0.5	0.5	1	0.1	0.4	80.0
308	13-Oct-13	0.5	0.5	15	0.0	0.5	100.0
309	14-Oct-13	12.5	12.5	4	9.5	3.0	24.0
310	14-Oct-13	0.5	0.5	1	0.1	0.4	80.0
311	15-Oct-13	27.0	14.5	20	23.4	3.6	13.3
312	16-Oct-13	7.5	4.5	24	3.3	4.2	56.0
313	23-Oct-13	32.5	22.0	166	16.2	16.3	50.2
314	24-Oct-13	49.0	11.0	18	44.6	4.4	9.0

No.	Event Date	Rainfall Depth (mm)	Peak Intensity (mm/hour)	ADWP (hour)	Runoff (mm)	Retention (mm)	Retention (%)
315	24-Oct-13	0.5	0.5	2	0.0	0.5	100.0
316	24-Oct-13	13.0	4.0	7	10.5	2.5	19.2
317	25-Oct-13	13.0	5.5	2	11.6	1.4	10.8
318	26-Oct-13	0.5	0.5	16	0.0	0.5	100.0
319	26-Oct-13	0.5	0.5	2	0.0	0.5	100.0