Modelling Water Retention in Modified Green Roofs – A Case Study Based On the Orlyplein Roof Park, Amsterdam

By

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RESEARCH DECLARATION

I declare that this report is entirely my own work and that any use of the work of others has been appropriately acknowledged as in-text citations and compiled in the reference list. I also confirm that the project has been conducted in compliance with the University's research ethics policy and evidence of this has been included in my thesis.

I agree that the project report can be made available as a Reference Document for other students in the Department of Geography, Environment and Disaster Management Information Room/Map Library.

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Abstract:

green roof is defined as the building that is completely or partially covered with a growing medium or vegetation. It is important to note that this growing medium is typically planted over a membrane of waterproof material. Green roof has many implementation and benefits. It has been documented in the research work of Galeassociates (2010) that green roofs are famous for serving a wide range of actions for the buildings. These include creating a habitat for wildlife, providing insulation, absorbing rainwater, decreasing stress in people and increasing benevolence around the roof by forming a more pleasing landscape. Orlyplein green park in the Netherlands, is a good example of turning normal bus park to greenest squares in Amsterdam. This case study is based on developing a model in order to study the hydrological behaviour of green roof by analysing different variables which have the potential to affect moisture content in green roof system. Model modification, sensitivity analysis and calculating actual evapotranspiration were part of the model development. In summary, helps in understanding pre-significant rain event retention and to assess overall volumetric performance, in order to utilize green park water management facility to the maximum level. The modification on this model helped in understanding and model green roof irrigation requirements to avoid potential drought risk.

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Chapter 1: Background

1.1Green infrastructure

Green infrastructure can be defined as buildings that take into respect the nature in terms of design and construction, which would reduce the negative impact on human and the surrounding natural environment (Gill, Handley and Ennos et al. 2007). The importance of green infrastructure is well known and supported by many environmental agencies such as the American Society of Civil Engineers and Environmental Protection Agency. A variety of green infrastructures, such as blue-green roofs, rainwater harvesting systems, rain gardens and permeable pavement, have been classified into best management performs and practices. (Gill, Handley and Ennos et al. 2007)

In spite of the differences and the multiplicity of evaluating green infrastructure systems between agencies, these systems share the basic fundamentals which focus on the same objectives of satisfying the Energy Independence and Security Act of 2007 which contain a proclamation states the need "to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow" (Peters 2012)

Stormwater runoff in urban cities makes a major influence on sewerage systems. In most developed cities, building roofs may participate for about 40 to 50% of the impermeable urban area (Bedient, et al. 2013). Any system that moderates the degree and volume of roof runoff has the potential to considered as Improved stormwater management (Bedient, et al. 2013).

Many countries and governments promote the use of Sustainable Drainage Systems (SuDS) to manage surface water runoff (Ruth and Coelho 2007) green roofs, soak ways, swales, rain gardens, infiltration basins and ponds are covered by and considered as a part of the Sustainable drainage systems. The water assembles naturally and reduce its influence through infiltration, attenuation, and storage. These techniques constitute the most sustainable approach for the management of rainwater when compared with traditional methods adopted in buried sewer networks. Sustainable Cost-effective stormwater management methods exceed the goal of controlling the amount of runoff to reach the improvement of water quality in urban areas (Ruth and Coelho 2007)

The SuDS method exceeds the requirement to control runoff. SuDS method aiming to improve urban water quality and provide water amenity. Green roofs have the potential to achieve these three objectives concurrently. In addition, green roofs achieve SuDS concepts in controlling rainfall close to the source as possible. And participate in rainwater treatment. This single independent system can manage runoff more than any SuDS technique (Ruth and Coelho 2007)

Anderson, Lambrinos, and Schroll (2010) have defined green roof as the building that is completely or partially covered with a growing medium or vegetation. It is important to note that this growing medium is typically planted over a membrane of waterproof material. According to Stovin, Dunnett, and Hallam (2007), it also often incorporates additional layers like irrigation systems, drainage, and root barrier. It has been documented in the research work of Galeassociates (2010) that green roofs are famous for serving a wide range of actions for the buildings. These include creating a habitat for wildlife, providing insulation, absorbing rainwater, decreasing stress in people and increasing benevolence around the roof by forming a more pleasing landscape. It has been suggested by Weiler and Scholz-Barth (2009) that green roofs play an inevitable and indispensable role in mitigating the heat island effect, while lowering urban air temperatures. In particular, Stovin, Dunnett, and Hallam (2007) have signified some of the most prominent functions of green roofs, which show that it offers substantial benefits of aesthetic value, pollution abatement, energy conservation, storm water management, as well as water management. Carson (2014) has highlighted that green roofs may have variable aesthetic value, pollution abatement, energy conservation, storm water management, and water harvesting benefits. Amid all of these benefits, storm water management appears to be the most prominent advantage that is offered by green roofs.

The idea of green rood is not new to many countries, it is used for different purposes and in un-engineered methods in the past. For example, in Egypt green roofs are used to get cleaned roofs and to grow vegetables for human use as presented in figure 1. the Hanging Gardens of Babylon is one of the famous historical example on green roofs and walls (El-Gohary, Nasr and Wahaab et al. 2000)

Figure 1 Green roofs in Egypt used in growing vegetables and clean roofs. *(El-Gohary, Nasr and Wahaab et al. 2000)*

1.2 Green roof types

There are two sorts of green rooftops extensive and intensive. The difference between these two types is the growing media depth. The growing media depth in extensive green roofs ranges from 5 to15 cm, while growing media depth in the intensive green roofs may exceed 15 cm, which makes this type of green roofs capable of supporting vegetation with deeper root structures and less drought tolerant. The problem of this type of green roofs is the additional weight that is added to the building structure especially in wet seasons. All green roofs construction should follow and meet environmental and regulatory legislation and aims (Luckett 2009). Figure 2 presents the difference between green roof type

Extensive Green Roof • thin soil, little or not irrigation, stressful conditions for plants	**Intensive Green Roof** • deep soil, irrigation system, more favorable conditions for plants
Advantages: • lightweight - roof generally does not require strengthening • suitable for large areas • suitable for roofs with 0-30° (slope) • low maintenance • often no need for irrigation and drainage systems • relatively little technical expertise needed • often suitable for retrofit projects • can leave vegetation to develop spontaneously • relatively inexpensive • looks more natural • easier for planning authority to demand green roof as a condition of planning approvals	**Advantages:** • allows greater diversity of plants and habitats • good insulation properties • can simulate a wildlife garden on the ground: can be made very attractive: visually often accessible, with more diverse utilization of the roof i.e. for recreation, growing food, as open space.
Disadvantages: • more limited choice of plants • usually no access for recreation or use • unattractive to some, especially in winter	**Disadvantages:** • greater weight loading on roof • need for irrigation and drainage systems (greater need for energy, water, materials, etc) • higher cost • more complex systems and expertise required

Figure 2: Comparison between intensive and extensive green roofs, advantages and disadvantages

Many studies focused recently on green roof benefits and implementation to mitigate climate change effect. One of the good example of green parks is the case that is used in this project, Orlyplein Roof Park, Amsterdam.

1.3 Orlyplein Roof Park Project description:

This project is based on a case study of a former bus station on the roof above Amsterdam Sloterdijk Station (NS) has been transformed from gray concreated area into green roof park for public use. Excess rainwater is collected in the drainage layer and used to irrigate the plants. The entrance to the station is located at the level of the green park as it can be seen in figure 3.

this 8,000 square meters of greenery, consisting of no less than 85,000 trees, flowers and plants transformed Orlyplein and tern it from normal bus park to greenest squares in the Netherlands, with an ingenious method to store water. This transformation benefited the shops, railway station, commercial building and restaurants to be an attractive location for public as it can be seen in figure 4. Moreover, this green park benefited the area in mitigating flood problems figure 5. (Amsterdam municipality website link)

Figure 3: the park outline presenting the location of the railway station and the park commercial project (Amsterdam municipality website)

*Figure 4: **front side of green park orientation, the commercial building such as restaurants, shops and hotels benefited economically from this project (Amsterdam municipality website link)***

Figure 5: railway station was flooded many times before the project of green park take a place (Amsterdam municipality website link)

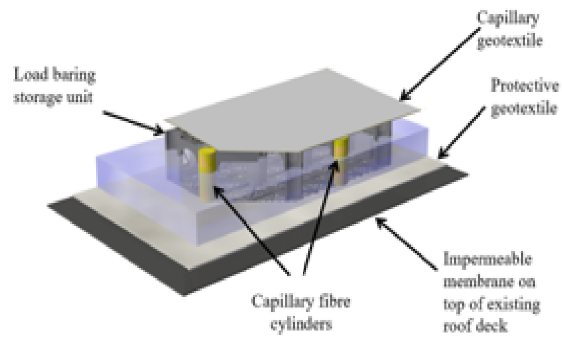
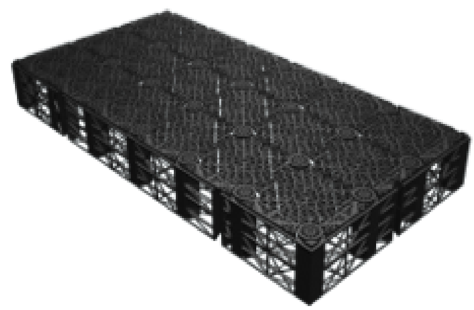
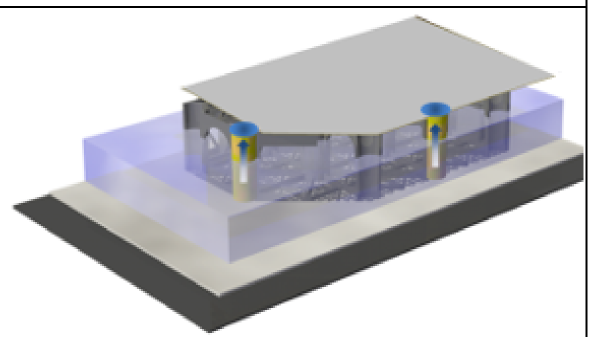
1.4 The design:

The design includes planting fields with a mixed flowering plants 40-80 cm high, trees in specially created Corten steel containers and various paths of 10 cm thick concrete tiles. Tables 1and 2 presents the system characteristics, components and constructing stages.

Table 1: 1 Orlyplein green park system characteristics

System characteristic	Description
Quantity	• 3,000 m^2 85 Capillary Permavoid • Specific density (kg/m3 dry weight) = 106 • Water storage at field capacity (l/m^3) = 960 • Water-stored-to-weight ratio (WSWR l/kg) = 9.1
maximum roof load	• 600 kg / m^2
water storage capacity	• 100 mm in the 30 cm substrate 50 mm (adjustable) in the 85 mm high Permavoid drainage layer substrate • Moderately fine sand (350 mu) with 8% organic matter • Average 30 cm deep • 110-160 l / m for the entire system
Water retention	• 70-95%
Dischai[illegible]cient	• 0.3-0.05
waterproof membrane	• Permalon, factory custom made
capillary cloth	• Permatex 300, the top and bottom of the units Permavoid construction
Depth	• 126-45 cm
Roof slop: Vegetation	• 0-5^0 (0-9%)
Plants type	• Bushes / woody plants / lawn

Table 2: Orlyplein green park components and constructing stages.

<table>
<tr>
<td>In order for the system to operate in storing water and irrigate topped vegetation passively, five main elements should be gathered in the system after the preconstruction and roof preparation work.
Impermeable membrane is placed on top of existing roof park. lateral capillary water transport back geotextile is the second layer comes on top of the impermeable membrane upon which the permavoid units are laid and covered with the lateral geotextile to prevent the loss of the substrate</td>
<td>
</td>
</tr>
<tr>
<td>Excess rainwater is collected in the permavoid layer which can hold up to 60 mm of water in each individual section. permavoid provide a solid foundation where even a truck can go, on the other hand they allow water and roots to penetrate and settle. Stormwater flow through the various sections of the permavoid e layer (following the slope of the roof), before overflow occurs as a result of heavy rain The permavoid layer is therefore necessary for storage and disposal of water.</td>
<td></td>
</tr>
<tr>
<td>The permavoid layer consist of cylindrical space where the yellow capillary fibers are fitted in. these fibers work in two directions. It passes water from substrate to the permavoid once the substrate is saturated with water during rain events and transport water from permavoid to the substrate at the time of drought, which supports the vegetation layer. This passive irrigation, makes the use of pumps, hoses, valves and nozzles, as well as well as the use energy, unnecessary in irrigating extensive green roofs</td>
<td></td>
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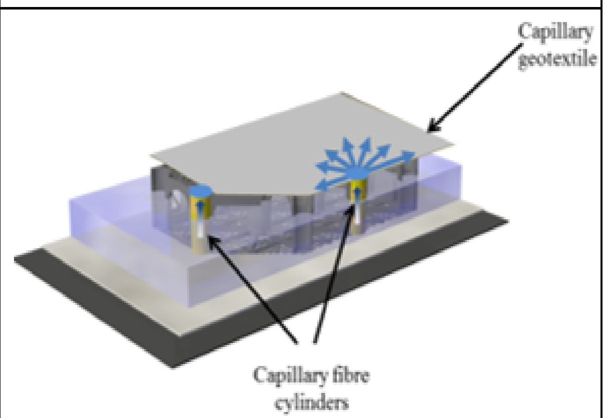
<td>The 85 mm Permavoid Unit, fitted with the yellow capillary fibers, is covered with lateral capillary water transport back geotextile (white, Permatex 300) this layer is then topped with the substrate and vegetation</td>
<td>
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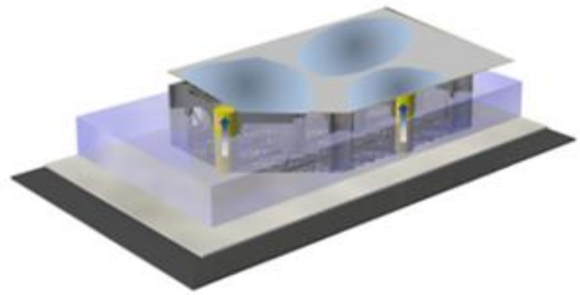
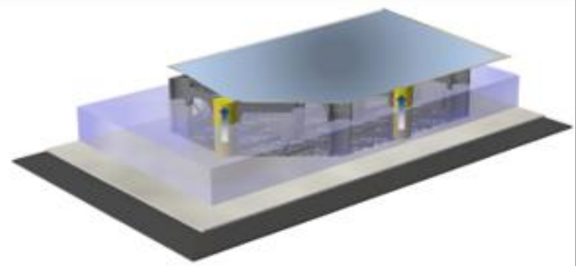
Note: to be continued next page

the volume of water that can be stored within the permavoid leaves an air space between the water body and the overlying substrate, which provides additional oxygen to the plants roots	
By storing the water in the permavoid and substrate in equivalent volume, the lode on roof will be less then when water stores in traditional green roof	
The Permavoid units are load bearing so that they are integral among all Dakpark are used: the capacity it does not matter whether planters, flowering plants, trees or pavement (concrete or asphalt pavement element) on is applied. Drainage, irrigation and lateral transport is guaranteed for entire roof arranged, also in future changes of the design in planting or hardening. The Permavoid units can include any type of planting and can be applied with any type of substrate may be used.	

Green parkes are type of SuDs, which holds a lot of benefits in one application the next chapter is presenting some of green roofs benefits

1.5 Aims and objectives

The objective of this study:

- To study orlyplein green park system and to change the model and show the ability of the model in investigating green park hydrology
- To investigate the best way of managing water on the orlyplein site
- to develop the very basic and inflexible model produced by van de Werken.
- To understand the hydraulic response of green roof in response to changing variable and analyzing the relationship between hydraulic performance of green roof and these variables.
- To improve stormwater retention, develop a method to calculate irrigation requirements

Chapter 2: Literature review

2.1 The Effectiveness of Green Roofs in Storm Water Management

As cities and urban areas are increasing, the natural infrastructure has started to be replaced by manmade surfaces that are made from concrete and asphalt. It has been recognised that these surfaces are responsible for preventing the rainwater from being absorbed into the ground (GSA-US, 2011). uncertain environmental conditions, possibly brought on by climate change, have resulted in increasing the intensity of rains. When the rain falls on the manmade water-resistant roofs, it results in increasing the flows of water; hence, results in flash flooding. In addition to this, it also results in affecting the quality of water through storm water discharges, as well as CSOs (combined-sewer overflows) (Stovin, et al 2007). storm water runoff has become one of the most severe issues that are being faced by the ecological system (Anderson, et al 2010). improper management of the storm water is responsible for contributing to water pollution and intense flooding (Susca et al 2011). green roofs play a prime role in managing storm water, in terms of the establishment of sustainable drainage systems (Stovin 2010). green roofs are the greatest ways of addressing the flows of wet weather, specifically in the urban areas (Berndtsson 2010). green roofs have great significance in minimising the rate of runoff by approximately sixty-five per cent (65%) (Stovin 2010). On the other hand, a report by (Associates G. 2010) has outlined other notable characteristics of green roofs that are related to its functionality in extending the time span of the rain water to leave the site. the majority of green roofs retain and intercepts the first ½ to ¾ inch of rainfall; thereby, result in restricting it from running off the roof and minimising the risk of floods. (Gregoire and Clausen 2011)

Green roofs have mainly two characteristic qualities, in terms of managing the storm water. The first characteristic quality is associated with retaining and slowing the storm water. In addition to this, the second characteristic includes the reduction of the pollutant levels in the storm water. (Rowe 2011). In terms of retaining and slowing the storm water, the green roofs operate in two primary ways. the first way as increasing the amount of storm water that is retained on the rooftop. The second way in which a green roof works, is related with the minimisation of the rate of flow of water, from rooftop to the sewer system (Carson 2014). A black and white roofs do not provide such effects, i.e., minimising or slowing down the rainwater runoff (GSA-US, 2011). A study has shown that the plants as well as other materials that are utilised in the green roof greatly contribute in holding back the storm water both temporarily and, via evapotranspiration, permanently if the water quantity did not exceed the green roof system capacity (Galeassociates 2010). However, the ability of the green roof in managing the storm water is dependent on wide range of factors. These factors include the size of the roof, the climate and seasonal conditions, the slope of roof, vegetation or plants, the growing medium, as well as the drainage layer. It is observed that all of these factors hold undeniable importance in minimising the peak rate of flow of water or the maximum runoff rate. the minimisation in the peak flow rate is dependent on roof's configuration, drainage material, the size and scope of roof, the growth medium, and the duration and intensity of storm. (Anderson, et al 2010) (Gregoire and Clausen 2011)

Green roofs have gained commendable popularity because of adequately managing the storm water. The appropriate management of storm water eventually result in controlling and reducing the pollutants that are present in storm water; hence, enhancing the quality of water once the storm water enters into streams and lakes (Stovin 2010) (Rowe2011). green roofs enhance the quality and characteristics of the rain water that overflows from roofs. It is due to the fact that the plants, on the green roofs, absorb some of contaminants or potential pollutants from the soil by storing them in their tissues. It shows that green roofs are one of the most commendable options that could foster flawless management of the storm water (Gregoire and Clausen 2011). Some studies presented that green roofs (through their buffering capacity) also help in managing the impacts of acid rain. (Anderson et al, 2010) and (Stovin 2010). many studies focused on the economic benefits of managing storm water through green roofs. The analysis of the views of the researcher has revealed that depending on the incentives and local regulations of storm water, green roofs praiseworthily support both municipalities and owners of the buildings, in terms of avoiding excessive costs (Weiler and Scholz-Barth 2009).

Green roofs have higher capabilities of managing natural hydrological processes, in a cost effective manner. Whilst it has been assessed that green roofs can be used with the pre-existing water retention initiatives so as to enhance the storm water management capabilities of a building. In other words, that it can be affirmed that green roofs offer an opportunity to the owners of the buildings to effectively manage storm water, without spending huge capital sums. However, it should be acknowledged that such stormwater management capabilities are severely limited in situations where the water storage capacity limit is reached and the roof has insufficient opportunity to drain/evaporate the water before the next rain event (Gregoire and Clausen 2011). This project is associated with a design of green roof that is specifically intended to address this problem. Some of the most prominent water retention initiatives that could be used with green roofs include permeable pavements, bio-retention basins, as well as filter strips. The study of (Weiler and Scholz-Barth 2009) has shown that the advanced technological tools, like cisterns and infiltration chambers can also be used with the green roofs so as to manage the storm water in an economic manner. This is due to the fact that these technologies support the functionality of the green roofs, without having the need of excessive maintenance. However, the disadvantages of pump unreliability and energy usage associated with that approach if the water is also to be used to support plant growth on the roof (Voeten et al 2016). when green roofs are utilised along with cisterns for the management of the storm water, it results in more consistent provisioning and capturing of harvested rain water. This feature ultimately results in minimising the demands of potable water for the irrigation of the landscape; hence, controlling the overall cost required for the irrigation. In particular, it can be affirmed that properly designed green roofs offer wide range of potential benefits, in terms of effectively managing the storm water. In this regard, the most evident benefits that have been found from the analysis of different studies include cost effectiveness, reducing the pollution in lakes and streams, as well as minimising ecological vulnerabilities that are resulted from inappropriate storm water management. (Anderson, et al 2010)

2.2 Rainfall Retention and Evapotranspiration in Green Roofs

It is asserted (Wadzuk, et al., 2013), that the society needs to adopt certain measures of preserving the natural resources, particularly to deal with the influences of urbanization on the natural resources of water. There is a need of understanding the key elements of hydrological cycle to obtain the benefits of green roofs, as the efficient mechanism of sustainable drainage system

(SuDs). Their study focused the green roof of "Villanova Urban Storm-water Partnership (VUSP) demonstration park near Philadelphia, Pennsylvania" to demonstrate the retention of rainfall and the Evapotranspiration (ET) component as well. With respect to the effective outcomes of green roofs, the designers are advised by these authors to adopt the guidelines of Germany to plan, install, and maintain the green roofs, or the E2398 and E2399 standards of ATSM, irrespective of the fact that the capacity available for green roofs varies based on different factors. These factors entail the impacts of season, plant species, previous dry days, and the climate during those days and previous rainfall as well. Accordingly, there is a need of incessant modelling of the SCMs, considering the elements of ET and the soil-moisture.

The rate of ET content in the green roofs needs to be examined extensively as it influences the effective storage capability of substrate with respect to the retention of rainfall. For attaining maximum benefits of SuDs, the components of reusability and infiltration are also considered along with ET. As a result, it is affirmed that the prospects of storm-water runoff control are reduced based on the analysis of ET for 3 years (2009-2011), by comparing the potential values of ET with the measured values in different climate conditions. (Wadzuk, et al., 2013)

A study by (Morgan et al 2013) emphasized the needs of understanding the essentials of hydrological cycle for the adequate preservation approaches of storm-water; thus, supporting the research agenda of (Wadzuk, et al., 2013). The study has signified the value of the design of the green roofs for achieving maximum rainfall retention. In this regard, the study has analysed randomized designs of multiple settings of green roof models. The outcomes of monitoring the rainfall retention during 2005-2008 reflect that the design of the system along with the presence of plants over the roof had positive impacts on the intended objectives of green roofs. the study has also examined the storm-water runoff with respect to ET content on the modular system of green roofs. Consequently, the analysis of the outcomes represents that the role of suspended precipitates, nitrate and turbidity is significant in determining the runoff quality and the rainfall retention, along with the aforementioned factors.

With respect to the concerned aspects of storm-water runoff and the associated impacts of climate conditions, the study of (Carpenter, and Kaluvakolanu, 2011), has evaluated the impacts of surface type of green roof sand adopted (SuDs) in the study. Since the process of urban development has minimized the ground surface areas for the preservation of natural resources, particularly, water resources, the roof areas are being technologically modified to be used for the same purpose of storm-water runoff. The study has analysed the runoff performance of 3 full-scale green roofs for a period of over 6 months. Flow meters for monitoring the runoff quality and samplers for analysing the water-quality were used. More specifically, there were 2 other roof settings of asphalt, and ballasted along with the green roof. As a result, the performance of green roof was observed to be comparatively efficient as the rainfall retention was recorded to be 68.25% along with reducing the discharge of rainfall volume by 88.86%. Additionally, even the nutrient and solid loadings in the water retention were reduced by the designs of green roofs.

The study of (Kasmin et al 2010), has presented the performance of green roofs in terms of the associated hydrological processes. The study has monitored the storm-water runoff in two settings; during the event of storm, and for the longer period of incessant simulation of the SCMs. In this regard, the most important element of design of the roof comprised of the storage components of substrate moisture and transient one. The capacity of substrate moisture represents the potential of rainfall retention of the roof. It is asserted that the Evapotranspiration content of the green roofs tend to restore the retention capacity of the roof after a particular period of storm event. The study outcomes reflect that the records of rainfall retention in the case of storm-water runoff represent the ET capacity of less than 1mm for a day under the climatic conditions of UK. Accordingly, it is estimated that at over one-week period would be required for the green roofs to recover the retention capacity fully under the dry conditions of weather. Nonetheless, this period needs to be quantified by using certain standard methods for attaining the maximum benefits of green roofs, pertaining to the retention of storm-water runoff. With respect to the significance of quantified ET values on monthly basis, multiple approaches have been in practice. These approaches include the monitoring of the entire green roofs prior to the storm events, which means the data of dry weather conditions. Moreover, as studied by the research of Wadzuk, et al., (2013), there must be an incessant modelling approach of calibrating the most important element of ET contents. On the other side, the study has also proposed the approach of "Thornthwaite ET formula", and the use of laboratory methods to measure evaporation rate in terms of ET quantification.

The study of Burszta-Adamiak, (2012), has focused the implication of green roofs in urban areas, where rainfall retention is highly desirable. It is carried out by sustainably managing the storm-water runoffs through the well-established designs of green roofs for eliminating the shortcomings of ground-level storage. The construction of new buildings includes the green roofs system as an essential component in Wroclaw, as the state realizes the limitations caused by the resulting increase in the soil surface to be sealed, and the inabilities of infiltrating and retaining natural storm-water. Based on the intended objectives of examining the significance of green roofs, the study has analysed the experimental sites of "the Science and Education Centre building of the University of Environmental and Life Sciences in Wroclaw" for 2 years (2009-2010) for the purpose of determining the retention potential of green roofs, along with the delays in the runoff and the associated reduction in the peak runoff. Meanwhile, it is affirmed that the data related to the rainfall retention of the green roofs design is not suitably estimated. Accordingly, the study yielded the conclusion that the green roofs have considerable potential in dealing with the management concerns of storm-water runoffs. It is governed by the multiple layers present in the design structure of the green roofs that validates the research outcomes of Morgan, Celik, and Retzlaff (2013), and Wadzuk, et al., (2013) as well. Moreover, the storm-water's outflow volume is also reduced even in the peak runoff conditions of rainfall. The significance of the green roofs is evident from the prospects that the analysis of 153 rainfall events yielded 85.7% efficient outcomes for green roofs. On the other side, the rainfall retention performance of the green roofs turned out to be around 100% for the rainfall events of up-to 1mm per day.

The impacts of urbanization are acknowledged to be replacing the permeable nature of the ground surfaces into comparatively impervious surface. As a result, it is noted that impacts of storm-water runoff are temporal to the drainage system of the urbanized states. Nonetheless, the needs of urbanization could not be refuted that has resulted in the adoption of green roofs as the alternatives to the shortcoming of ground-level rainfall retention. the significant aspects of the pre-development functioning capabilities and design of the green roofs as the credible SCMs has been reviewed. In this regard, the humid subtropical regions of Hong Kong have been examined with respect to the potential of green roofs in serving the intended objectives of rainfall retention, along with considering the significance of ET content. (Wong, and Jim, 2014). Moreover, the study has also analysed the depth of the substrate used in the design of the green roofs, along with the additional medium of " rockwool" that is used to absorb water and provided to the vegetative system and enhancing the retention potential of the green roofs. The overall period of analysis was 10 months that yielded the outcomes to be in favour of the effectiveness of the green roofs in retaining the rainfall. More specifically, the peak reduction in the runoff delays was also observed to be significant even when the system of green roofs had reached full capacity of moisture-storage (figure 6). Thus, the significance of green roofs is validated even in the tropical regions that reflect that the use of green roofs would be proficient in dealing with the storm-water runoffs of tropical regions as well. However, in this project the retention potential of the green roofs in enhanced by using permavoid which has more capacity to store water when compared with typical green roof system. Capillary fibres are used to provide plants with water (Newman A. et al , 2016)

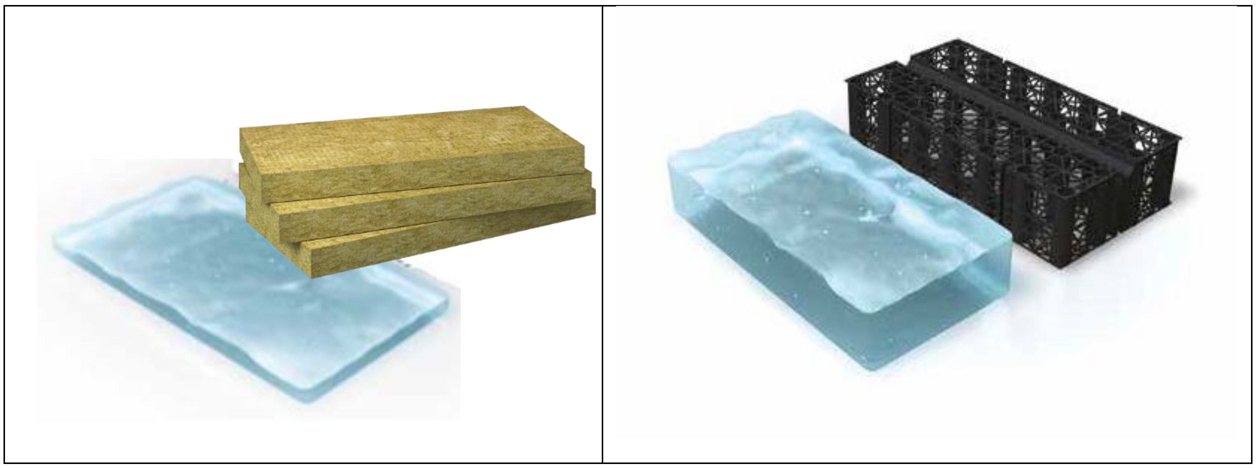


Figure 6: the capacity of permavoid which is used this project case study and rockwool that is used in typical green roof to hold water (source: Permavoid System Technical Manual)

2.3 Green Roofs Efficiency in Heat Isolation and Heat and Mass Transfer

Rayner, (2015), has described green roofs as an effective solution to reduce the energy budgets of buildings that entails a slight reduction in the costs of winter heating, but considerable reduction in the energy demands for summer cooling. It is carried out by reducing the surface temperatures of roof that results in changing the heat transfer; thus, potentially enhancing the performance of HVAC "Heating, Ventilation and Air Conditioning" systems of buildings. green roofs are regarded as effective resources of resolving the problems being faced at environmental level, with respect to urban and building levels. Among the most adverse cases, the issue of global warming or rapidly increasing heat within the environment demands significant considerations (Zinzi, and Agnoli, 2012). In this regard, the innovative approach of green roofs has been serving the aforementioned problem dealing is an incredible manner. There is a great need of development of a pleasant environment that is unattainable to be facilitated by the conventional roofs. Accordingly, the green roofs with their potential of improving the issues of storm-water runoffs, reducing pollution from the atmosphere and even noise are also efficient in the reduction of heat contents along with eliminating the adverse impacts of carbon footprints (Fioretti, et al., 2010; Santamouris, et al., 2007; Castleton, et al., 2010; Lazzarin, Castellotti, and Busato, and 2005).

Green roofs potentially improve the energy efficiency of the buildings through the enhancement of the process of heat transfer all the way through roofs. Within the premises of green roofs, the temperature of the surrounding is reduced that results in the improved efficiency of HVAC systems of the building. It is carried out by the provision of cooling impact to the fluid prior to its returning back to the chiller. As a result, even the photovoltaic panels also receive the benefits of this reduction in the atmospheric temperature as their efficiency gets improved (Castleton, et al., 2010). the significance of green roofs for the heat related issues of buildings. It is established that the green roofs tend to enhance the permanence of the membranes of roofing of the building based on potentially limiting the subjected thermal stress (Kosareo, and Ries, 2007; Teemusk, and Mander, 2009Teemusk, and Mander, 2010).

With respect to the implications of green roofs at the city level, numerous studies have asserted that the deployment of green roofs over the buildings significantly lessens the effect of UHIs (Urban Heat Islands). UHIs are the areas having hot weather conditions that are mainly due to the urbanized activities of the individuals. The process of urbanization is continually in the phase of development that reflects that the effect of UHIs cannot be mitigated, unless external efforts are implemented (Zinzi, and Agnoli, 2012). Moreover, even UHIS effects are believed to be the significant contributors of global warming. Nonetheless, the individuals are facilitated with the benefits of green roofs significantly (Alexandri, and Jones, 2008; Takebayashi, and Moriyama, 2007). Since the needs of maintaining the temperature in certain regions are of extreme level, the design of green roofs entails considerable significance as well. As a result, green roofs are identified by two types: extensive and intensive. The extensive green roofs are characterised by the soil thickness of not more than10 cm-15cm, while the intensive green roofs have the characteristic soil thickness of over 15cm-20cm (Fioretti, et al., 2010; Feng, Meng, and Zhang, 2010; Sailor, 2008; Spala, et al., 2008; Williams, Rayner, and Raynor, 2010; Getter, Rowe, and Cregg, 2009). According to the study of Castleton, Stovin, Beck, and Davison, (2010), extensive type of green roofs has no need of added strengthening, based on their minimum additional loads; thus, these green roofs are appropriate for the retrofitting of buildings.

It is affirmed that the climatic conditions are different for different regions across the world. Accordingly, it is asserted that the selection of the green roof depends upon the characteristic climate of the region, where the building(s) is present. With respect to the climatic conditions of Australia, the selected green roofs design and features would be different as compared to the climate of European regions (Williams, Rayner, and Raynor, 2010). It is established that in the summer season, the surface temperature of the "conventional roofs" of the buildings is very high as compared to other seasons. With the prospects of deploying green roofs rather than conventional roofs, the indoor heat conditions are comparatively better. It is based on the fact that numerous effects are associated with the green roofs designed characteristics that tend to yield cooler effect even in thermal conditions. These effects include the factors of thermal resistance of soil used in the roof design, foliage shading, and the content of Evapotranspiration (ET). With the cumulative impacts of these characteristics featured in the design of green roofs, the heat flux of the buildings receives significant effects. By heat flux means, the rate of transfer or exchange of heat in between the indoor and outdoor thermal conditions of the building. With respect to the surface temperature of green roofs, it is noted that the external surfaces of the slabs of roofs have low temperatures both in the hot and cold weather conditions. More specifically, the green roofs have low amplitudes or fluctuations as compared to the conventional roofs. As a result of these low-frequency fluctuations of heat flux, the roofing membranes of the building receives minimized thermal stress; thus, improving the longevity (Kosareo, and Ries, 2007; Teemusk, and Mander, 2009 Teemusk, and Mander, 2010).

The study of Susca, Gaffin, and Dell'Osso, (2011), has evaluated the significance of green roofs at building and urban scale. In this regard, the study has examined the performance of three roofs; green, black and white. Accordingly, the study has noted the difference of 2°C in between the temperatures of the UHIs of New York, describing the significant impacts of green roofs in improving the climatic conditions, by means of using a "climatological model". Santamouris, et al., (2007) has also examined the influence of green roofs on the indoor thermal conditions of buildings in Athens. The study asserted that the use of green roofs in the buildings has resulted in saving the cooling energy required, in a significant manner. For instance, it was noted that the cooling demands of an office building in Athens were reduced by the deployment of green roof as compared to the conventional roof. On monthly basis, the study observed a decline in the energy demands by 15% to 39% for the entire building, and there was a reduction of 27% to 58% in the demands for the top floor of the building.

The impacts of green roof are positive on the performance of buildings in urban areas in terms of facilitating with cooling effect even in hot weather conditions (Ouldboukhitine, et al., 2011). Moreover, the foliage used in the designing of the green roofs provides the reflective properties that result in harnessing the radiations of the sun in an efficient manner. In this regard, the study has deployed the method of thermodynamics along with characterizing the thermo-physical features of the components of green roof. Ouldboukhitine, et al., (2011) have focused on the equations of energy balance for the soil and foliage content of green roof. Accordingly, the impacts of the ET content and the mass transfer characteristics were studied, which was followed by the addition of water-balance equation and numeric simulation as well. The evolution of temperatures at soil ground and foliage levels was evaluated by the model, using the inputs of drainage water and the temperature of the roof. The parametric study of Ouldboukhitine, et al., (2011) then compared the temperature differences in between the inner and outer surfaces of the building that was significantly of about 30°C. Consequently, the effects of mass transfer were also productive in improving the performance of the building along with the reduction in the errors of the model used.

In the same manner, the study of Djedjig, et al., (2012), has described the significance of green roofs in terms of the transfer of heat and mass. The overall performance of the green roofs in improving the thermal conditions of the buildings with respect to the modelling and coupling of water balance of the substrates used in the designing of the green roofs and the associated content of ET was assessed. It is noted that the impacts of the variations in the water balance are significant on the ET intensity and the substrate. Accordingly, the model used in the study that is based on hydrologic and thermal aspects entails the effects of wind speed associated with the foliage used in the green roofs. It was carried out by calculating the resistance in the transfer of heat and mass within the canopy of leaves. Djedjig, et al., (2012), has studied the green roof's significance in this regard at the "University of La Rochelle" by comparing the experimental results with the numeric data. Consequently, by using the parametric studies describing the behaviour of green roof, and modelled balances of energy, the mechanism of transfer of heat and mass was analysed. As a result, there was a notable difference of 25 °C in the surface temperature, entailing the coupling effects of ET content in the enhancement of the green roof's performance.

2.4 Biodiversity

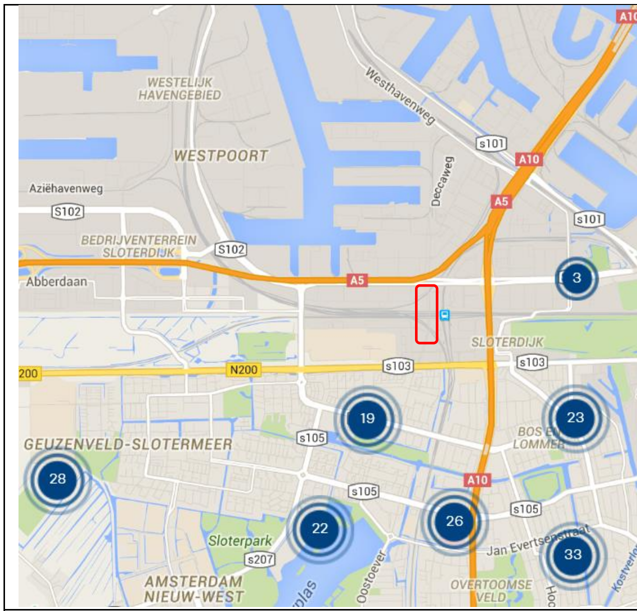
Green rooftops give a chance to creature and plant living spaces to exist in urban territories, the greater part of which have been lost through loss of green space in development and urban improvement. They can give nourishment, settling open doors and resting places for species, for example, insects, ants, bugs, flies, honey bees, creepy crawlies, leafhoppers, uncommon plants, settling winged animals (minimal ringed plover, northern lapwing and skylark) and lichens (Matteson, K.C. and Langellotto, G.A., 2010). Be that as it may, reasonably they can just give natural surroundings to species which can adjust to and create survival methodologies for compelling neighbourhood conditions, and which are sufficiently portable to achieve living spaces on rooftops, for example, A study was conducted in Switzerland presented the importance of green roofs to honey bees. The study presented that green roofs which contained a mix of wildflowers and sedums plants were visited by honey bees during the foraging season [April to September], while green roofs that contained sedums plants were visited by bumblebees only during June to July, when sedum species had flower. This study recorded 77 different bee species, where 54 of these species occur in the UK. 21 out of 54 species were documented during the long-term of studding green roofs and invertebrate biodiversity in London. (Brenneisen S et al, 2005)

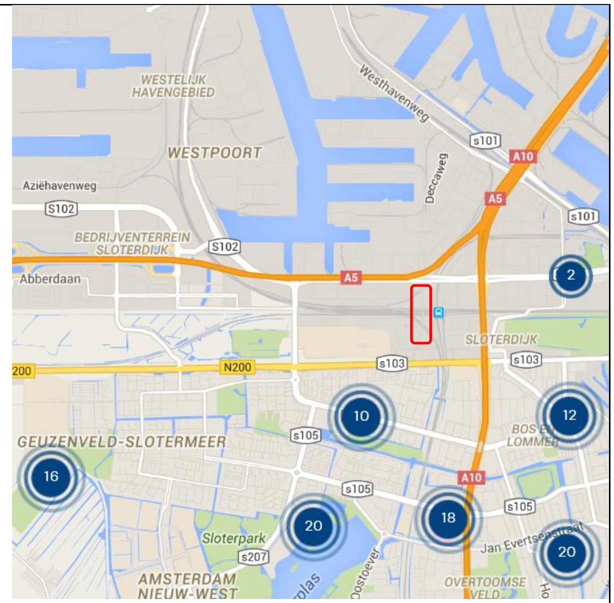
bees gather pollen to feed larval and the adults feed on flowers nectar. some species collect food from particular species of flower (monolectic), while other bee species feed on related flowers (oligolectic). labiates and leguminous flowers are good source of nectar for some species of bumblebees and Long-tongued bees. Moreover, daisy family are source of nectar for short-tongued species. Other short tongues species have a tendency to visit flowers with short corolla such as asteraceae, rosaceae, and apiaceae. Green roofs with wide range of vegetation and wildflowers, are impeccable for many foraging bees. Biodiverse green roof are suitable sites for foraging from early spring to late summer and can provide a sustainable habitat for honey bees in urban environments. Mosses and water which is available on many green roofs is considered as a drinking source for bees. (Brenneisen S et al, 2005)

2.5 social benefit

Reduced crime level is one of the benefits that Orlyplein green roof is claimed to have added to the area. This has been reported in the local newspaper (Het Parool-article entitled: Amsterdam wint twee prijzen voor natuur op straat link). This was also supported by some information gathered from police department in Amsterdam (Politie, Amsterdam, Regionaal Service Centrum) (appendix 1) which indicates that the crime level decreased in the project area starting from the operation year and continued until the same year that the Orlyplein green roof was operated in 2014. Figures 7 – 10.

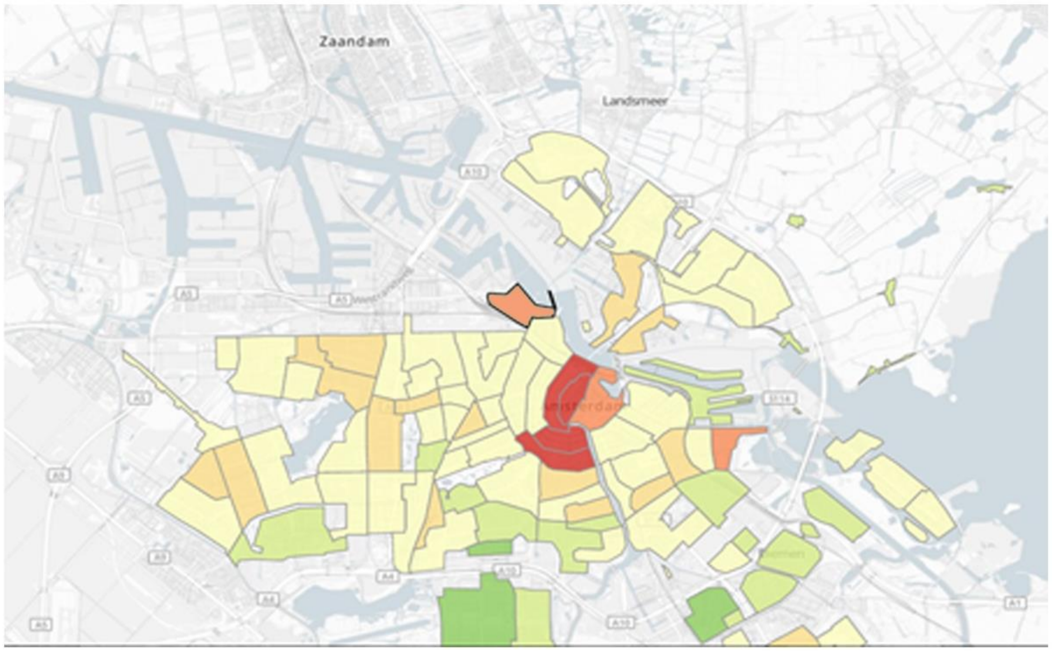
Alta Bates Medical Center in Berkeley CA presented a case study that, focused on the benefits of a green roof on patients and staff. Part of the study methodology was based on interviews investigating type of activities held in in the green roof. Responses were falling in the theme of relaxing, talking, eating, strolling, and "outdoor therapy." (Ward Thompson, Roe and Aspinall et al. 2012) A study by Frances Kuo highlighted that well managed green spaces can reduce stress, drop recovery time and reduce crime levels. These benefits can be provided by green roofs. Another study by Sullivan reported that generally crime levels were expressively lower in residence area near green spaces, and reported domestic violence ranks were lower in managed greener areas, (Pataki, Carreiro and Cherrier et al. 2011), Finally, a statistics presented in a study that started in 2005 by UK Crime Scene Investigator (CSI, 2008) mentioned that the Landscape quality improvements carried at 57-hect. industrial estate in Lang Thwaite Grange, Wakefield, West Yorkshire helped in creating 200 new jobs and a decrease in the Crime level by 70% in 12 months. (Ward Thompson, Roe and Aspinall et al. 2012)

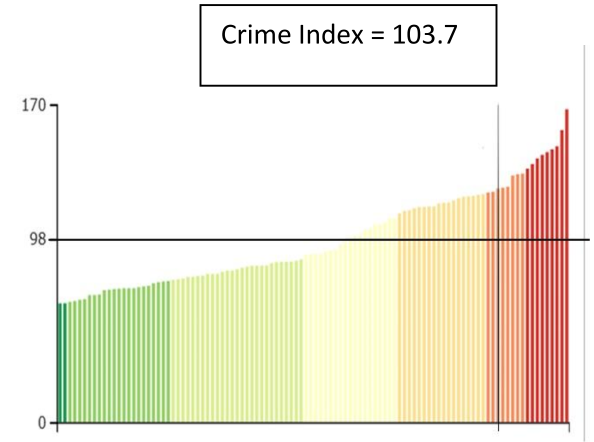




The crime level value of Orlyplein - 2014 in areas that 5 km away from the study area Source: Politie | Amsterdam | Regionaal Service Centrum. The study area framed with red	The crime level value of Orlyplein - 2015 in areas that 5 km away from the study area Source: Politie | Amsterdam | Regionaal Service Centrum. The study area framed with red

Figure 7: The crime level value of Orlyplein – 2014 & 2015 in areas that 5 km away from the study area. The comprising presenting a reduction of crime level in 2015





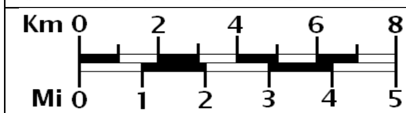
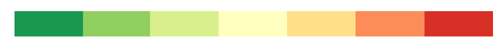


Figure 8: The crime Index Value of Orlyplein of 2012 (black bordered area in the map)

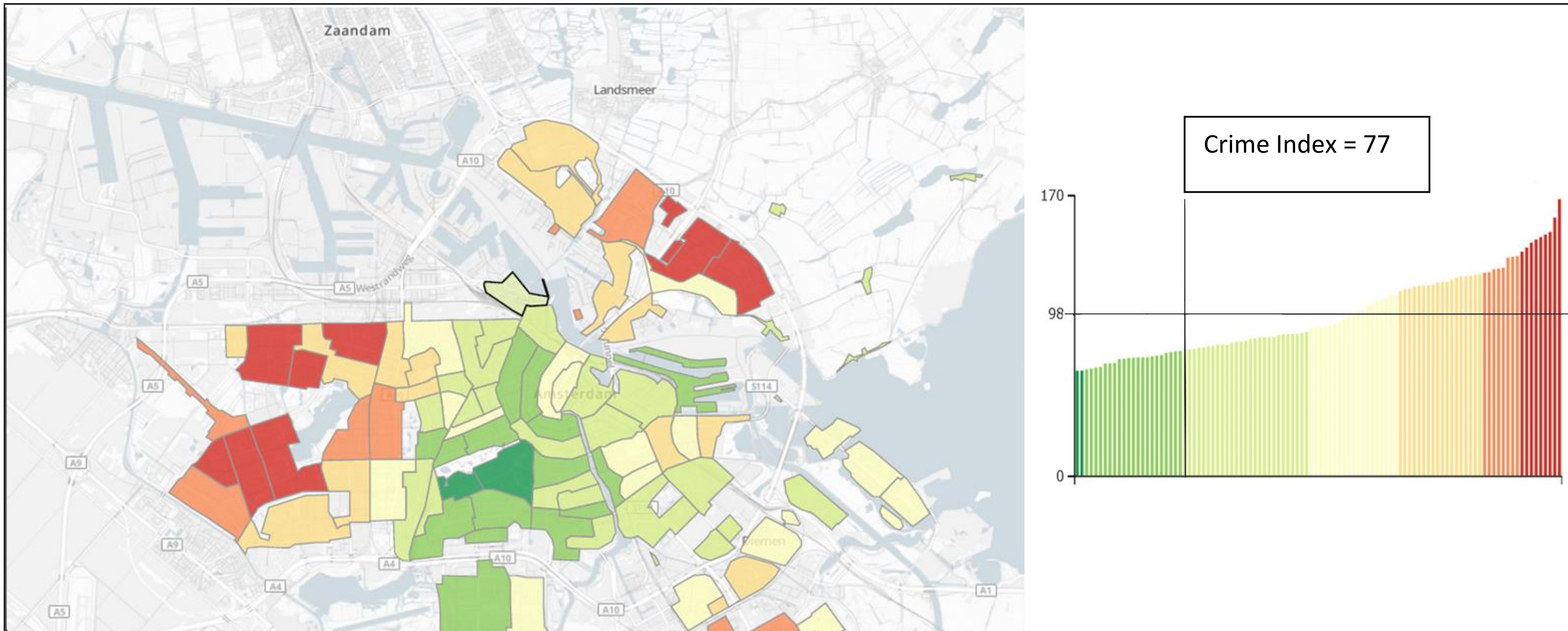


Safer secure

less

Source: Politie | Amsterdam | Regionaal Service Centrum

Date:



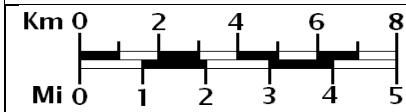


Figure 9: The crime Index Value of Orlyplein of 2015 (black bordered area in the map)

Safer less secure

Source: Politie | Amsterdam | Regionaal Service Centrum

Date:

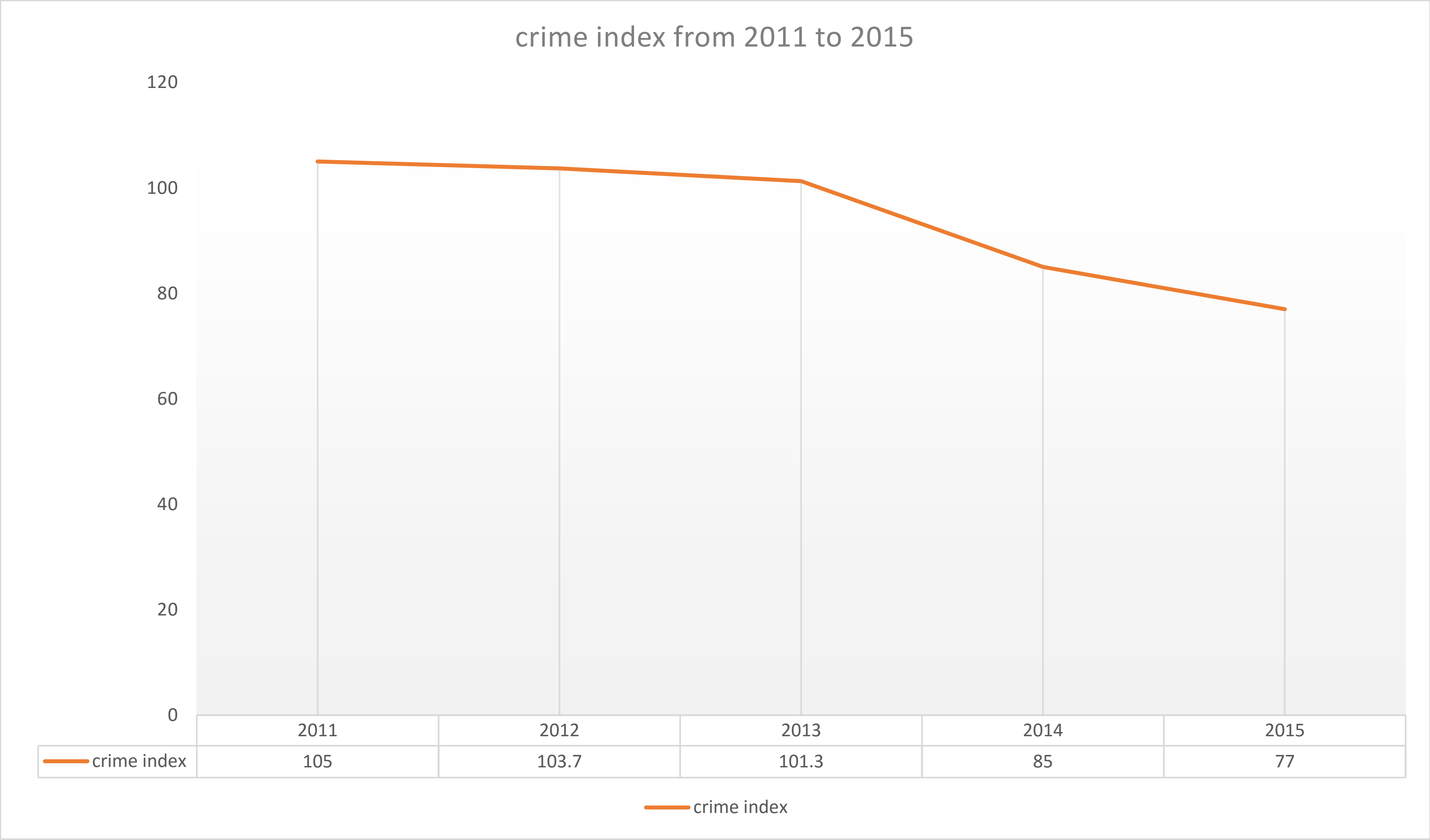


Figure 10: a graph presenting the crime index from 2011 to 2015, as it can be seen, that the crime level start to decrease from 2013, the year which this green park project was started

2.6 Potential roadblocks preventing Rooftop Garden implementation

There are a few challenges that need to be factored in while taking the implementation of rooftop garden into consideration.

2.6.1 Costs

One main impediment with rooftop gardens is the initial cost. Intensive gardens will entail a higher expense initially, since they would necessitate greater maintenance as well as a higher range of vegetation, while extensive roofs will be the most convenient to install. However, (Francis and Lorimer 2011) opine that with the improvement in installing and producing green roof components, the higher will be the cost savings in the long term, leading to quality discounts and heightened customer savings.

2.6.2 Maintenance

The maintenance of a roof is predicated on its intensiveness. While the plants can be grown directly on the roof, (Williams, N.S et al, 2010) point out that they can also be grown beforehand at ground level before being put on the roof. This will contribute greatly towards the two other issues - maintenance and accessibility. Even in case where the plants themselves get planted on the roof, they will need the transportation of substrate, possibly leading to weight concerns as well as logistical issues. The heavier the load, the more the need for other potentially expensive loading methods, which can also cause health problems. More intensive roofs would necessitate a heightened irrigation to retain the health of the plants healthy. Alternately, an automated sort of irrigation can be initiated which will predicate on its economic as well as logistical feasibility. (Williams, N.S et al, 2010)

2.6.3 Pollution

According to (Francis and Lorimer 2011), although fertilisation facilitates biomass accumulation, it can boost the plants' susceptibility to drought. What was intended to initially promote the growth of plants could actually deter them. Similarly, fertilizers can invade the water system and lead to inadequate water quality and potential algal blooms down the water system, owing to the harmful contents in the form of phosphorous and nitrogen, which can damage plants and fishes (Francis and Lorimer 2011) As plants begin to absorb the pollution, they can get released on leaf surfaces, which could then land up in the storm water system, thus resulting in water pollution. Thus, it is crucial that in cases of intensive green roofs, there is a close monitoring of the usage of irrigation and fertilizers irrigation, to ensure that the water escaping from the roof remains unpolluted.

2.7 Benefit of green roof modelling

In summery green are considered as multi benefit systems when it comes to mitigate environmental problems. This natural system is controlled by many variables such as evapotranspiration, precipitation, substrate quality, vegetation type, wind speed and temperature. In this study a particular focus is made on evapotranspiration and precipitation, which are considered to be the key factors in green roof modelling when it comes to water retention and preserving vegetation. (Czemiel Berndtsson 2010)

In order for green roof system to perform to the optimum level. It should be studied and investigated through research and experiments. the observational records that are used in many studies, are less than two years' duration. This is considered as a barrier when it comes to understand and draw an understandable conclusion about green roofs performance. Stovin et al. (2012) study highlighted that it is important to use modelling as a tool in order to understand and develop green roof systems.

Green roof modelling helps in predicting the future effect of the system and its elements by performing experiments with different scenarios in a short time compared to laboratory experiments. Additionally, these experiments help in planning the future studies and which parts to focus on as its effect and priority. The knowledge gained from understanding and developing the model can be transpired and implemented in other model (Anon. 2013)

Feeding the model with present knowledge and evaluating the outcomes can help in predicting the effect in future. This can carry some error percentage but it provides the basic effect on future. Models generates better understanding on how any elements and system factors work, this can contribute in bringing system to work in the optimum level through developing new scenarios, process and techniques and to produce new materials and practices. (Anon. 2013)

The next chapters are presenting a stages of developing a previous model that was created by van de Werken on Orlyplein green park system. The model investigated two main variables, precipitation and evapotranspiration, in relation to preserving water and storm water retention.

Chapter 3 methodology

3.1 MODEL MODIFICATION-EARLY STAGES METHODOLOGICAL IMPROVEMENTS

3.1.1 ABOUT THE PREVIOUS ORLYPLEIN GREEN ROOF MODEL

The previous Orlyplein green roof model which this project is based on, was provided to the author by her supervisor with a view to studying the model, making improvements then using it to investigate the best way of managing water on the Orlyplein site The Microsoft Excel-based model had been produced by Laurens van de Werken as part of an internship at Permavoid Ltd. It had previously been used by Voeten et al (2016) in a modified form but it was the original, unmodified version that was supplied.

As mentioned previously the model uses the general water balance equation

$$ET = P - Q\ (+/- \Delta S) \qquad (1)$$

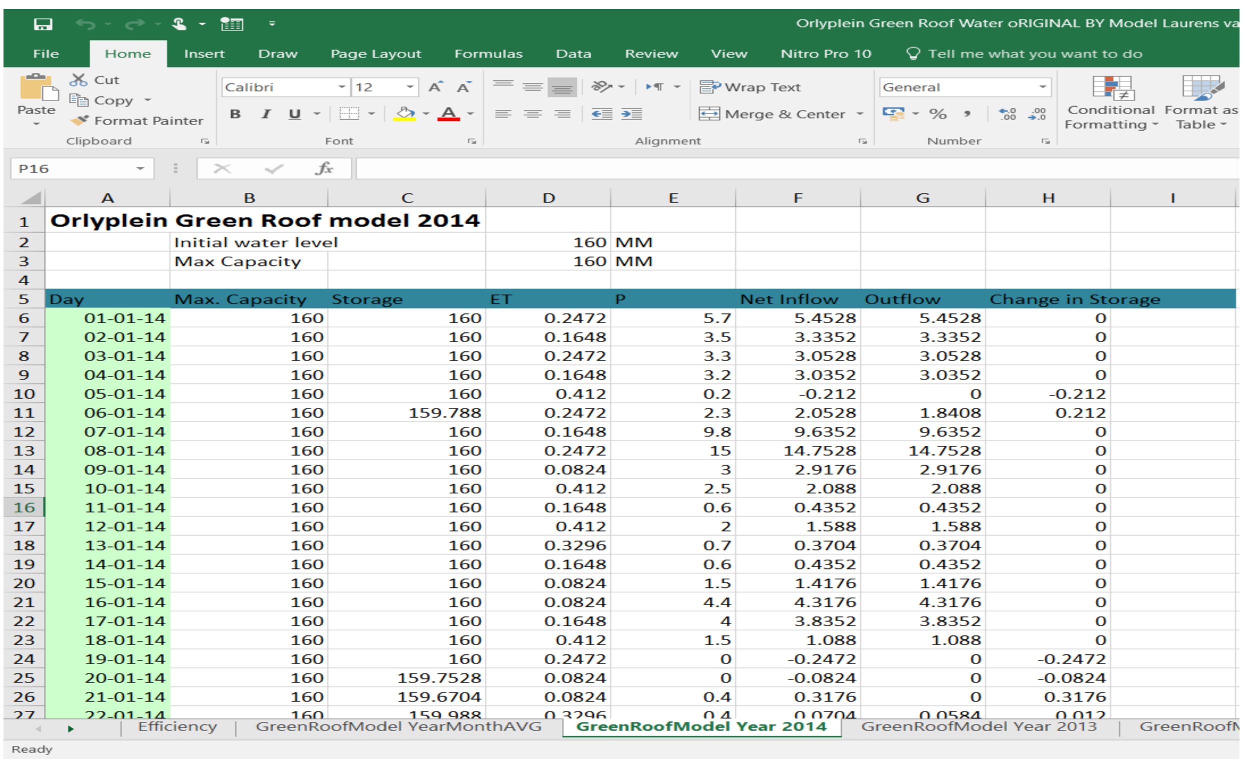
Where:

- ET is the evapotranspiration,
- P is the precipitation,
- Q is the amount of discharge (runoff) and,
- ΔS the change in water storage

Both represented variables, evapotranspiration and precipitation data were said (Alan Newman Pers Com 2016) to have been sourced from the KNMI weather station De Bilt and Amsterdam. The distance between the green roof that is used as a case study in this project and De Bilt station is around 39.8 Km. according to the KNMI, the closest observation station for the area of the Orlyplein green roof is airport Schiphol which is located 9 Km away from the study area (figure 11 & 12). It was assumed that the evapotranspiration was taken to be representative for Orlyplein green roof, which was calculated by the KNMI using Makkink method (Hiemstra P. and Sluiter R., 2011). A general view of the model is presented in (Screen dump 1). The model in Microsoft Excel, presenting the maximum capacity, storage, evapotranspiration, precipitation, net inflow, outflow and change in drainage. The spreadsheet also contained low time resolution models based on annual and monthly data but these were not considered further.

Figure 11: locations of metrological stations in Netherlands (source KNMI)

Figure 12: Arial photography of the DE BIL T met. Station which was approached by Laurens van de Werken and the SCHIPHOL met. Station that is closer to case study



	A	B	C	D	E	F	G	H
1	**Orlyplein Green Roof model 2014**							
2		Initial water level		160	MM			
3		Max Capacity		160	MM			
4								
5	Day	Max. Capacity	Storage	ET	P	Net Inflow	Outflow	Change in Storage
6	01-01-14	160	160	0.2472	5.7	5.4528	5.4528	0
7	02-01-14	160	160	0.1648	3.5	3.3352	3.3352	0
8	03-01-14	160	160	0.2472	3.3	3.0528	3.0528	0
9	04-01-14	160	160	0.1648	3.2	3.0352	3.0352	0
10	05-01-14	160	160	0.412	0.2	-0.212	0	-0.212
11	06-01-14	160	159.788	0.2472	2.3	2.0528	1.8408	0.212
12	07-01-14	160	160	0.1648	9.8	9.6352	9.6352	0
13	08-01-14	160	160	0.2472	15	14.7528	14.7528	0
14	09-01-14	160	160	0.0824	3	2.9176	2.9176	0
15	10-01-14	160	160	0.412	2.5	2.088	2.088	0
16	11-01-14	160	160	0.1648	0.6	0.4352	0.4352	0
17	12-01-14	160	160	0.412	2	1.588	1.588	0
18	13-01-14	160	160	0.3296	0.7	0.3704	0.3704	0
19	14-01-14	160	160	0.1648	0.6	0.4352	0.4352	0
20	15-01-14	160	160	0.0824	1.5	1.4176	1.4176	0
21	16-01-14	160	160	0.0824	4.4	4.3176	4.3176	0
22	17-01-14	160	160	0.1648	4	3.8352	3.8352	0
23	18-01-14	160	160	0.412	1.5	1.088	1.088	0
24	19-01-14	160	160	0.2472	0	-0.2472	0	-0.2472
25	20-01-14	160	159.7528	0.0824	0	-0.0824	0	-0.0824
26	21-01-14	160	159.6704	0.0824	0.4	0.3176	0	0.3176
27	22-01-14	160	159.988	0.3296	0.4	0.0704	0.0584	0.012

Screen dump 1: A general overview of Laurens van de Werken model

The model provides the total amount of runoff from the green roof, based on daily precipitation and evapotranspiration rates. The Orlyplein green roof consisted of 82.4% vegetation (= 8000 m^2)

and 17.6% paved surface. The model's original Author had readjusted the evapotranspiration data assuming that it occurred only in the vegetative areas of the roof park as shown in figure 4

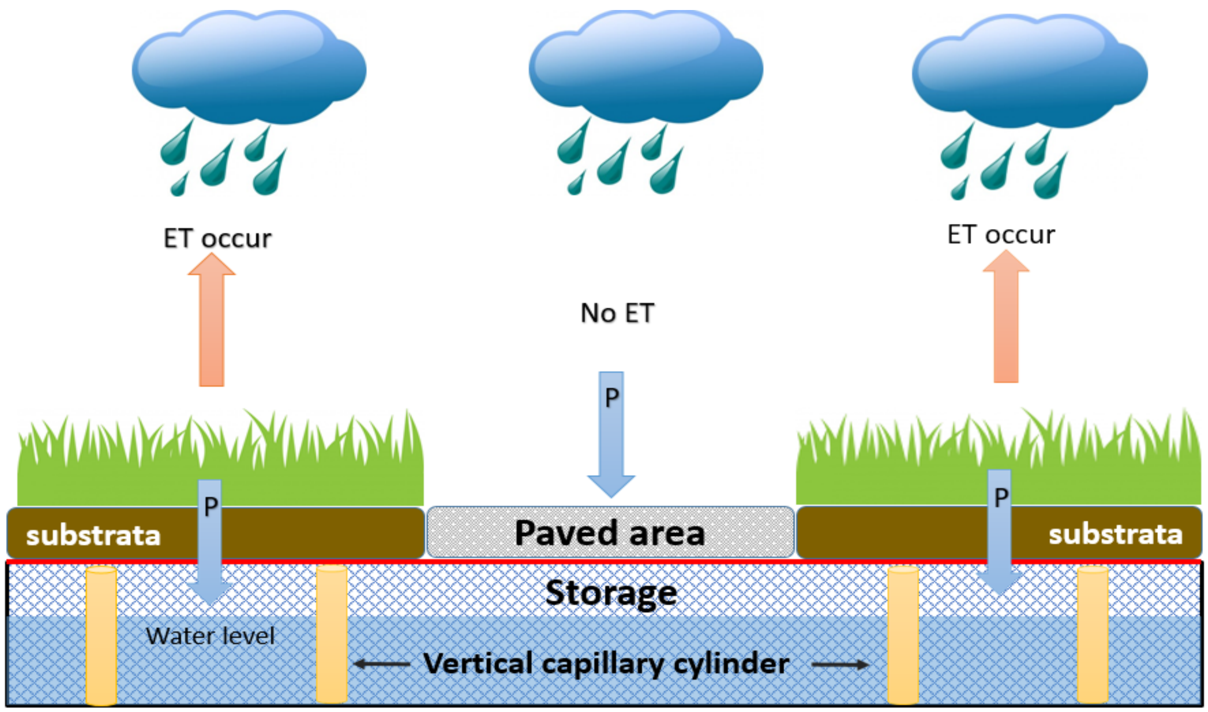


Figure 13: Precipitation infiltrate the paved and the substrata but evapotranspiration occurs exclusively to the vegetative areas.

By using the general water balance equation, the model was designed and cells were connected as following:

- Max capacity = 160 mm
- Storage which depend on maximum capacity and net inflow
- ET & P as "numerical values"
- Net inflow = P –ET
- Outflow = if storage + net inflow < max capacity = 0 otherwise, it is storage – max capacity + net inflow
- Change in storage = net inflow – outflow

The time scale that was presented by van de Werken (Alan Newman Pers Com 2016) was from 2000 to 2014. This data thus simulates the behavior of green roof as if it was built 15 years ago. Until the very late stages of this work it was assumed that the ET data provided by van de Werken was correct. This has now been corrected. In addition, it was found that data was available from a much closer weather statin than used by van de Werken. This has been incorporated into the final model. This however does not detract from the value of the modeling exercise for the following reasons:

1) A wide range of yearly ET data is available and all of the data presented by van de Werken are reasonable ET values.

2) The main aim of this exercise was to develop the very basic and inflexible model produced by van de Werken. The limitations of van de Werken approach were incorporated in very late stages of the model which is now well on the way to become both complete and flexible to transfer to other green roofs.

3.2 Communication and requesting of additional data

Before proceeding to explain the updates that have been added to the model and methodology, it is important to address the communication issues (particularly between UK and the Netherlands), which were launched in the project time line from mid-June to early August of 2016. The early communications were related to the social impact of roof parks on the surrounding environment. It was suggested suggested (Alan Newman Pers Com 2016) that there was evidence (anecdotal) that the Orlyplein green roof had produced an effect in reducing crime levels in the area surrounding the project. Although not directly related to the modeling this was considered important background information and thus a first step was to attempt to communicate with the police in Amsterdam (Politie, Amsterdam, Regionaal Service Centrum) to get some data about the crime level around the project area from 2013 to 2015 (See Apendix 1).

Preliminary information was obtained which has been presented in the introduction, but to confirm theis information. Further to this a Mr. T. Boxem (Amsterdam Rainproof) was also contacted to get more details on the this subject but also to obtain further details on the characteristics of plants and vegetated area in the project (see Appendix 1). an article from the local newspaper was sent, and it supported the findings from the police station Statistics.

Additionally, communication was initiated with Mr. J Voeten (Permavoid Ltd) to obtain some information about substrate particle analysis (which was added later to the model) and also to provide some additional information about the physical properties of the substrate used in the system.

On another important matter, the issue with the misunderstanding of metrological data (which is discussed in section 3.1) needs to be addressed . Communications with the Dutch Weather Service (KNMI) reveled a problem which was eventually solved in relation to van de Werken’s use of weather data. The KNMI weather station was communicated initially to obtain information about the daily level of rainfall and evaporation to update the model with 2015 data sheet. It should be noted that these communications had a positive impact on understanding van de Werken model and which helped in discovering the errors such as van de Werken’s missinterpretation of the meaning of a (-1) value in the precipitation data (Appendix 2) as supplied by KNMI, the adjustment of ETp values, and selection of the nearest metrological station to the project.

Despite the fact that early efforts in communication were attempted responses from the meteorological center arrived late. However the researcher was able to update data using computer modeling and minimize the error as much as it can be done in the time limit of the project as is detailed later in this chapter.

3.3 Modification and Early Stage Improvments

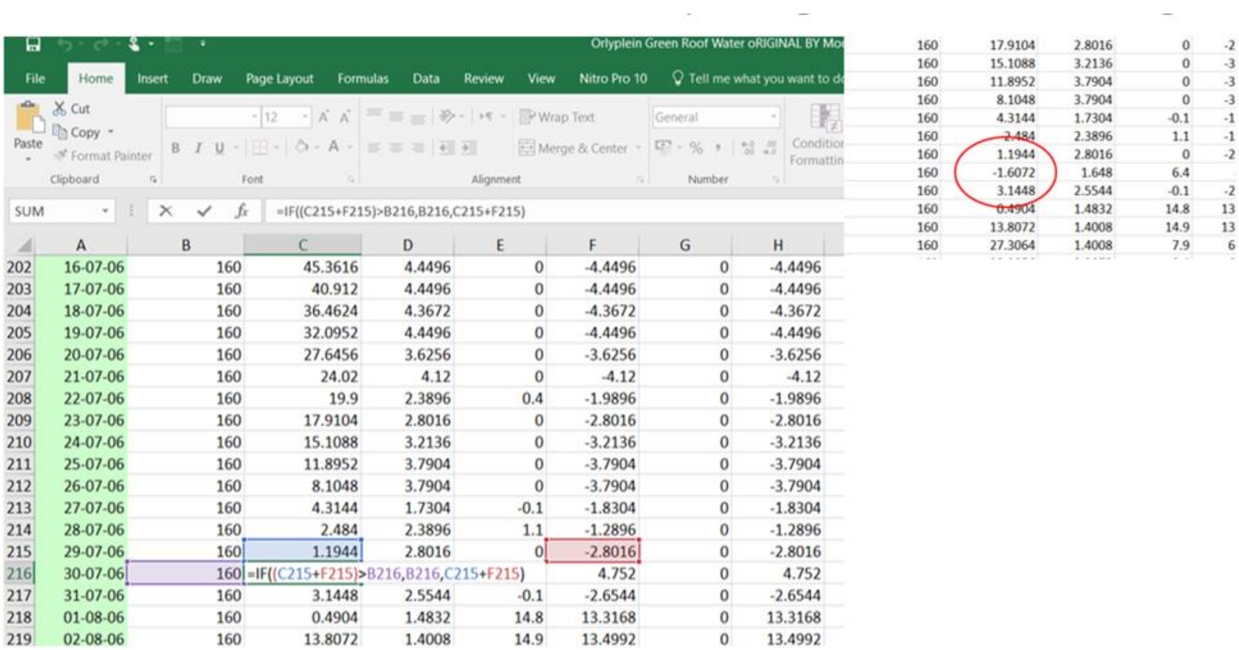
3.3.1 Preliminary Logical Modification- Water Content Below Zero

In order to build different scenarios and perform experiments using the model, it was an essential step to understand the model with all its details. This was made difficult because little explanation of how the model operated was built into the spreadsheet and much time was taken up in trying to understand the logic. By observing the model, negative values were observed in the storage values.

This was due to the fact that van de Werken had essentially allowed water to evapotranspire from a roof which was devoid of water. These negative values were thus unrealistic because the lowest value that GRS can hold is zero water, so the values in GRS should be ranging from 160 mm to 0mm.The logical formula that was used to calculate the green roof storage capacity during rain events within a period of time was modified using nested" If" function to replace negative storage values by zero values.

The IF function in Excel can be nested, when records have multiple conditions to meet. The FALSE value is being replaced by another If function to make a further test. (screen dumps 2&3)

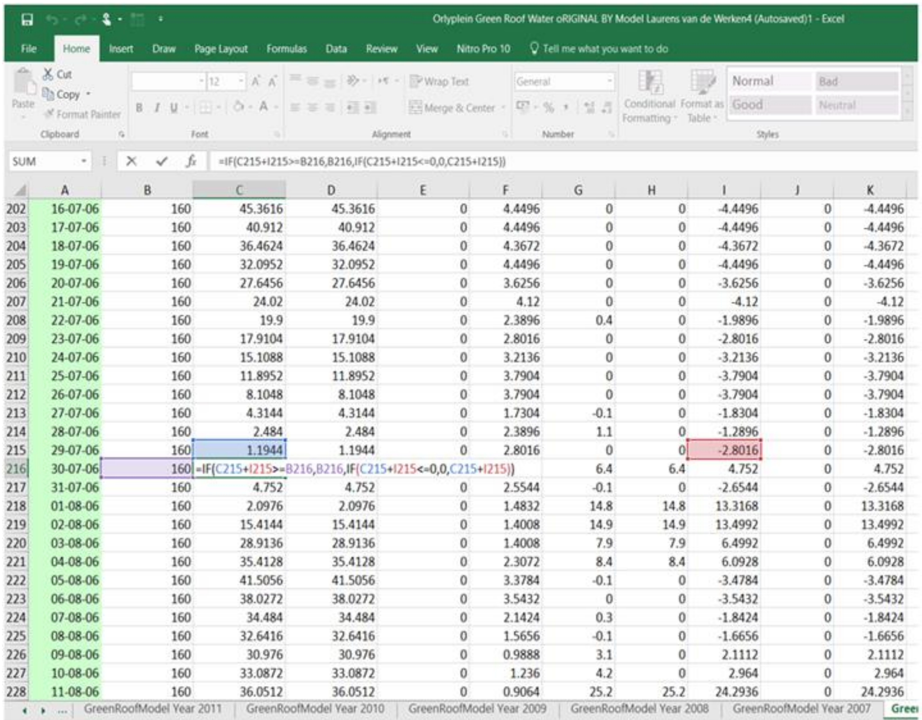
The logic in the formula bar was : if storage +net flow was > or = to the maximum capacity, the value that should appear in the storage is 160, and if storage + net flow was < or = to 0 then the value that should appear in the storage is 0. otherwise it should be the sum of storage and net flow which can be any number between 160 and 0. screen dumps 2&3 presents the change in formulas and the storage values.



	A	B	C	D	E	F	G	H
202	16-07-06	160	45.3616	4.4496	0	-4.4496	0	-4.4496
203	17-07-06	160	40.912	4.4496	0	-4.4496	0	-4.4496
204	18-07-06	160	36.4624	4.3672	0	-4.3672	0	-4.3672
205	19-07-06	160	32.0952	4.4496	0	-4.4496	0	-4.4496
206	20-07-06	160	27.6456	3.6256	0	-3.6256	0	-3.6256
207	21-07-06	160	24.02	4.12	0	-4.12	0	-4.12
208	22-07-06	160	19.9	2.3896	0.4	-1.9896	0	-1.9896
209	23-07-06	160	17.9104	2.8016	0	-2.8016	0	-2.8016
210	24-07-06	160	15.1088	3.2136	0	-3.2136	0	-3.2136
211	25-07-06	160	11.8952	3.7904	0	-3.7904	0	-3.7904
212	26-07-06	160	8.1048	3.7904	0	-3.7904	0	-3.7904
213	27-07-06	160	4.3144	1.7304	-0.1	-1.8304	0	-1.8304
214	28-07-06	160	2.484	2.3896	1.1	-1.2896	0	-1.2896
215	29-07-06	160	1.1944	2.8016	0	-2.8016	0	-2.8016
216	30-07-06	160	=IF((C215+F215)>B216,B216,C215+F215)			4.752	0	4.752
217	31-07-06	160	3.1448	2.5544	-0.1	-2.6544	0	-2.6544
218	01-08-06	160	0.4904	1.4832	14.8	13.3168	0	13.3168
219	02-08-06	160	13.8072	1.4008	14.9	13.4992	0	13.4992

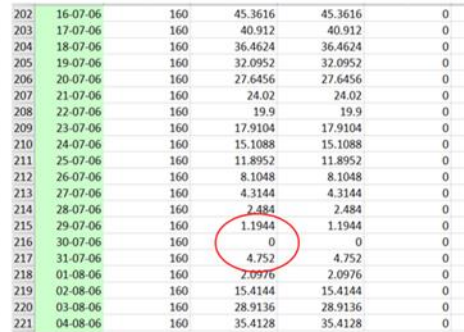
160	17.9104	2.8016	0	-2
160	15.1088	3.2136	0	-3
160	11.8952	3.7904	0	-3
160	8.1048	3.7904	0	-3
160	4.3144	1.7304	-0.1	-1
160	2.484	2.3896	1.1	-1
160	1.1944	2.8016	0	-2
160	-1.6072	1.648	6.4	
160	3.1448	2.5544	-0.1	-2
160	0.4904	1.4832	14.8	13
160	13.8072	1.4008	14.9	13
160	27.3064	1.4008	7.9	6

Screen dump 2: The storage records of 2003 presenting a negative value in predicting the water level in the "storage" (refer to sec. 4.1 for the resulted graph)



=IF(C215+I215>=B216,B216,IF(C215+I215<=0,0,C215+I215))

	A	B	C	D	E	F	G	H	I	J	K
202	16-07-06	160	45.3616	45.3616	0	4.4496	0	0	-4.4496	0	-4.4496
203	17-07-06	160	40.912	40.912	0	4.4496	0	0	-4.4496	0	-4.4496
204	18-07-06	160	36.4624	36.4624	0	4.3672	0	0	-4.3672	0	-4.3672
205	19-07-06	160	32.0952	32.0952	0	4.4496	0	0	-4.4496	0	-4.4496
206	20-07-06	160	27.6456	27.6456	0	3.6256	0	0	-3.6256	0	-3.6256
207	21-07-06	160	24.02	24.02	0	4.12	0	0	-4.12	0	-4.12
208	22-07-06	160	19.9	19.9	0	2.3896	0.4	0	-1.9896	0	-1.9896
209	23-07-06	160	17.9104	17.9104	0	2.8016	0	0	-2.8016	0	-2.8016
210	24-07-06	160	15.1088	15.1088	0	3.2136	0	0	-3.2136	0	-3.2136
211	25-07-06	160	11.8952	11.8952	0	3.7904	0	0	-3.7904	0	-3.7904
212	26-07-06	160	8.1048	8.1048	0	3.7904	0	0	-3.7904	0	-3.7904
213	27-07-06	160	4.3144	4.3144	0	1.7304	-0.1	0	-1.8304	0	-1.8304
214	28-07-06	160	2.484	2.484	0	2.3896	1.1	0	-1.2896	0	-1.2896
215	29-07-06	160	1.1944	1.1944	0	2.8016	0	0	-2.8016	0	-2.8016
216	30-07-06	160	=IF(C215+I215>=B216,B216,IF(C215+I215<=0,0,C215+I215))				6.4	6.4	4.752	0	4.752
217	31-07-06	160	4.752	4.752	0	2.5544	-0.1	0	-2.6544	0	-2.6544
218	01-08-06	160	2.0976	2.0976	0	1.4832	14.8	14.8	13.3168	0	13.3168
219	02-08-06	160	15.4144	15.4144	0	1.4008	14.9	14.9	13.4992	0	13.4992
220	03-08-06	160	28.9136	28.9136	0	1.4008	7.9	7.9	6.4992	0	6.4992
221	04-08-06	160	35.4128	35.4128	0	2.3072	8.4	8.4	6.0928	0	6.0928
222	05-08-06	160	41.5056	41.5056	0	3.3784	-0.1	0	-3.4784	0	-3.4784
223	06-08-06	160	38.0272	38.0272	0	3.5432	0	0	-3.5432	0	-3.5432
224	07-08-06	160	34.484	34.484	0	2.1424	0.3	0	-1.8424	0	-1.8424
225	08-08-06	160	32.6416	32.6416	0	1.5656	-0.1	0	-1.6656	0	-1.6656
226	09-08-06	160	30.976	30.976	0	0.9888	3.1	0	2.1112	0	2.1112
227	10-08-06	160	33.0872	33.0872	0	1.236	4.2	0	2.964	0	2.964
228	11-08-06	160	36.0512	36.0512	0	0.9064	25.2	25.2	24.2936	0	24.2936



202	16-07-06	160	45.3616	45.3616	0
203	17-07-06	160	40.912	40.912	0
204	18-07-06	160	36.4624	36.4624	0
205	19-07-06	160	32.0952	32.0952	0
206	20-07-06	160	27.6456	27.6456	0
207	21-07-06	160	24.02	24.02	0
208	22-07-06	160	19.9	19.9	0
209	23-07-06	160	17.9104	17.9104	0
210	24-07-06	160	15.1088	15.1088	0
211	25-07-06	160	11.8952	11.8952	0
212	26-07-06	160	8.1048	8.1048	0
213	27-07-06	160	4.3144	4.3144	0
214	28-07-06	160	2.484	2.484	0
215	29-07-06	160	1.1944	1.1944	0
216	30-07-06	160	0	0	0
217	31-07-06	160	4.752	4.752	0
218	01-08-06	160	2.0976	2.0976	0
219	02-08-06	160	15.4144	15.4144	0
220	03-08-06	160	28.9136	28.9136	0
221	04-08-06	160	35.4128	35.4128	0

Screen dump 3: After formula modification, the storage records of 2003 presenting a note (0) value in predicting the water level in the "storage" (refer to sec. 4.1 for the resulted graph)

3.4 Improvements to the Model's Flexibility

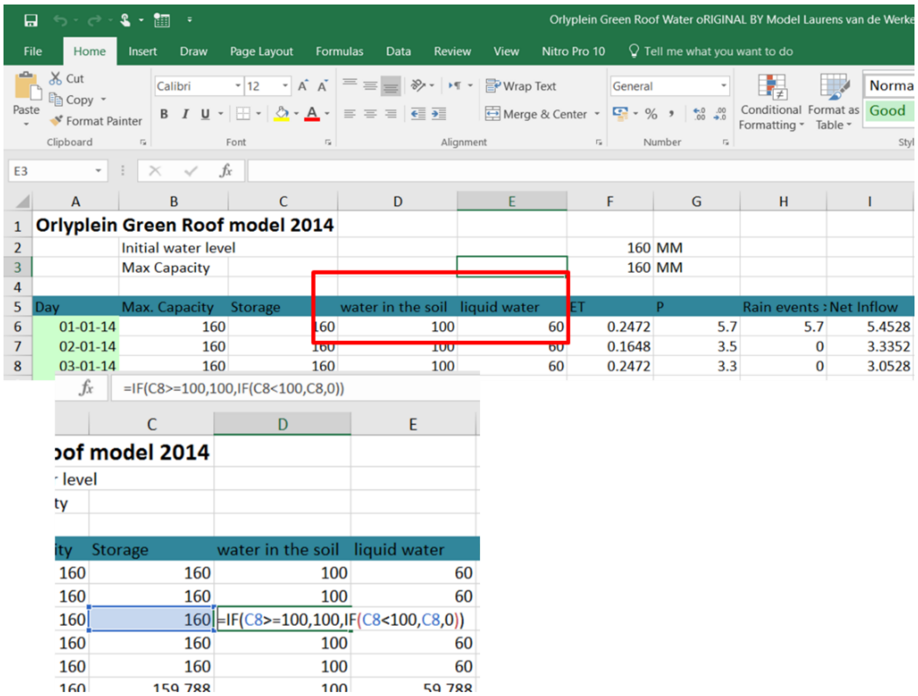
3.4.1 Dividing the Stored Water into Realistic Compartments

One of the desired targets was to study the effect of changing the two variables P and ET on the storage values and to study the performance of the model in response to various water management decisions. One limitation in flexibility of the model was that whist the "storage" is consisting of two different systems they were are represented a single (combined) value in the van de Werken model. Green roof storage in this system consists of storage in the substrate that is natural, contain vegetation and affected by different levels of temperatures, wind speed, precipitation ad evapotranspiration. On the other hand, the second part of the storage is the permavoid which basically there to store excess free water after it passes the first layer (and then pass it back to the substrate by capillarity).

In order to facilitate the process of building different scenarios based on changing P and ET values (dealt with later), the storage values were divided into values for water in substrate and for liquid water in the Permavoid layer as follows:

- The green roof consists of a storage unit that contain a subbase of permavoid overlaid with a mixture of fine sand with 8% organic matter acting as growing and storing medium at the same time. Because the sub-base is able to store up to 60 mm of rainfall, the storage values were divided to liquid water and water in the soil (100mm). This step can help in controlling and changing the overflow from the system.

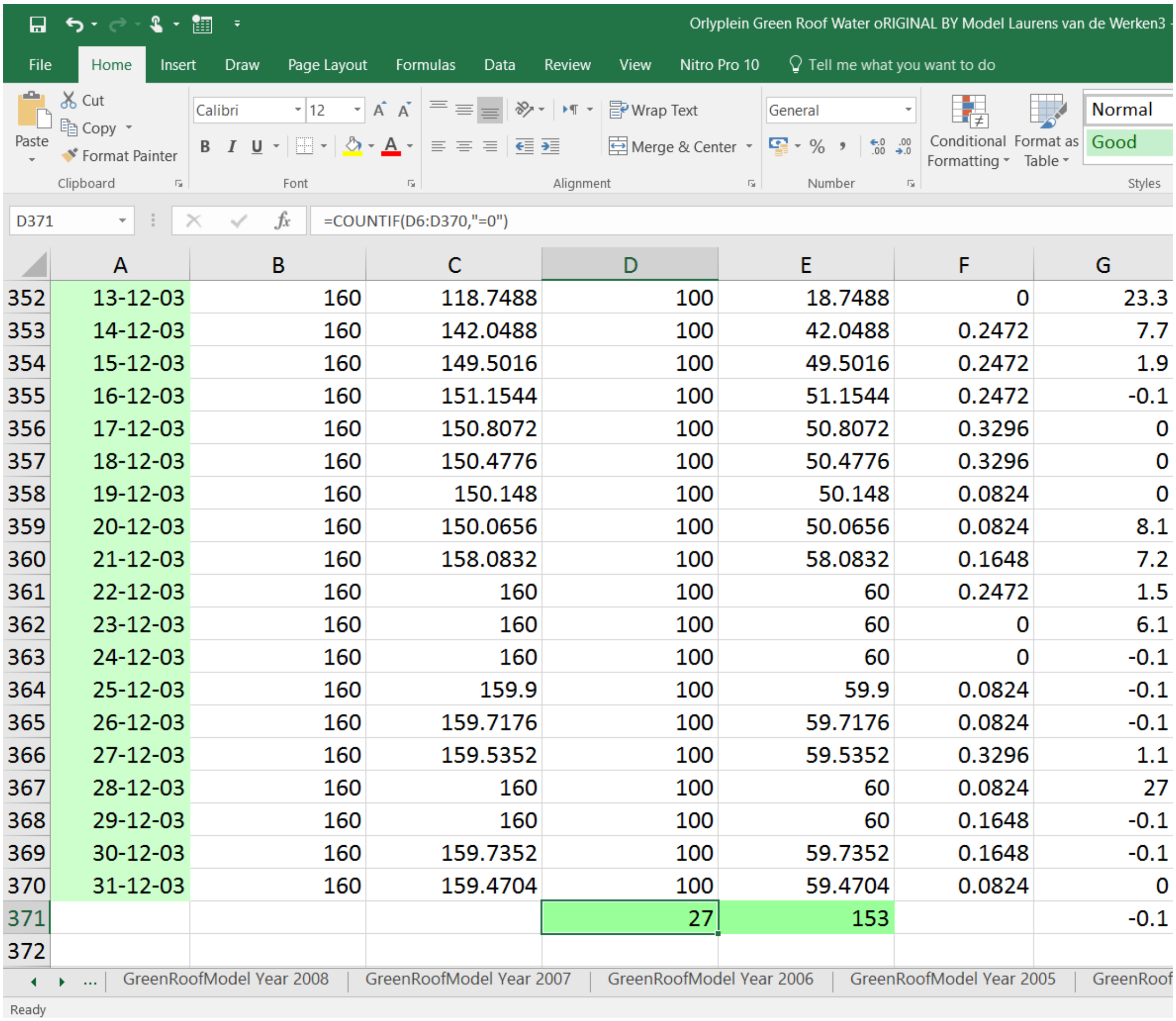
- The logical formula that was used to calculate the proper values of (water in soil) and (liquid water in storage) was modified using nested if function
- The logical formula was in the form of [if value in the storage >=100, then the value that should appear in (water in soil) record = 100. if value in storage record <100, then it is = value papered in that record, otherwise it should be = zero]
- The same logic was used with values in (liquid water). Screen dump 4 presents this modification



Screen dump 4: The "storage was divided to "water in soil" and "liquid water" in respond to the quantites mentioned in (Voeten, J.G., van de Werken, L. and Newman, A.P., 2016)

3.4.2 Keeping Track of The "Empty Storage" Days

Flowing the previous modification and to visualize the normal current situation of P and ET, and the changes of these values on the storage with its both subsystems, it was important to know the number of days that the storage was empty and which subsystems is affected most. The second step was to count how many days that the green park was without water for both layers, the substrate and the storage permavoid. This was performed by adding simple count function to all records. Screen dump5 is representing the one of the dry years (2003) of the 15 years. As a result, the substrate had no water for 27 days while the storage permavoid was empty for 153

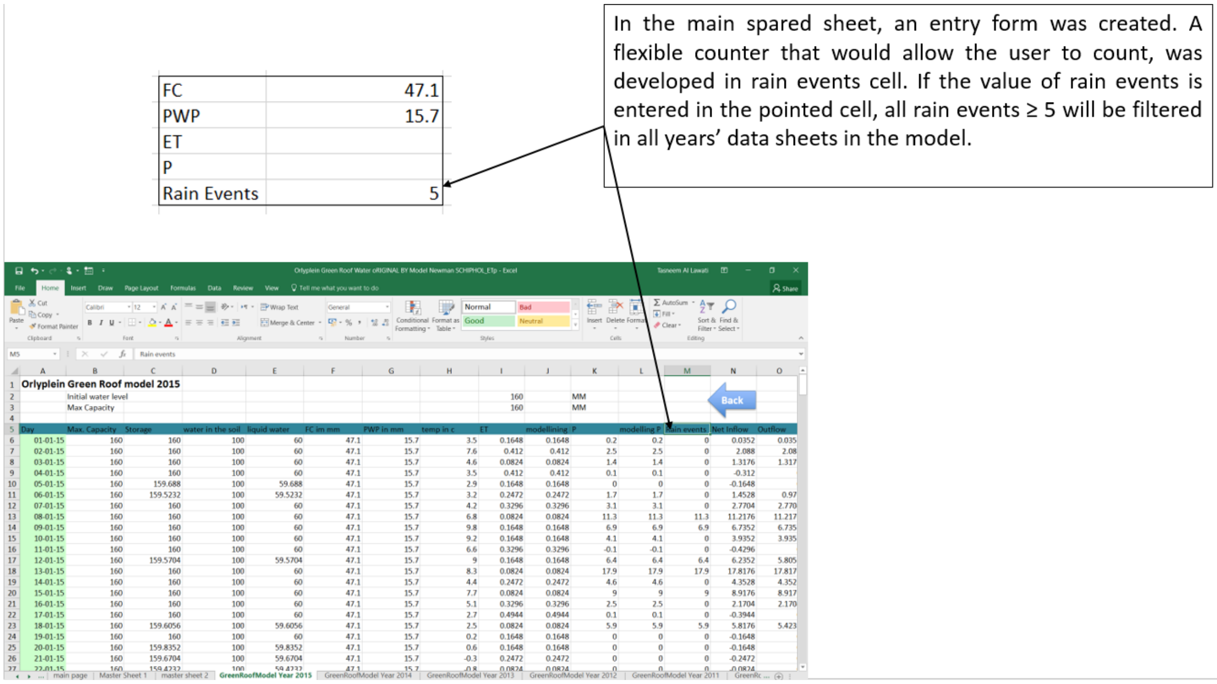


	A	B	C	D	E	F	G
352	13-12-03	160	118.7488	100	18.7488	0	23.3
353	14-12-03	160	142.0488	100	42.0488	0.2472	7.7
354	15-12-03	160	149.5016	100	49.5016	0.2472	1.9
355	16-12-03	160	151.1544	100	51.1544	0.2472	-0.1
356	17-12-03	160	150.8072	100	50.8072	0.3296	0
357	18-12-03	160	150.4776	100	50.4776	0.3296	0
358	19-12-03	160	150.148	100	50.148	0.0824	0
359	20-12-03	160	150.0656	100	50.0656	0.0824	8.1
360	21-12-03	160	158.0832	100	58.0832	0.1648	7.2
361	22-12-03	160	160	100	60	0.2472	1.5
362	23-12-03	160	160	100	60	0	6.1
363	24-12-03	160	160	100	60	0	-0.1
364	25-12-03	160	159.9	100	59.9	0.0824	-0.1
365	26-12-03	160	159.7176	100	59.7176	0.0824	-0.1
366	27-12-03	160	159.5352	100	59.5352	0.3296	1.1
367	28-12-03	160	160	100	60	0.0824	27
368	29-12-03	160	160	100	60	0.1648	-0.1
369	30-12-03	160	159.7352	100	59.7352	0.1648	-0.1
370	31-12-03	160	159.4704	100	59.4704	0.0824	0
371				27	153		-0.1
372							

Screen dump 5: Number of "Empty Storage" Days in the dry years (2003)

3.4.3 Providing a "Counter" to Identify the Number of "Rain Events "Within a Year.

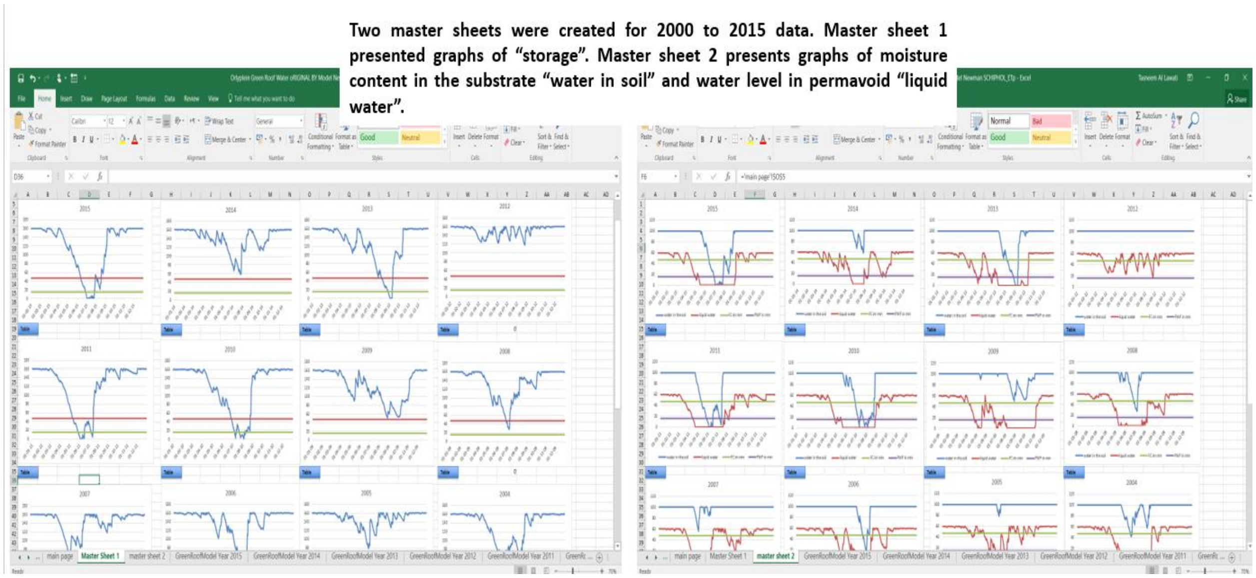
It was later intended to look at the effect of "Dumping "water from the permavoiud layer in response to predicted rainfall. This would be done as part of the water management of the system to assist in flood control. As part of this it was decided to introduce a flexible counter that would allow user to count, in each year, the number of times that water might have been "Dumped". In order to study the rain events, a logical formula was developed within the model to highlight the rain events with an amount that can be varied easily by the operator. Screen dump 6 clarify this step



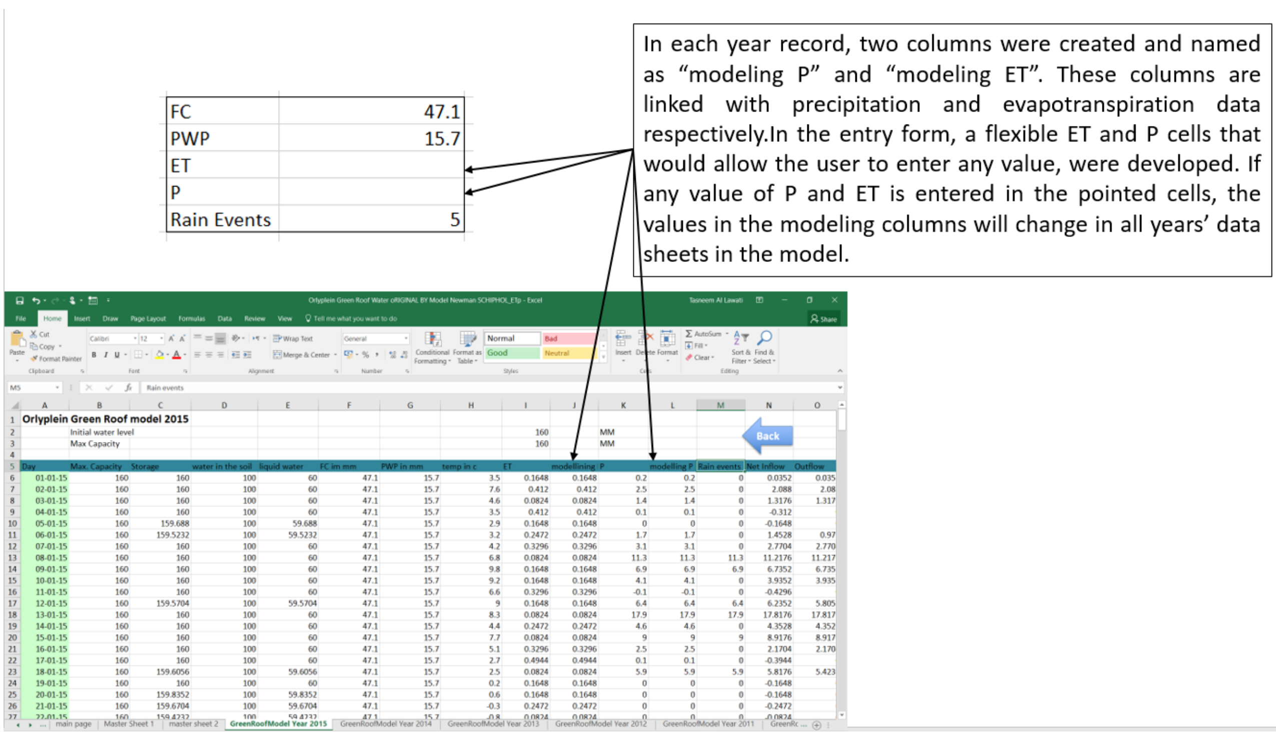
Screen dump 6: Filtering rain events by using a flexible counter that would allow user to count, in each year, by adding a logical formula (cell address>= value in entry cell)

3.4.4 Providing a "graphs" to convert the change in model to appear on graphs Within a (master sheet 1& 2)

It is hard to observe a change in a model containing daily records of 16 years, by going through, comparing and observing each record. the solution was to create a master sheet that contains 2000 to 20015 graphs. Because evapotranspiration and precipitation are the variables that have an effect on the moisture content of the green park, these graphs are linked to "modeling P" and "modeling ET" where any change in the variable will appear as a change in the graphs. This step helped in the sensitivity analysis, examining uncertainty in the rainfall data and examining the effect of modeling moisture content using actual evapotranspiration instead of potential evapotranspiration. The following screen dumps (7 to 10) will clarify the creation of graphs master sheets.



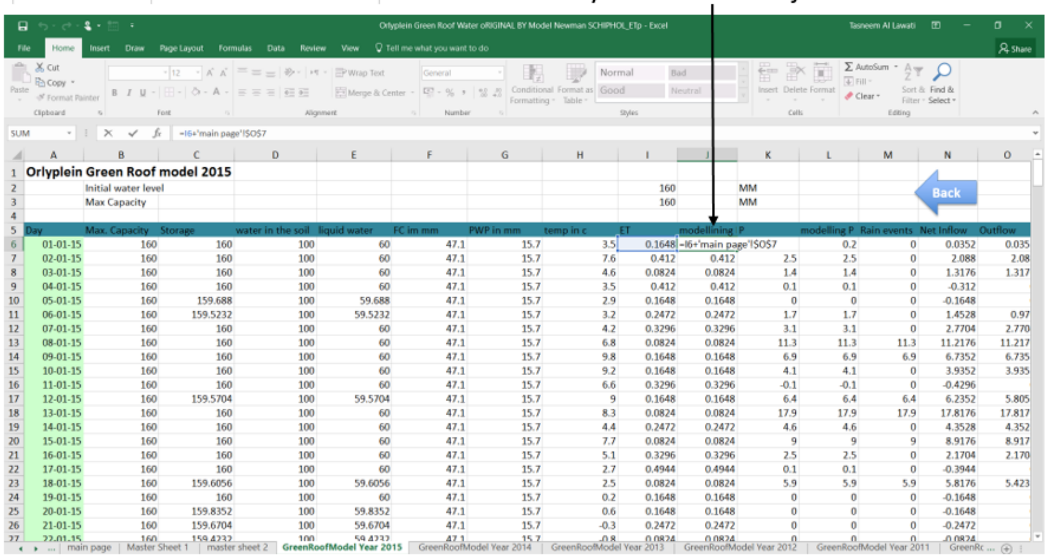
Screen dump 7: Moisture content graphs of green park from 2000 to 2015 presented as "storage in master sheet 1 and as "water in soil" and "liquid water" in master sheet two.



Screen dump 8: The process of controlling and testing evapotranspiration and precipitation by using entry form cells and modeling columns for these two variables

FC	47.1
PWP	15.7
ET	3
P	
Rain Events	5

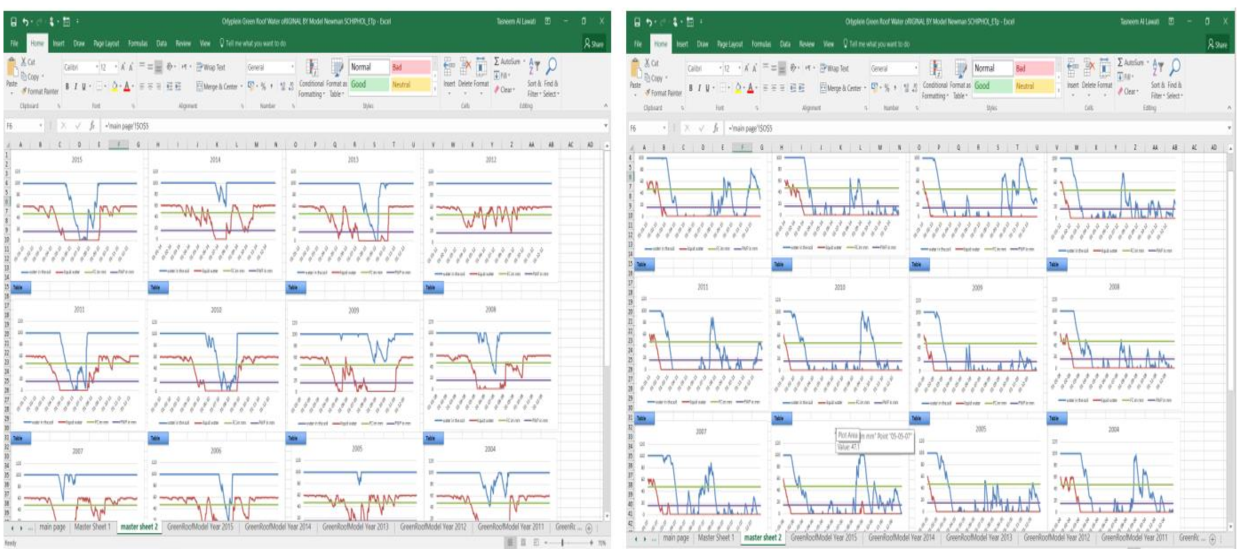
For example: if a value of 3 mm was entered in the ET cell in the entry form, 3 mm will be added to the values of ET records base on the equation (= cell address in ET column + 3mm from the main page) the result of the change will appear in the ET modeling column. Note that all values in ET record will increase by 3 mm and not just one cell



=I6+'main page'!$O$7

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Orlyplein Green Roof model 2015														
2		Initial water level							160		MM				
3		Max Capacity							160		MM				
4															
5	Day	Max. Capacity	Storage	water in the soil	liquid water	FC im mm	PWP in mm	temp in c	ET	modellining	P	modelling P	Rain events	Net Inflow	Outflow
6	01-01-15	160	160	100	60	47.1	15.7	3.5	0.1648	=I6+'main page'!$O$7		0.2	0	0.0352	0.035
7	02-01-15	160	160	100	60	47.1	15.7	7.6	0.412	0.412	2.5	2.5	0	2.088	2.08
8	03-01-15	160	160	100	60	47.1	15.7	4.6	0.0824	0.0824	1.4	1.4	0	1.3176	1.317
9	04-01-15	160	160	100	60	47.1	15.7	3.5	0.412	0.412	0.1	0.1	0	-0.312	
10	05-01-15	160	159.688	100	59.688	47.1	15.7	2.9	0.1648	0.1648	0	0	0	-0.1648	
11	06-01-15	160	159.5232	100	59.5232	47.1	15.7	3.2	0.2472	0.2472	1.7	1.7	0	1.4528	0.97
12	07-01-15	160	160	100	60	47.1	15.7	4.2	0.3296	0.3296	3.1	3.1	0	2.7704	2.770
13	08-01-15	160	160	100	60	47.1	15.7	6.8	0.0824	0.0824	11.3	11.3	11.3	11.2176	11.217
14	09-01-15	160	160	100	60	47.1	15.7	9.8	0.1648	0.1648	6.9	6.9	6.9	6.7352	6.735
15	10-01-15	160	160	100	60	47.1	15.7	9.2	0.1648	0.1648	4.1	4.1	0	3.9352	3.935
16	11-01-15	160	160	100	60	47.1	15.7	6.6	0.3296	0.3296	-0.1	-0.1	0	-0.4296	
17	12-01-15	160	159.5704	100	59.5704	47.1	15.7	9	0.1648	0.1648	6.4	6.4	6.4	6.2352	5.805
18	13-01-15	160	160	100	60	47.1	15.7	8.3	0.0824	0.0824	17.9	17.9	17.9	17.8176	17.817
19	14-01-15	160	160	100	60	47.1	15.7	4.4	0.2472	0.2472	4.6	4.6	0	4.3528	4.352
20	15-01-15	160	160	100	60	47.1	15.7	7.7	0.0824	0.0824	9	9	9	8.9176	8.917
21	16-01-15	160	160	100	60	47.1	15.7	5.1	0.3296	0.3296	2.5	2.5	0	2.1704	2.170
22	17-01-15	160	160	100	60	47.1	15.7	2.7	0.4944	0.4944	0.1	0.1	0	-0.3944	
23	18-01-15	160	159.6056	100	59.6056	47.1	15.7	2.5	0.0824	0.0824	5.9	5.9	5.9	5.8176	5.423
24	19-01-15	160	160	100	60	47.1	15.7	0.2	0.1648	0.1648	0	0	0	-0.1648	
25	20-01-15	160	159.8352	100	59.8352	47.1	15.7	0.6	0.1648	0.1648	0	0	0	-0.1648	
26	21-01-15	160	159.6704	100	59.6704	47.1	15.7	-0.3	0.2472	0.2472	0	0	0	-0.2472	
27	22-01-15	160	159.4232	100	59.4232	47.1	15.7	-0.8	0.0824	0.0824	0	0	0	-0.0824	

Screen dump 9: An example of how the change in value of ET reflects on: ET modeling" column in the model

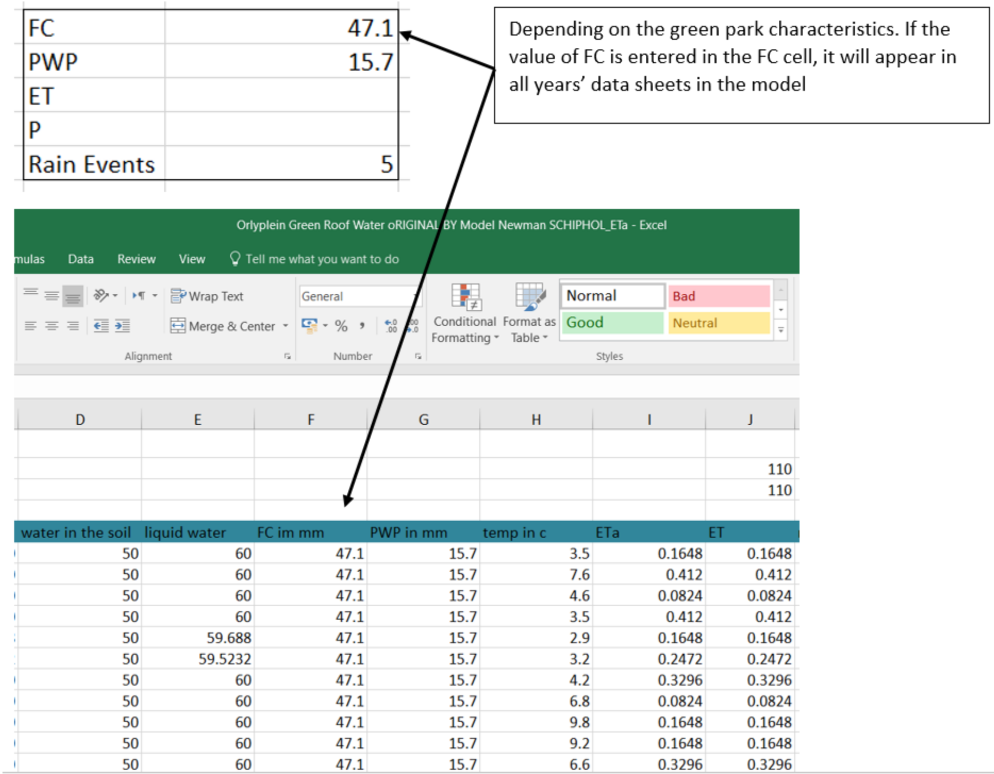


Screen dump 10: Increasing the values of ET by 3 mm appeared in the graphs from 2000 to 2015

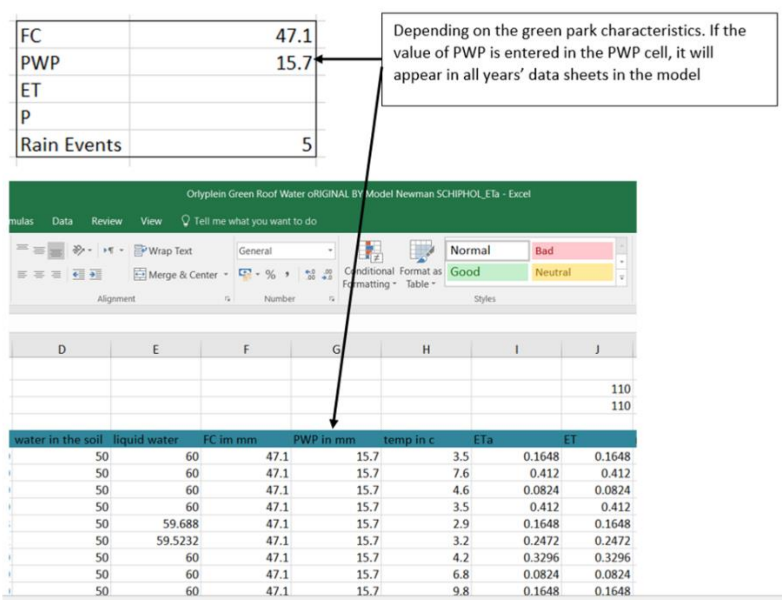
3.5 substrate physical characteristics lab experiments

The GR system is natural, so a lot of factors affecting the movement of water in substrate including substrate particle size, and its physical properties. In order to study the hydraulic behavior of the GRS and link evapotranspiration to the substrate moisture content, four tests were carried out in order to identify field capacity and permanent wilting point (refer to appendix 3 for more details for each experiment).

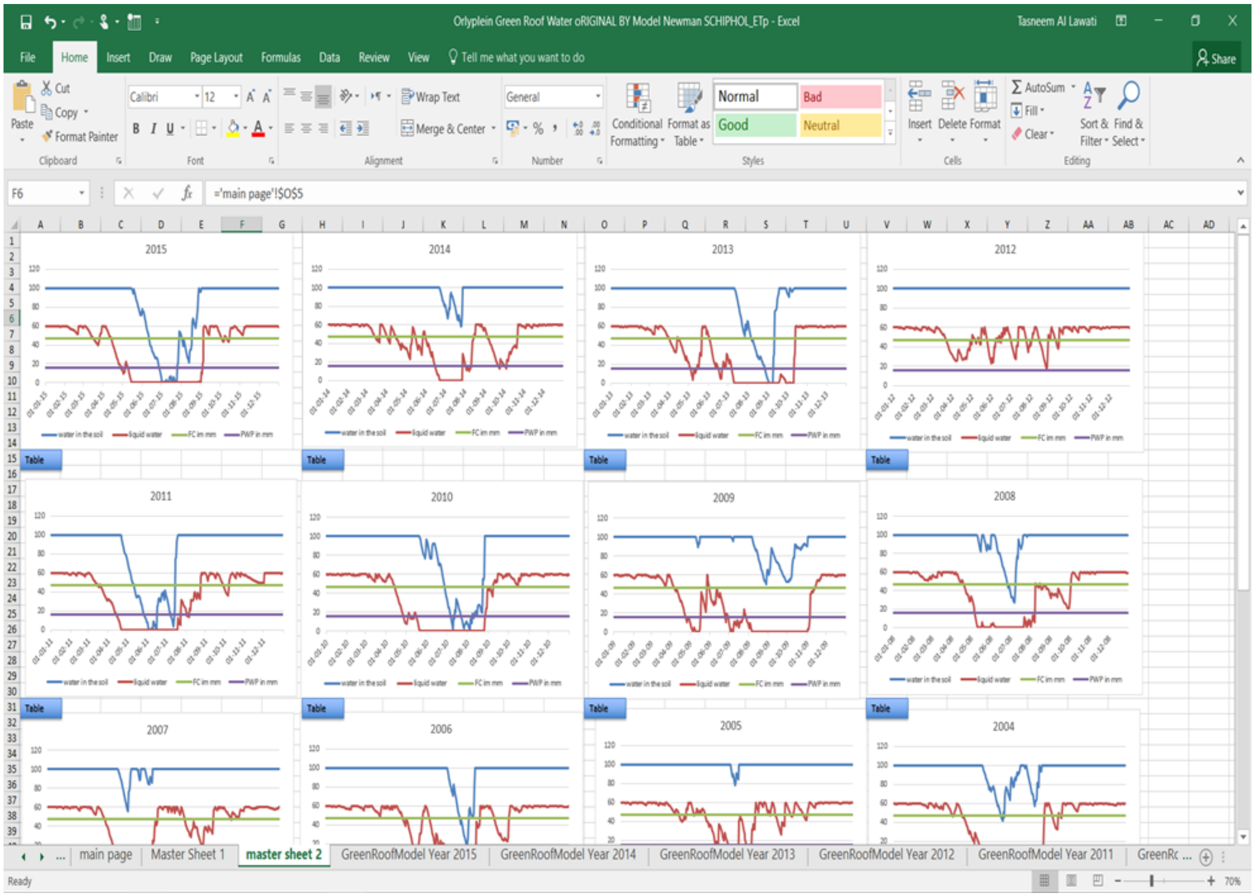
1. Soil moisture content: this experiment was based on investigating how much a sample of Orlyplein GRP substrate can hold moisture to provide for plants. This was performed by measuring a soil sample after water stop leaching from pots, weight it, dry it in oven for 24 h and finally weight the sample once it dry.
2. Soil field capacity: to determine the water-holding capacity of the soil, a 100 gram of soil was placed in a funnel placed in flask. a 100 ml of water was added to the soil sample and after a while, the amount of water in the flask is measured when water stopped leaching from funnel.
3. Plant test wilting point teat: based on growing some plants in the same substrate that is used in The Orlyplein GRP and irrigate the soil with sufficient amount of water for 2 to 3 days and then wait for the plants to show wilting symptoms. soil samples were taken from pots, weight on scale and oven dry for 24 hours.
4. Oedometer was used to keep soil sample under different pressure, the first round was to calculate field capacity and second time to calculate permanent wilting point. The sample was measured for weight before and after the test to calculate the amount of water left in the sample. Field capacity and permeant wilting point information were introduced to the model. see screen dumps (11 to 13)



Screen dump 11: Field capacity value that was concluded from the experiments based on the green park characteristics, entered in the entry form and appeared in all years' records



Screen dump 12: Permanent wilting point value that was concluded from the experiments based on the green park characteristics, entered in the entry form and appeared in all years' records



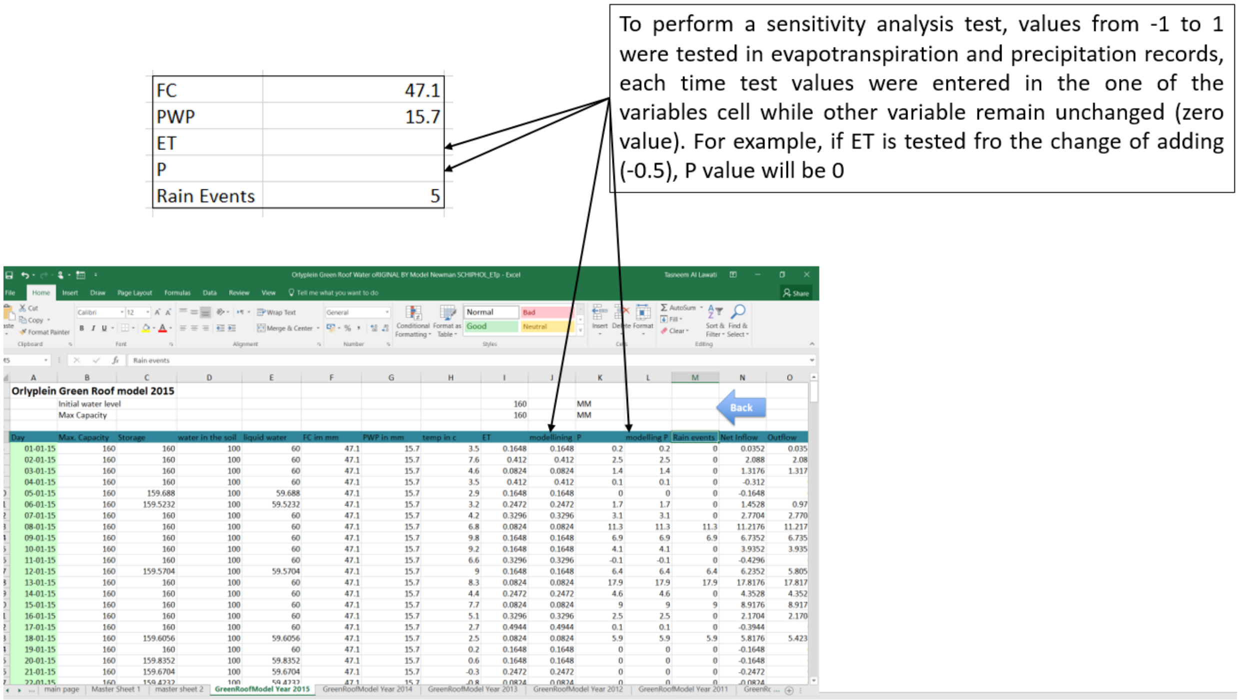
Screen dump 13: Field capacity and permanent wilting point data were uploaded to the model and introduced to the graphs in master sheet 1 and 2. The green line is field capacity and the purple line is presenting permanent wilting point.

3.6 Design supportive models

3.6.1 Sensitivity analysis

Sensitivity studies help in identifying the strength of key factors that the system based on and how a minimum or maximum change can benefit associated environmental elements in the system. Modeling allow to carry out sensitivity studies in order to measure and assess how variations in key variables used in a system alter its behavior which in turn helps in estimating the future risks or benefits related with proposed changes in a system.

Since GRS is responding naturally to the change in evapotranspiration, soil particle size, wind speed, temperature and precipitation along with other natural factors affecting the water navigation in the GRS, it was essential to perform sensitivity analysis, in order to define how significance is the effect if the change occur on some factors such as P and ET on green roof. The following screen dumps (14 to 19) are presenting the steps of this test. Results of sensitivity analysis is presented in section 4.4 in chapter 4



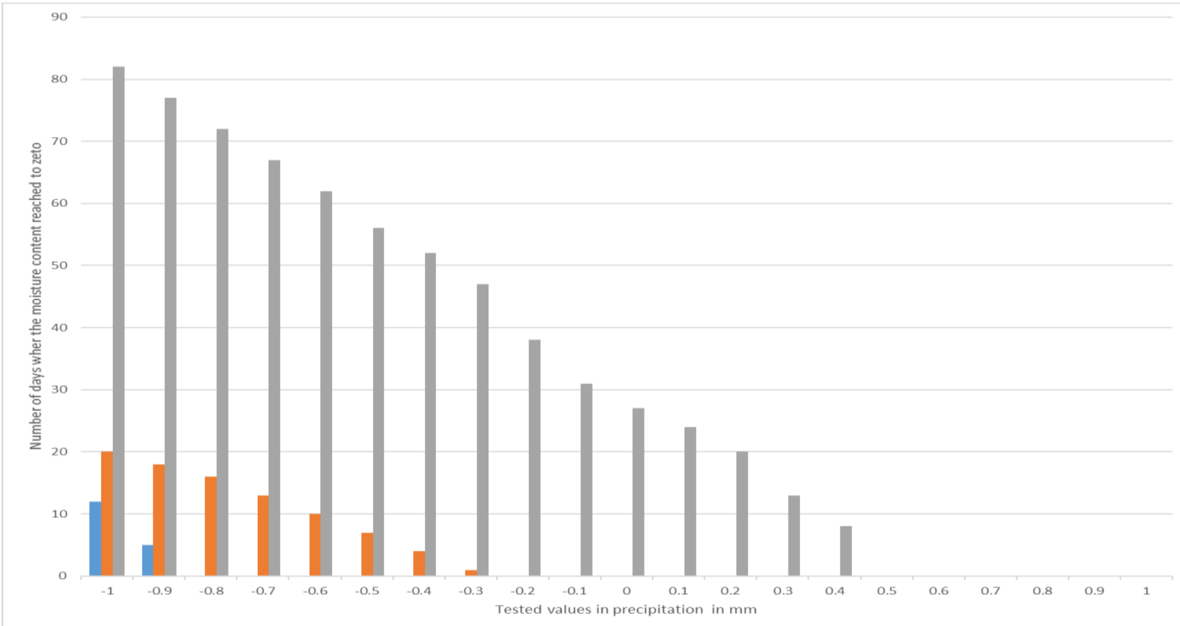
Screen dump 14: Performing sensitivity analysis test on two variable, ET and P

Once the test values (from -1 to 1) entered in entry form cells, ET or P values were changed in the model. this change appeared in modeling ET or P columns which linked to the net inflow. As the net inflow changes, water in substrate and permavoid change. Using count formula, number of days where moisture content in the substrate = 0 were calculated for the selected years

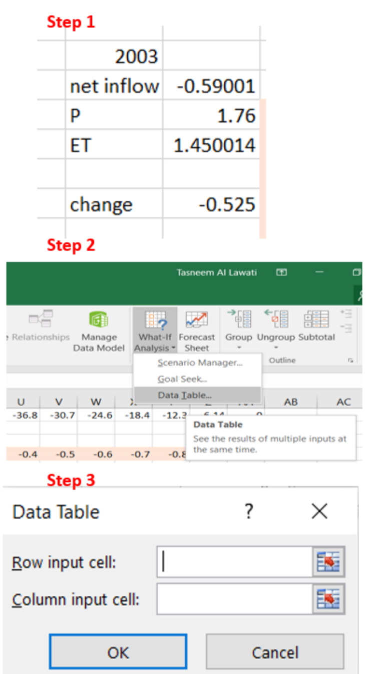
1	sensitivity analysis ET			
2	values	2012	2008	2003
3	-1	0	0	0
4	-0.9	0	0	0
5	-0.8	0	0	0
6	-0.7	0	0	0
7	-0.6	0	0	0
8	-0.5	0	0	0
9	-0.4	0	0	1
10	-0.3	0	0	9
11	-0.2	0	0	12
12	-0.1	0	0	15
13	0	0	0	18
14	0.1	0	0	23
15	0.2	0	0	30
16	0.3	0	1	37
17	0.4	0	6	43
18	0.5	0	8	48
19	0.6	0	11	56
20	0.7	0	13	60
21	0.8	0	15	65
22	0.9	0	18	71
23	1	2	20	77
24				
25				

1	sensitivity analysis P			
2	values	2012	2008	2003
3	-1	12	20	82
4	-0.9	5	18	77
5	-0.8	0	16	72
6	-0.7	0	13	67
7	-0.6	0	10	62
8	-0.5	0	7	56
9	-0.4	0	4	52
10	-0.3	0	1	47
11	-0.2	0	0	38
12	-0.1	0	0	31
13	0	0	0	27
14	0.1	0	0	24
15	0.2	0	0	20
16	0.3	0	0	13
17	0.4	0	0	8
18	0.5	0	0	0
19	0.6	0	0	0
20	0.7	0	0	0
21	0.8	0	0	0
22	0.9	0	0	0
23	1	0	0	0
24				
25				

Screen dump 15: Number of days where moisture content in the tested years reached to zero were tabulated for each variable separately



Screen dump 16: Sensitivity analysis results were graphed, each variable was graphed separately



The graph presented the change in precipitation while ET was always referred as a zero value. Since these two variable have an impact on net inflow which will affect the moisture content in the system, a table presenting the amount of change in net inflow if both variable were changed. This was done by

Step 1: calculating the average of ET and P for the tested years. Then get the net inflow from Average P-Average ET

Step 2: using the feature that is built in excel to generate data table through "what if Analysis"

Step 3: average values of ET and P were inserted in each cell as (row was ET and column was P)

Screen dump 17: Steps of creating sensitivity analysis table for the tested years using values from -1 to 1 mm and average values of ET and P for the tested years

	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1
1	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356	1.525	1.695	1.864	2.034	2.203	2.373	2.542	2.712	2.881	3.051	3.22	3.39
0.9	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356	1.525	1.695	1.864	2.034	2.203	2.373	2.542	2.712	2.881	3.051	3.22
0.8	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356	1.525	1.695	1.864	2.034	2.203	2.373	2.542	2.712	2.881	3.051
0.7	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356	1.525	1.695	1.864	2.034	2.203	2.373	2.542	2.712	2.881
0.6	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356	1.525	1.695	1.864	2.034	2.203	2.373	2.542	2.712
0.5	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356	1.525	1.695	1.864	2.034	2.203	2.373	2.542
0.4	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356	1.525	1.695	1.864	2.034	2.203	2.373
0.3	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356	1.525	1.695	1.864	2.034	2.203
0.2	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356	1.525	1.695	1.864	2.034
0.1	-1.53	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356	1.525	1.695	1.864
0	-1.69	-1.53	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356	1.525	1.695
-0.1	-1.86	-1.69	-1.53	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356	1.525
-0.2	-2.03	-1.86	-1.69	-1.53	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186	1.356
-0.3	-2.2	-2.03	-1.86	-1.69	-1.53	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017	1.186
-0.4	-2.37	-2.2	-2.03	-1.86	-1.69	-1.53	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847	1.017
-0.5	-2.54	-2.37	-2.2	-2.03	-1.86	-1.69	-1.53	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678	0.847
-0.6	-2.71	-2.54	-2.37	-2.2	-2.03	-1.86	-1.69	-1.53	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508	0.678
-0.7	-2.88	-2.71	-2.54	-2.37	-2.2	-2.03	-1.86	-1.69	-1.53	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339	0.508
-0.8	-3.05	-2.88	-2.71	-2.54	-2.37	-2.2	-2.03	-1.86	-1.69	-1.53	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169	0.339
-0.9	-3.22	-3.05	-2.88	-2.71	-2.54	-2.37	-2.2	-2.03	-1.86	-1.69	-1.53	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0	0.169
-1	-3.39	-3.22	-3.05	-2.88	-2.71	-2.54	-2.37	-2.2	-2.03	-1.86	-1.69	-1.53	-1.36	-1.19	-1.02	-0.85	-0.68	-0.51	-0.34	-0.17	0

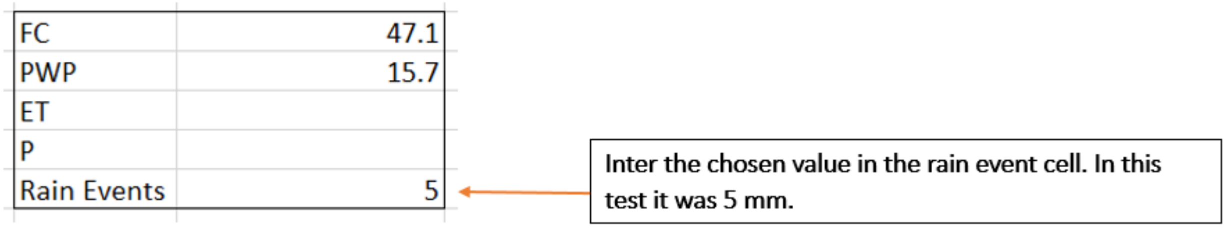
Screen dump 18: Resulted sensitivity analysis table for the tested years using values from -1 to 1 mm and average values of ET and P for the tested years

	10%	9%	8%	7%	6%	5%	4%	3%	2%	1%	0%	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%	-10%
10%	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136	0.153	0.169	0.186	0.203	0.22	0.237	0.254	0.271	0.288	0.305	0.322	0.339
9%	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136	0.153	0.169	0.186	0.203	0.22	0.237	0.254	0.271	0.288	0.305	0.322
8%	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136	0.153	0.169	0.186	0.203	0.22	0.237	0.254	0.271	0.288	0.305
7%	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136	0.153	0.169	0.186	0.203	0.22	0.237	0.254	0.271	0.288
6%	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136	0.153	0.169	0.186	0.203	0.22	0.237	0.254	0.271
5%	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136	0.153	0.169	0.186	0.203	0.22	0.237	0.254
4%	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136	0.153	0.169	0.186	0.203	0.22	0.237
3%	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136	0.153	0.169	0.186	0.203	0.22
2%	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136	0.153	0.169	0.186	0.203
1%	-0.15	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136	0.153	0.169	0.186
0%	-0.17	-0.15	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136	0.153	0.169
-1%	-0.19	-0.17	-0.15	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136	0.153
-2%	-0.2	-0.19	-0.17	-0.15	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136
-3%	-0.22	-0.2	-0.19	-0.17	-0.15	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102	0.119
-4%	-0.24	-0.22	-0.2	-0.19	-0.17	-0.15	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085	0.102
-5%	-0.25	-0.24	-0.22	-0.2	-0.19	-0.17	-0.15	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068	0.085
-6%	-0.27	-0.25	-0.24	-0.22	-0.2	-0.19	-0.17	-0.15	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051	0.068
-7%	-0.29	-0.27	-0.25	-0.24	-0.22	-0.2	-0.19	-0.17	-0.15	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034	0.051
-8%	-0.31	-0.29	-0.27	-0.25	-0.24	-0.22	-0.2	-0.19	-0.17	-0.15	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017	0.034
-9%	-0.32	-0.31	-0.29	-0.27	-0.25	-0.24	-0.22	-0.2	-0.19	-0.17	-0.15	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0	0.017
-10%	-0.34	-0.32	-0.31	-0.29	-0.27	-0.25	-0.24	-0.22	-0.2	-0.19	-0.17	-0.15	-0.14	-0.12	-0.1	-0.08	-0.07	-0.05	-0.03	-0.02	0

Screen dump 19: A sensitivity analysis table for the tested years using values from -10% to 10% of ET and P averages using the same steps that were followed to create the previous table.

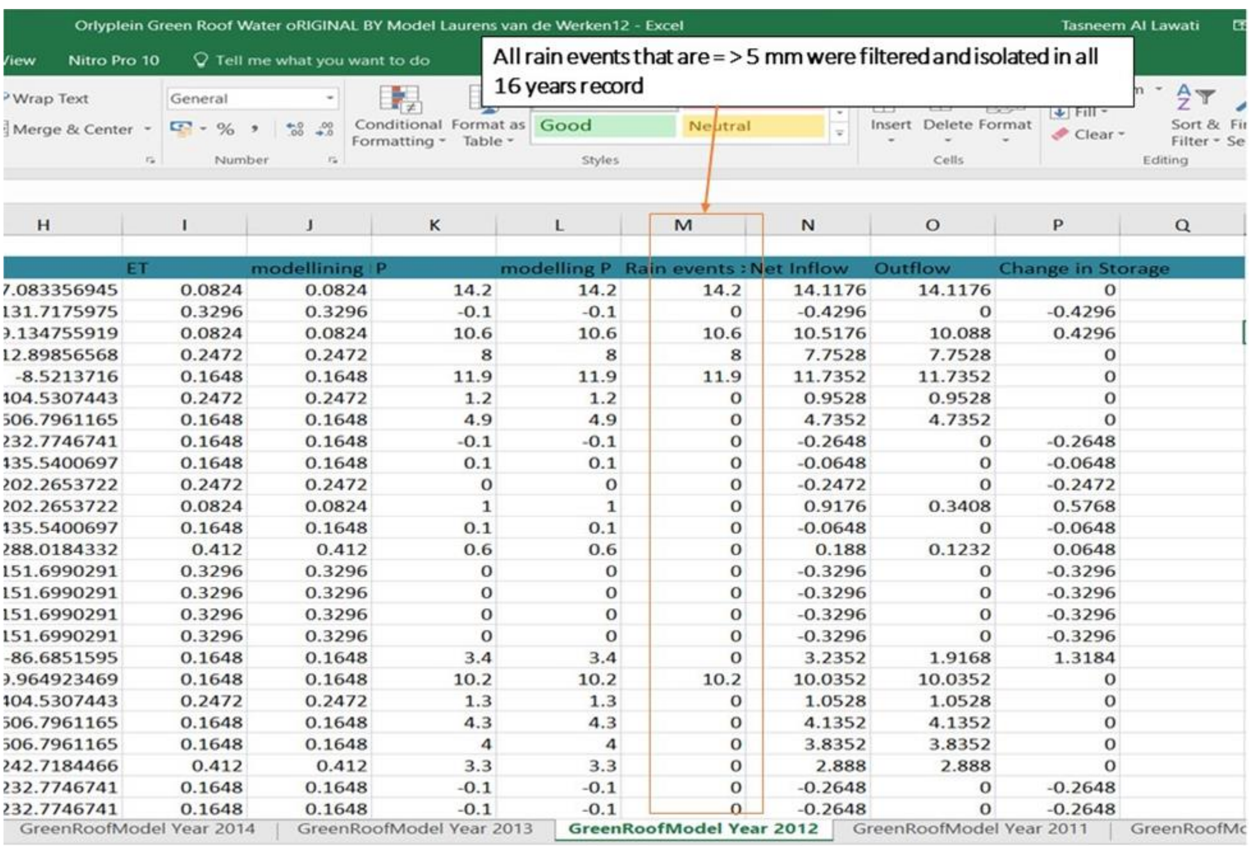
3.6.2 Examining Uncertainty in the Rainfall Data

As it was mentioned earlier, the vegetation and the growing medium play a main role in water retention. The natural part of green roof system acts as a sponge in holding water in rain events and pass it to the storage once it is saturated. This natural system is also depending on rain events to be active and alive, which gives an importance to relay on almost accurate forecast but because this is not the case all the time the question raised was what if the forecast data were holding, for example, a 10% (this was taken as an example in the first instance) error in rain events, i.e., 10% of the time a predicted rain event did not occur? How would the green roof react? As a result, the probability scenario was designed to answer these question. The first step in building this scenario was choosing a wet, a normal and a dry year from the 15 years set. The years were 2012, 2008 and 2003 respectively. For this exercise, a normal value of 5 mm was chosen as a rain event that would usually in the water being dumped if the resulting rain would cause an overflow from the Permavoid. This was considered a reasonable value that an automated system could control to,(Newman Pers Covn, 2016) but it should be considered as an example only. The following screen dumps (20 to 28) explain the methodology of this test. These steps were repeated for data of 2003 and 2008. Results are presented in section 4.5. These screen dumps are presented with minimal explanation because of the constrictions of the word limit. However, for readers prepared to study these in conjunction with the live software they should be self-explanatory



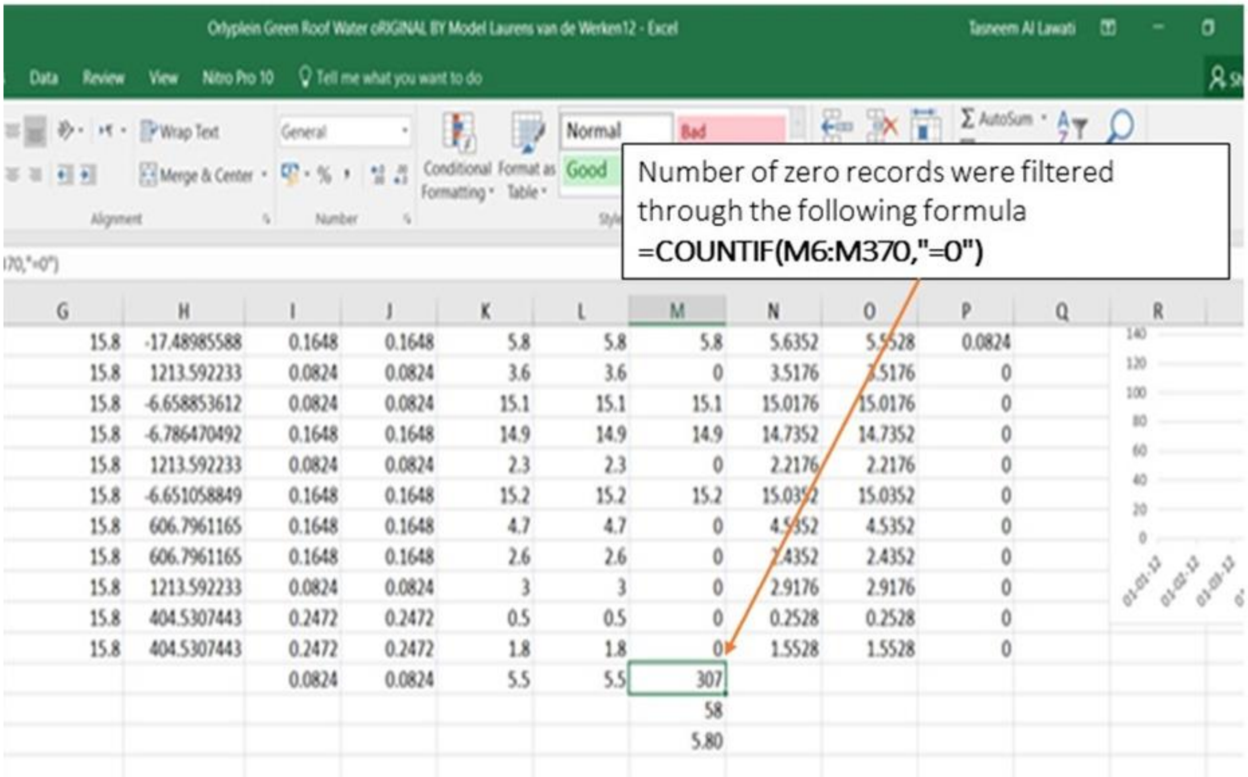
FC	47.1
PWP	15.7
ET	
P	
Rain Events	5

Screen dump 20: Examining uncertainty in the rainfall Data started with choosing rain events value to base the filtering process on.

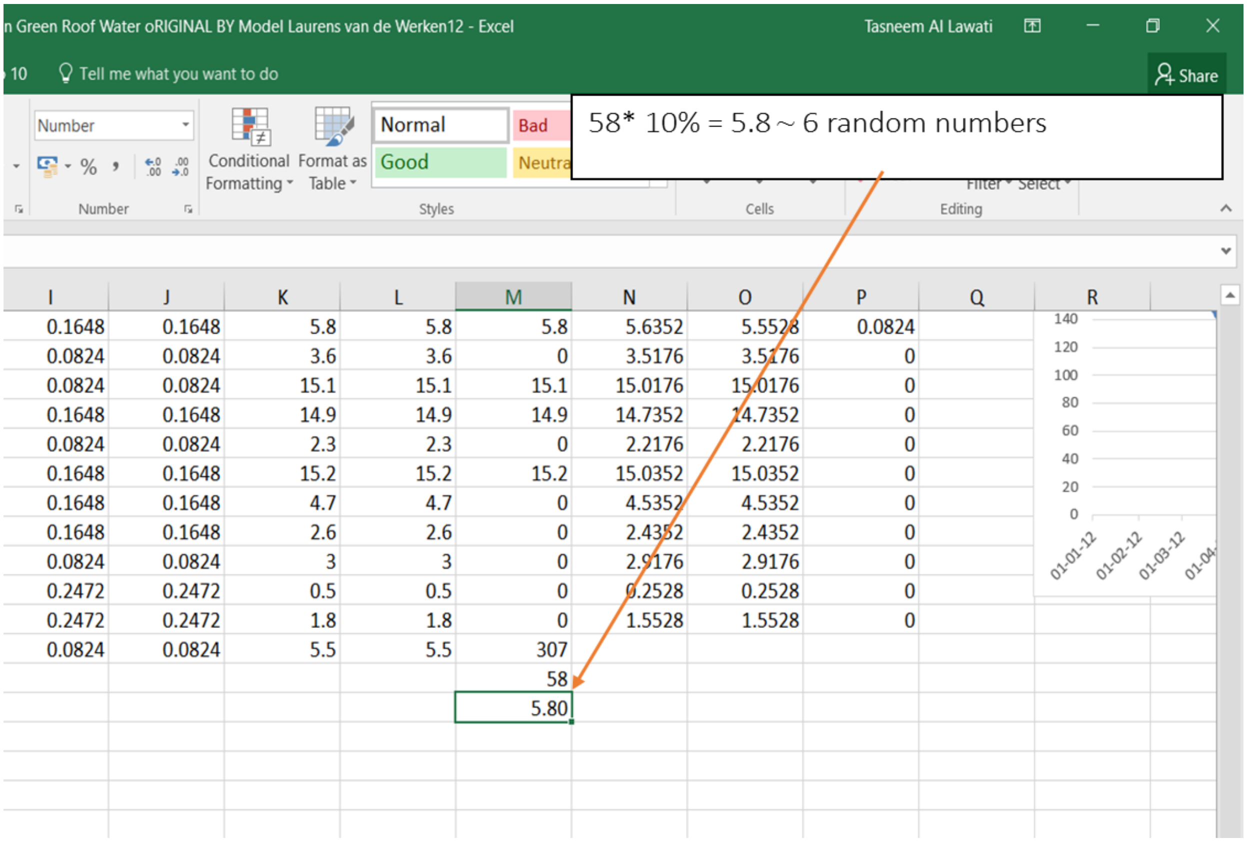


H	I	J	K	L	M	N	O	P
	ET	modellining	P	modelling P	Rain events :	Net Inflow	Outflow	Change in Storage
7.083356945	0.0824	0.0824	14.2	14.2	14.2	14.1176	14.1176	0
131.7175975	0.3296	0.3296	-0.1	-0.1	0	-0.4296	0	-0.4296
9.134755919	0.0824	0.0824	10.6	10.6	10.6	10.5176	10.088	0.4296
12.89856568	0.2472	0.2472	8	8	8	7.7528	7.7528	0
-8.5213716	0.1648	0.1648	11.9	11.9	11.9	11.7352	11.7352	0
404.5307443	0.2472	0.2472	1.2	1.2	0	0.9528	0.9528	0
506.7961165	0.1648	0.1648	4.9	4.9	0	4.7352	4.7352	0
232.7746741	0.1648	0.1648	-0.1	-0.1	0	-0.2648	0	-0.2648
435.5400697	0.1648	0.1648	0.1	0.1	0	-0.0648	0	-0.0648
202.2653722	0.2472	0.2472	0	0	0	-0.2472	0	-0.2472
202.2653722	0.0824	0.0824	1	1	0	0.9176	0.3408	0.5768
435.5400697	0.1648	0.1648	0.1	0.1	0	-0.0648	0	-0.0648
288.0184332	0.412	0.412	0.6	0.6	0	0.188	0.1232	0.0648
151.6990291	0.3296	0.3296	0	0	0	-0.3296	0	-0.3296
151.6990291	0.3296	0.3296	0	0	0	-0.3296	0	-0.3296
151.6990291	0.3296	0.3296	0	0	0	-0.3296	0	-0.3296
151.6990291	0.3296	0.3296	0	0	0	-0.3296	0	-0.3296
-86.6851595	0.1648	0.1648	3.4	3.4	0	3.2352	1.9168	1.3184
9.964923469	0.1648	0.1648	10.2	10.2	10.2	10.0352	10.0352	0
404.5307443	0.2472	0.2472	1.3	1.3	0	1.0528	1.0528	0
506.7961165	0.1648	0.1648	4.3	4.3	0	4.1352	4.1352	0
506.7961165	0.1648	0.1648	4	4	0	3.8352	3.8352	0
242.7184466	0.412	0.412	3.3	3.3	0	2.888	2.888	0
232.7746741	0.1648	0.1648	-0.1	-0.1	0	-0.2648	0	-0.2648
232.7746741	0.1648	0.1648	-0.1	-0.1	0	-0.2648	0	-0.2648

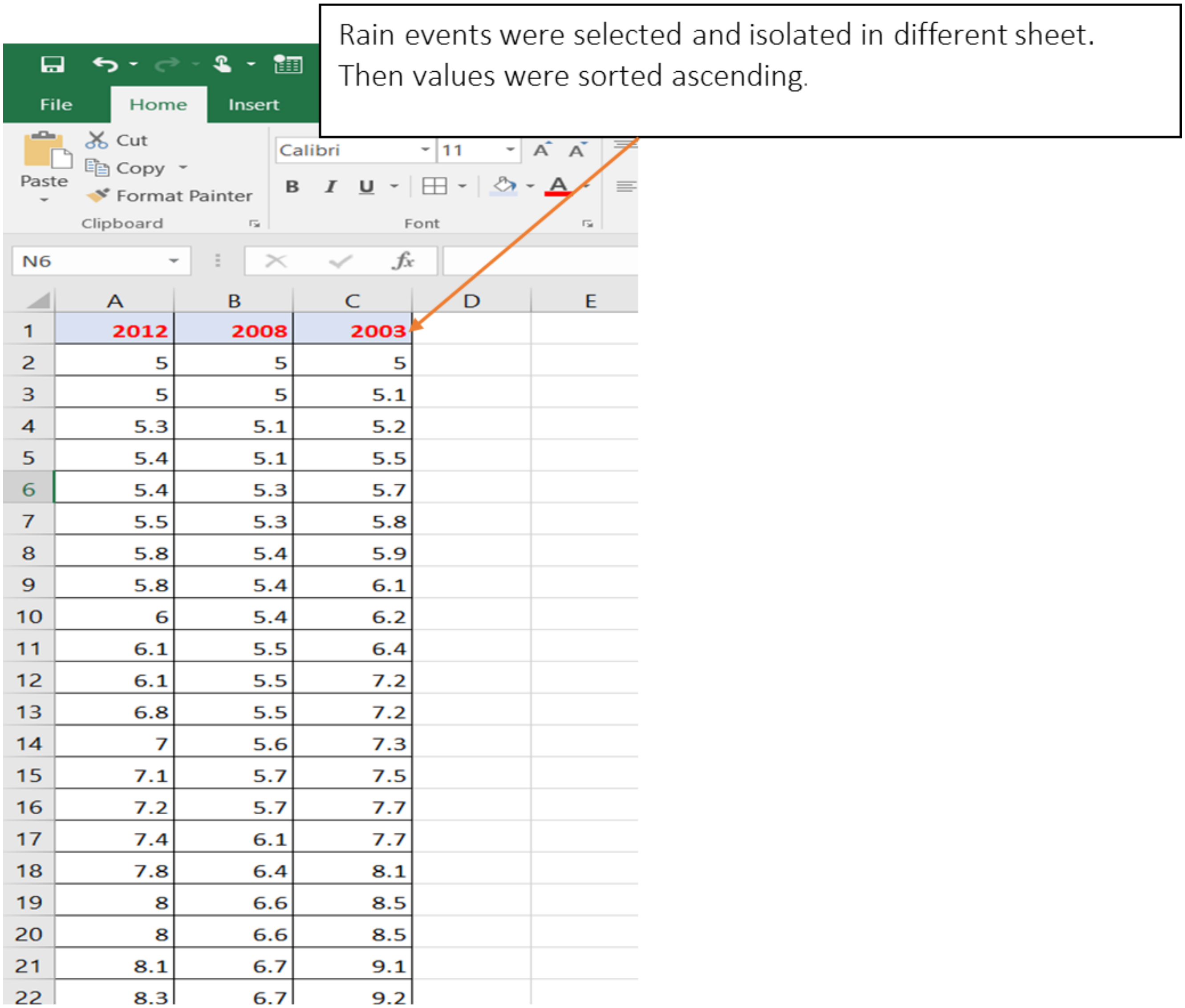
Screen dump 21: Rain events were filtered in the selected years



Screen dump 22: Geting numbers of days where rain events ≥5mm count formula used to count days with no rain events

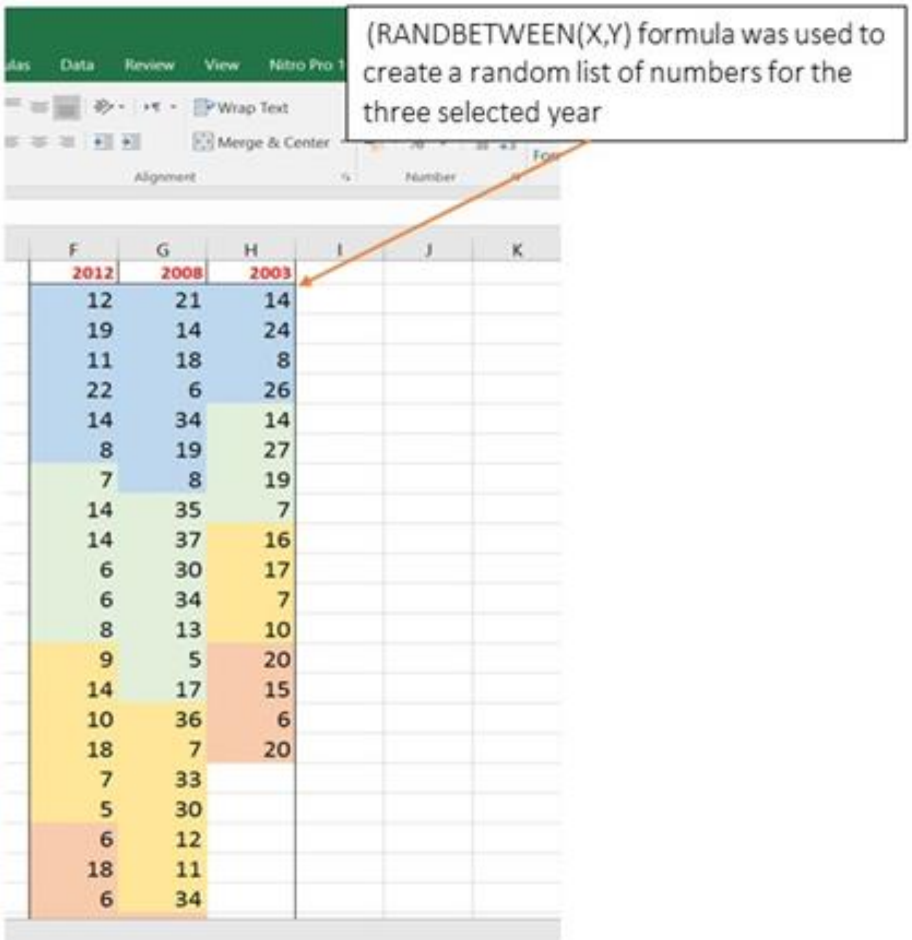


Screen dump 23: Number of events were calculated based on (365 days – 307 days) and 10% of resulted value was established

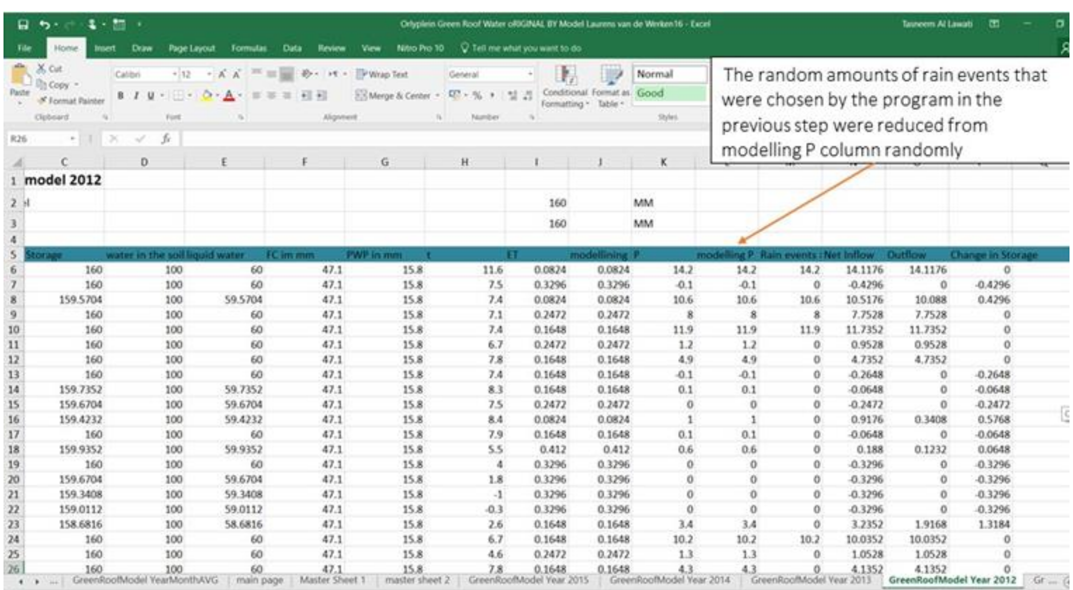


	A	B	C
1	2012	2008	2003
2	5	5	5
3	5	5	5.1
4	5.3	5.1	5.2
5	5.4	5.1	5.5
6	5.4	5.3	5.7
7	5.5	5.3	5.8
8	5.8	5.4	5.9
9	5.8	5.4	6.1
10	6	5.4	6.2
11	6.1	5.5	6.4
12	6.1	5.5	7.2
13	6.8	5.5	7.2
14	7	5.6	7.3
15	7.1	5.7	7.5
16	7.2	5.7	7.7
17	7.4	6.1	7.7
18	7.8	6.4	8.1
19	8	6.6	8.5
20	8	6.6	8.5
21	8.1	6.7	9.1
22	8.3	6.7	9.2

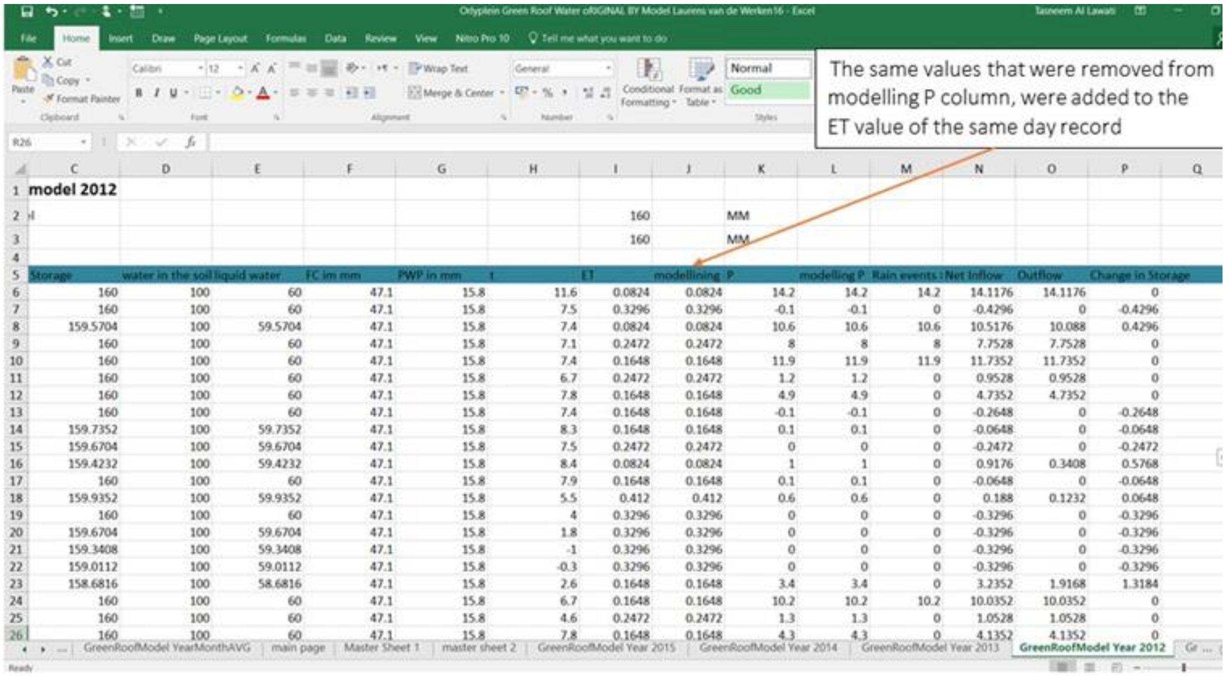
Screen dump 24: Rain events sorted ascending to allocate value ranges from low to high rang



Screen dump 25: RANDBETWEEN function was used to randomize value selection from high and low values of rain events



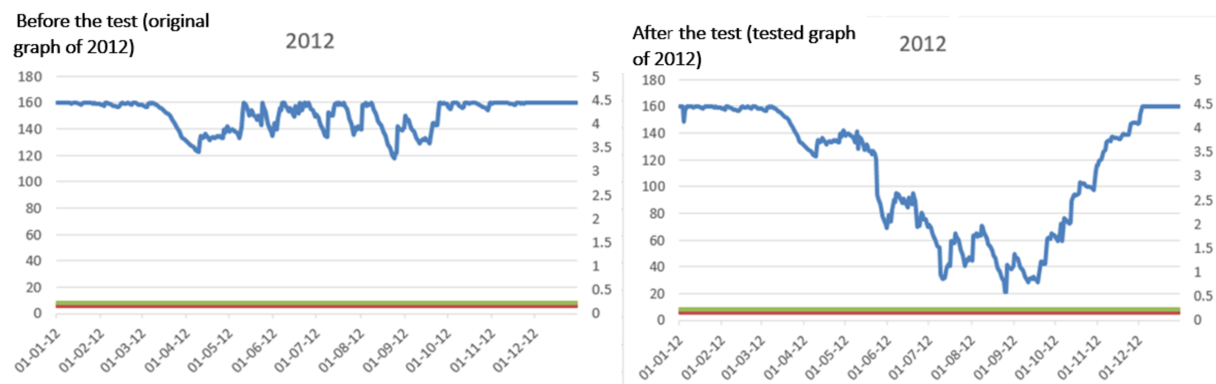
Screen dump 26: The process of controlling and testing precipitation by using entry form" P" cell and modeling column



Storage	water in the soil	liquid water	FC im mm	PWP in mm	t	ET	modellining	P	modelling P	Rain events :	Net Inflow	Outflow	Change in Storage
160	100	60	47.1	15.8	11.6	0.0824	0.0824	14.2	14.2	14.2	14.1176	14.1176	0
160	100	60	47.1	15.8	7.5	0.3296	0.3296	-0.1	-0.1	0	-0.4296	0	-0.4296
159.5704	100	59.5704	47.1	15.8	7.4	0.0824	0.0824	10.6	10.6	10.6	10.5176	10.088	0.4296
160	100	60	47.1	15.8	7.1	0.2472	0.2472	8	8	8	7.7528	7.7528	0
160	100	60	47.1	15.8	7.4	0.1648	0.1648	11.9	11.9	11.9	11.7352	11.7352	0
160	100	60	47.1	15.8	6.7	0.2472	0.2472	1.2	1.2	0	0.9528	0.9528	0
160	100	60	47.1	15.8	7.8	0.1648	0.1648	4.9	4.9	0	4.7352	4.7352	0
160	100	60	47.1	15.8	7.4	0.1648	0.1648	-0.1	-0.1	0	-0.2648	0	-0.2648
159.7352	100	59.7352	47.1	15.8	8.3	0.1648	0.1648	0.1	0.1	0	-0.0648	0	-0.0648
159.6704	100	59.6704	47.1	15.8	7.5	0.2472	0.2472	0	0	0	-0.2472	0	-0.2472
159.4232	100	59.4232	47.1	15.8	8.4	0.0824	0.0824	1	1	0	0.9176	0.3408	0.5768
160	100	60	47.1	15.8	7.9	0.1648	0.1648	0.1	0.1	0	-0.0648	0	-0.0648
159.9352	100	59.9352	47.1	15.8	5.5	0.412	0.412	0.6	0.6	0	0.188	0.1232	0.0648
160	100	60	47.1	15.8	4	0.3296	0.3296	0	0	0	-0.3296	0	-0.3296
159.6704	100	59.6704	47.1	15.8	1.8	0.3296	0.3296	0	0	0	-0.3296	0	-0.3296
159.3408	100	59.3408	47.1	15.8	-1	0.3296	0.3296	0	0	0	-0.3296	0	-0.3296
159.0112	100	59.0112	47.1	15.8	-0.3	0.3296	0.3296	0	0	0	-0.3296	0	-0.3296
158.6816	100	58.6816	47.1	15.8	2.6	0.1648	0.1648	3.4	3.4	0	3.2352	1.9168	1.3184
160	100	60	47.1	15.8	6.7	0.1648	0.1648	10.2	10.2	10.2	10.0352	10.0352	0
160	100	60	47.1	15.8	4.6	0.2472	0.2472	1.3	1.3	0	1.0528	1.0528	0
160	100	60	47.1	15.8	7.8	0.1648	0.1648	4.3	4.3	0	4.1352	4.1352	0

Screen dump 27: The process of controlling and testing precipitation by using entry form" ET" cell and modeling column

The change in the behavior of P and ET was illustrated in the graphs of the tested years as the records were changed by 10 %. The fooling graphs are presented as an **example** before and after the test



Screen dump 28: An example of examining uncertainty in the rainfall Data of 2012

3.7 Calculating actual evapotranspiration from potential evapotranspiration

As mentioned earlier, green roof systems (GRS) are natural systems that influenced by many natural occurring elements such as temperature, precipitation and evapotranspiration. Water move out of the GRS trough evapotranspiration process which is altered by the grain size, organic matter percentage, vegetation type, and thickness of the substrate (Berghage et al.,2007; WolfandLundholm,2008). Therefor it is important to measure evapotranspiration quantities to control plant water need that influencing plant growth.

Many studies presented the importance to model ET because it is playing a main role in stormwater management, energy conservation, and urban vegetation provision. High ET values in relation with raiser in temperature will increase the cooling efficacy of GRS. High levels of solar energy lead to high levels of ET. This mean that more water quantity is leaving the system science ET has a relation with soil moisture content. Low moisture level means that the system has more space in absorbing and delaying runoff. Additionally, higher evapotranspiration rates have to be considered in their effect on the substrate water reservoir through times of drought. A study by M. Uhl and L.Schiedt (2008) highlighted that the denser the vegetation cover in GRS, the more it is efficient in managing storm water. To benefit from multi-advantages of green roof. Vegetation should be healthy and alive. This presents the importance of ET modelling as water is essential for plant growth.

The balance between moisture demand and moisture supply is what ensures health plant growth. Drought in green roof system results from an imbalance between these two components. Precipitation provides the water for irrigation in GRS. Water demand is usually measured by evapotranspiration. Potential evapotranspiration – which is referred as ET0 in some studies - is the predicted maximum amount of water that would be evapotranspired if enough water were available in the substrate system from precipitation. It predicts the ability of the atmosphere to remove water from the green roof vegetation and substrate surface through the processes of evaporation and transpiration assuming no control on water supply. This means that ETp is not limited to the system moisture content (h), field capacity (h fc) or permanent wilting point (h pwp) see figure 14.

Actual evapotranspiration is how much water actually is evapotranspired and is limited by the amount of water that is available. ETa is always less than or equal to ETp. It measures the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration. Unlike ETp, ETa is limited to the system moisture content (h), field capacity (h fc) or permanent wilting point (h pwp). This means that

Crop water need = Potential evapotranspiration - Actual evapotranspiration (2)

ETa = ETp * (moisture content / field capacity) (3)

Since the relationship between ETa and ETp depends upon the soil moisture content and field capacity, equation (2) can be presented as fooling depending upon the level of moisture content.

- $ETa = ETp$ when $h \geq h_{FC}$ (4)
- $ETa = ETp$ * (h-h_{WP} / h_{FC} - h_{WP}) when $h_{WP} < h < h_{FC}$ (5)

- $Et = 0$ when $h \leq h_{PWP}$ (6)

As was mentioned earlier, the van de Werken model was based on ETp, and took no account of substrate water content Because ETp is not controlled by system moisture content, the values in the model tends to be overestimate. Theoretically, this will have an effect on the storage since the net inflow of the system is p -ET. Which will reduce the accuracy of the model. To explore this more the following steps (screen dumps 29 to 31) were taken to introduce the ETa to the model with the three described conditions that are related to h, h fc and h pwp. Results are presented in section 4.6

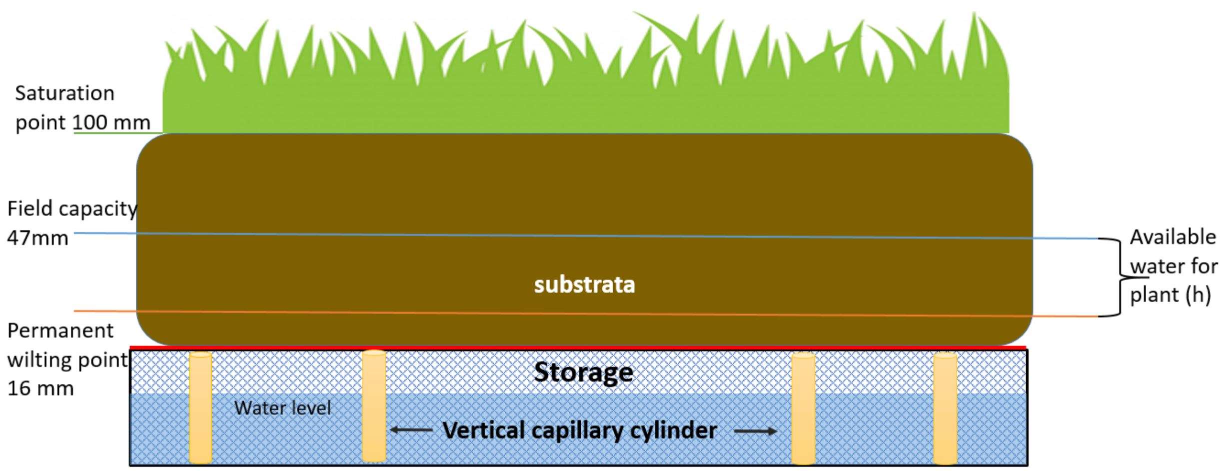
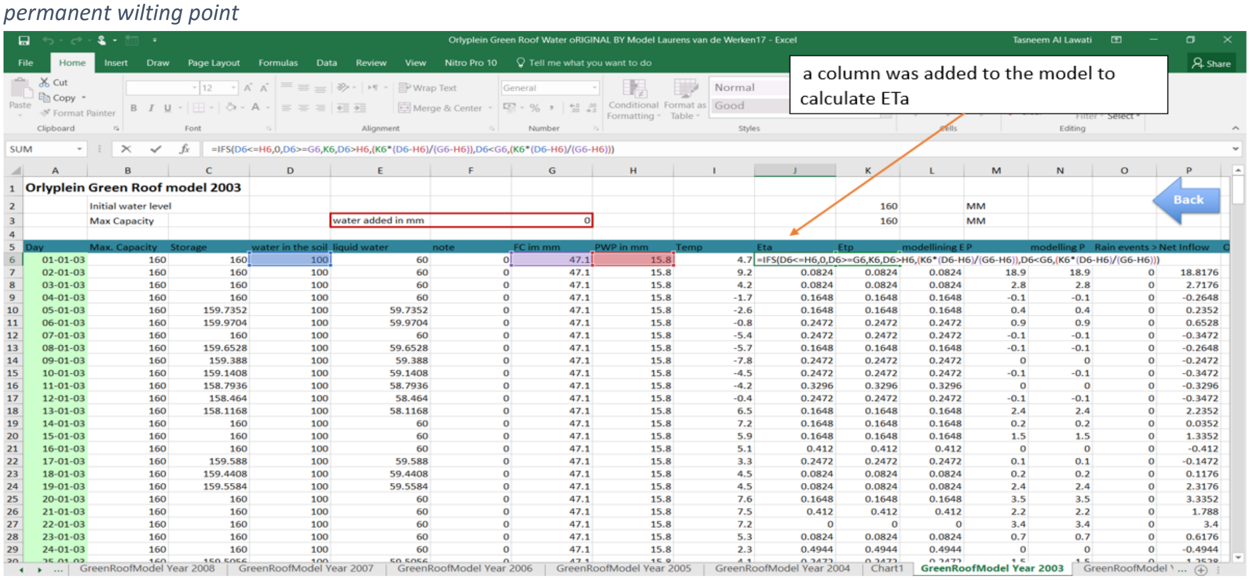
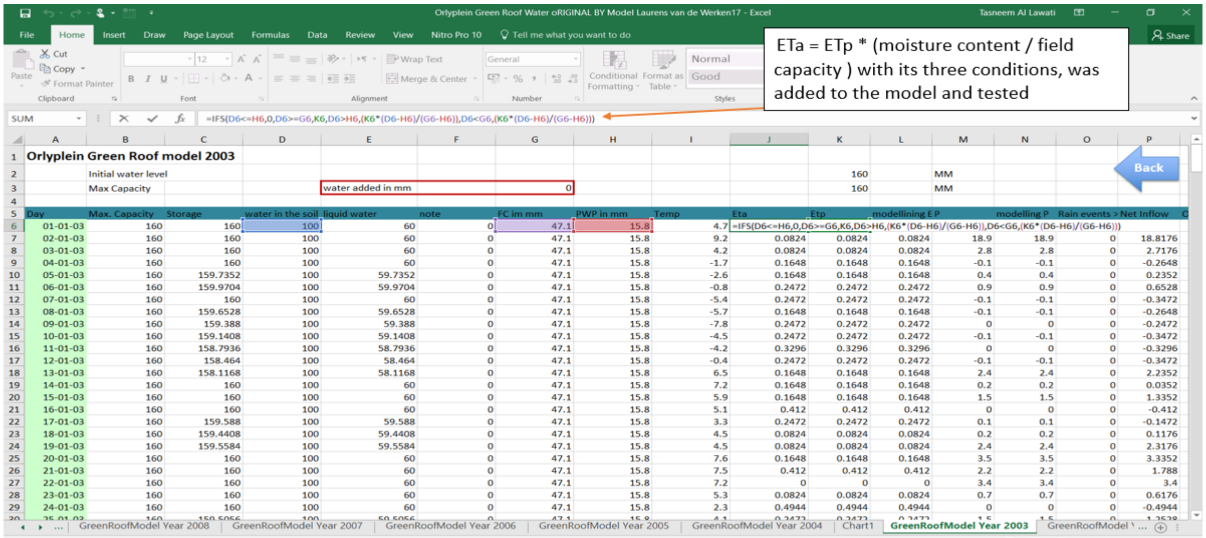


Figure 14: A conceptual model presenting the saturation level, field capacity and permanent wilting point of the green park used as a case study in the project. The available water for plants is the moisture content level between fields capacity and permanent wilting point

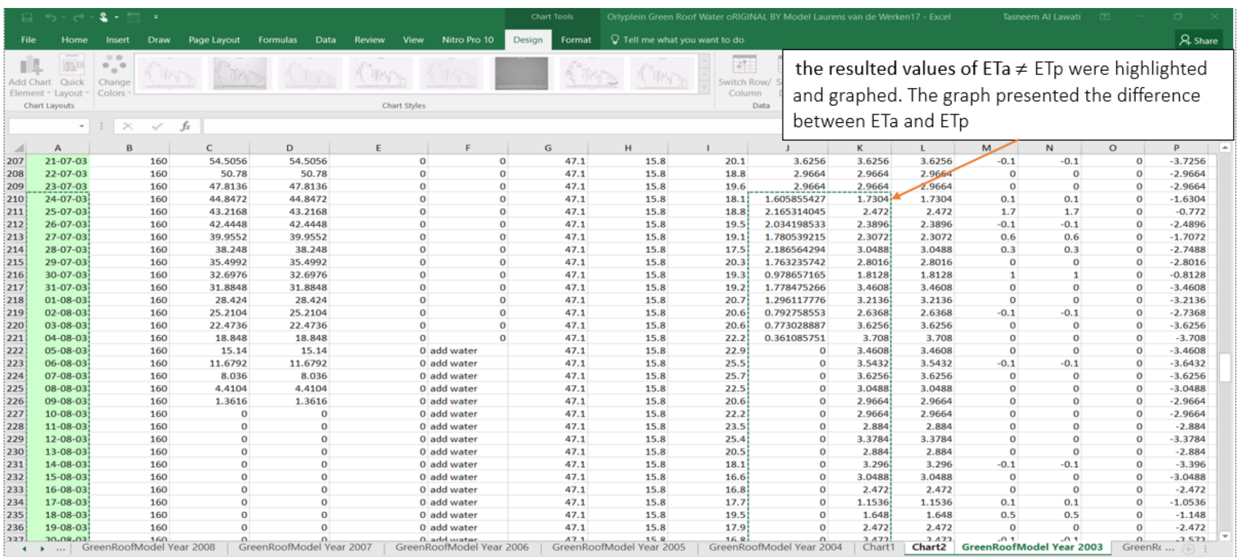


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Orlyplein Green Roof model 2003															
2		Initial water level									160		MM			
3		Max Capacity			water added in mm		0				160		MM			
4																
5	Day	Max. Capacity	Storage	water in the soil	liquid water	note	FC im mm	PWP in mm	Temp	Eta	Etp	modellining E	P	modelling P	Rain events >	Net Inflow
6	01-01-03	160	160	100	60	0	47.1	15.8	4.7	=IFS(D6<=H6,0,D6>=G6,K6,D6>H6,(K6*(D6-H6)/(G6-H6)),D6<G6,(K6*(D6-H6)/(G6-H6)))						
7	02-01-03	160	160	100	60	0	47.1	15.8	9.2	0.0824	0.0824	0.0824	18.9	18.9	0	18.8176
8	03-01-03	160	160	100	60	0	47.1	15.8	4.2	0.0824	0.0824	0.0824	2.8	2.8	0	2.7176
9	04-01-03	160	160	100	60	0	47.1	15.8	-1.7	0.1648	0.1648	0.1648	-0.1	-0.1	0	-0.2648
10	05-01-03	160	159.7352	100	59.7352	0	47.1	15.8	-2.6	0.1648	0.1648	0.1648	0.4	0.4	0	0.2352
11	06-01-03	160	159.9704	100	59.9704	0	47.1	15.8	-0.8	0.2472	0.2472	0.2472	0.9	0.9	0	0.6528
12	07-01-03	160	160	100	60	0	47.1	15.8	-5.4	0.2472	0.2472	0.2472	-0.1	-0.1	0	-0.3472
13	08-01-03	160	159.6528	100	59.6528	0	47.1	15.8	-5.7	0.1648	0.1648	0.1648	-0.1	-0.1	0	-0.2648
14	09-01-03	160	159.388	100	59.388	0	47.1	15.8	-7.8	0.2472	0.2472	0.2472	0	0	0	-0.2472
15	10-01-03	160	159.1408	100	59.1408	0	47.1	15.8	-4.5	0.2472	0.2472	0.2472	-0.1	-0.1	0	-0.3472
16	11-01-03	160	158.7936	100	58.7936	0	47.1	15.8	-4.2	0.3296	0.3296	0.3296	0	0	0	-0.3296
17	12-01-03	160	158.464	100	58.464	0	47.1	15.8	-0.4	0.2472	0.2472	0.2472	-0.1	-0.1	0	-0.3472
18	13-01-03	160	158.1168	100	58.1168	0	47.1	15.8	6.5	0.1648	0.1648	0.1648	2.4	2.4	0	2.2352
19	14-01-03	160	160	100	60	0	47.1	15.8	7.2	0.1648	0.1648	0.1648	0.2	0.2	0	0.0352
20	15-01-03	160	160	100	60	0	47.1	15.8	5.9	0.1648	0.1648	0.1648	1.5	1.5	0	1.3352
21	16-01-03	160	160	100	60	0	47.1	15.8	5.1	0.412	0.412	0.412	0	0	0	-0.412
22	17-01-03	160	159.588	100	59.588	0	47.1	15.8	3.3	0.2472	0.2472	0.2472	0.1	0.1	0	-0.1472
23	18-01-03	160	159.4408	100	59.4408	0	47.1	15.8	4.5	0.0824	0.0824	0.0824	0.2	0.2	0	0.1176
24	19-01-03	160	159.5584	100	59.5584	0	47.1	15.8	4.5	0.0824	0.0824	0.0824	2.4	2.4	0	2.3176
25	20-01-03	160	160	100	60	0	47.1	15.8	7.6	0.1648	0.1648	0.1648	3.5	3.5	0	3.3352
26	21-01-03	160	160	100	60	0	47.1	15.8	7.5	0.412	0.412	0.412	2.2	2.2	0	1.788
27	22-01-03	160	160	100	60	0	47.1	15.8	7.2	0	0	0	3.4	3.4	0	3.4
28	23-01-03	160	160	100	60	0	47.1	15.8	5.3	0.0824	0.0824	0.0824	0.7	0.7	0	0.6176
29	24-01-03	160	160	100	60	0	47.1	15.8	2.3	0.4944	0.4944	0.4944	0	0	0	-0.4944
30	25-01-03	160	159.5056	100	59.5056	0	47.1	15.8	4.1	0.2472	0.2472	0.2472	1.5	1.5	0	1.2528

Screen dump 29: As actual evapotranspiration links to moisture content level, and potential evapotranspiration, it was essential to add actual evapotranspiration to le model



*Screen dump 30: Actual evapotranspiration was calculated using the logical formula of ETa = ETp*actual saturation level / field capacity level.*



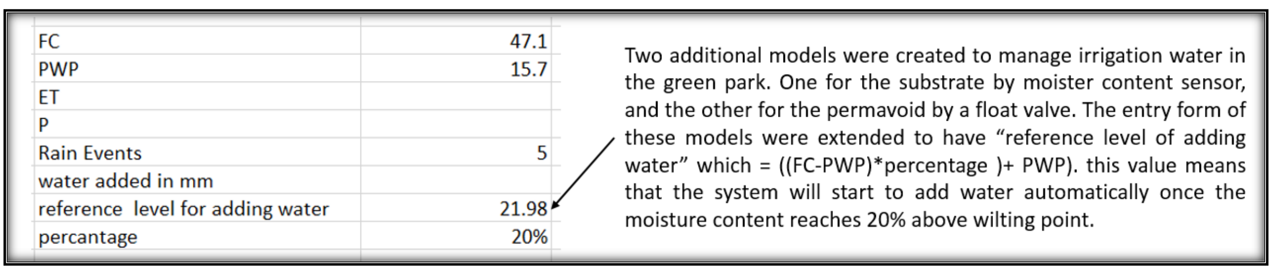
Screen dump 31: the model presented a difference between actual evapotranspiration and potential evapotranspiration values. The difference occurred when moisture content was between field capacity and permanent wilting point.

3.8 management of water with a float valve or moisture content meter – developing models for tracking water status and green roof system hydrological Performance

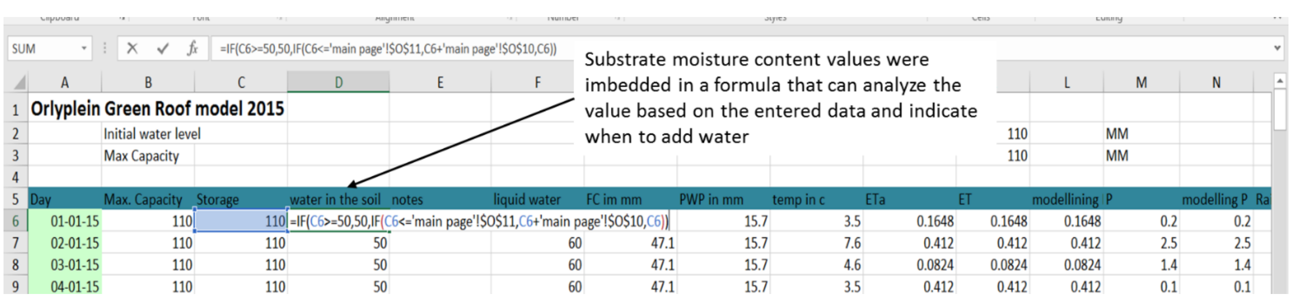
As green roof's multi-benefits are realized, the demand of using green roof system increases in the urbanized areas. This might require the use of irrigation systems that connect to high spatial models or programs that can determine the need of water to keep vegetation alive. These models should use data describing green roof growing medium water status. (Lambrinos J. 2015). Developing models that controls and monitor water demand and status in green roofs combined with efficient irrigation systems could minimize the impact of water stress in green roofs significantly. (Lambrinos J. 2015). The models or systems that are used in monitoring parameters when it comes to runoff retention or energy conservation can be adaptive and modified to help in providing water to irrigate green roof in dry period. All these techniques are associated with cost barrier which leads to the need to develop commercialized off-the-shelf models.

the modified model -which based on actual evapotranspiration equation- was used to calculate the amount of water that the system should be recharged with in order to keep the vegetation alive. 20%of the moisture content was calculated as following
((field capacity – permanent wilting point level) *20%) + permanent wilting point water level = 22 mm

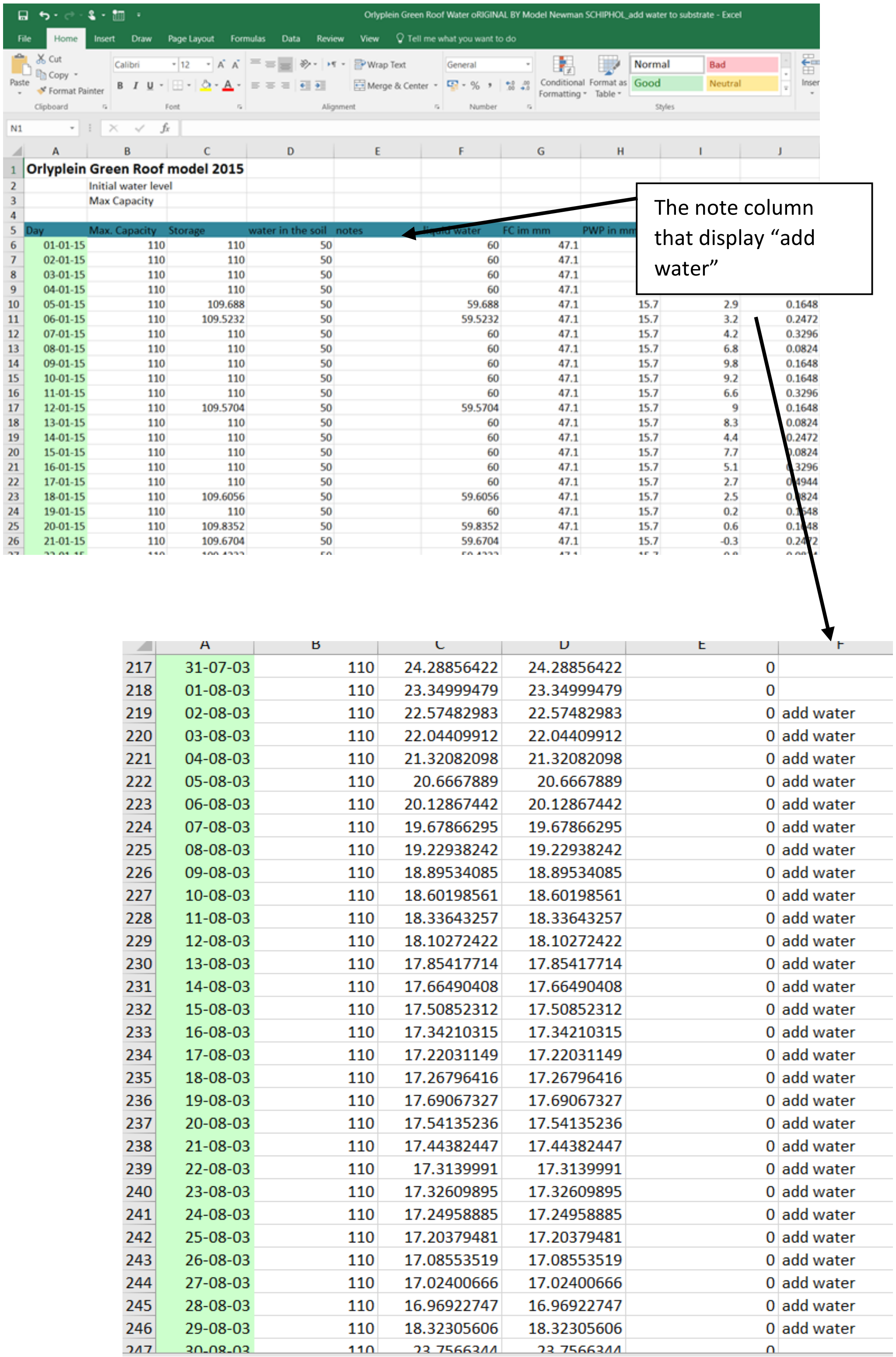
the second step was to link the substrate with this value as shown in the following screen dumps (32 to 35)



Screen dump 32: extended data entry form for managing irrigation water in green park



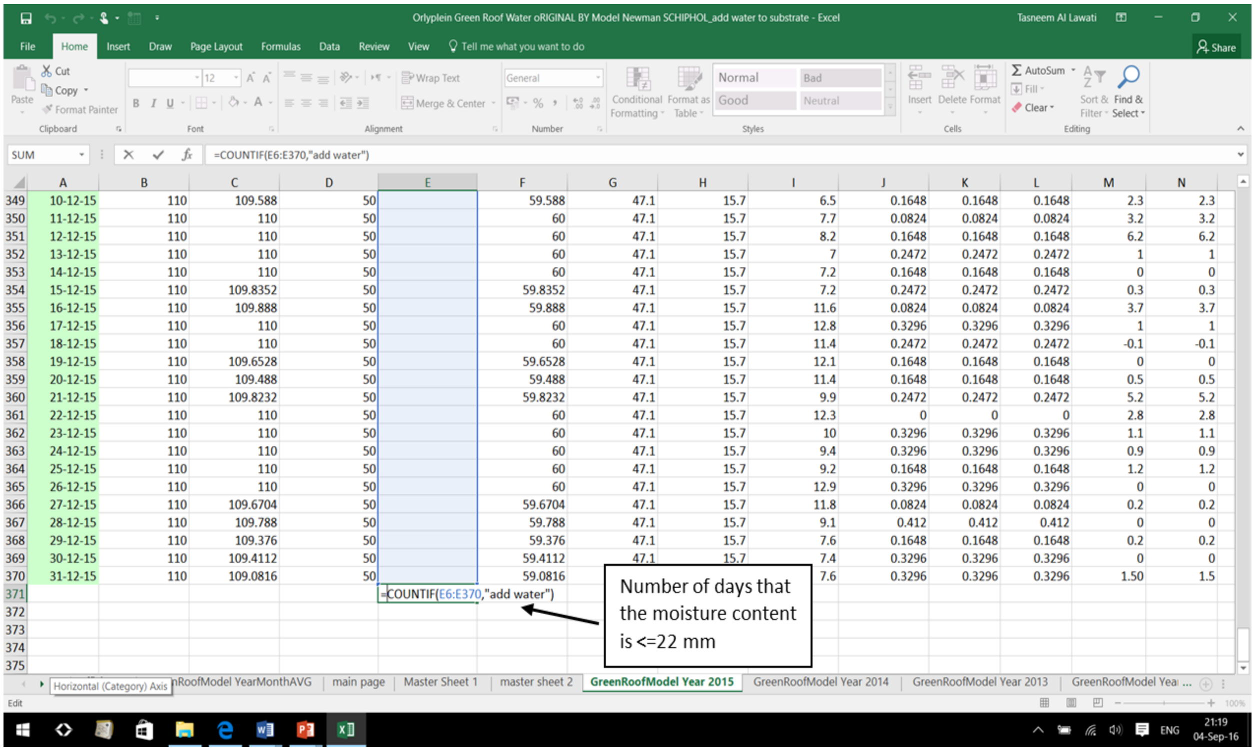
Screen dump 33: Substrate moisture content is controlled by a formula linked to "storage" vales and reference water level.



	A	B	C	D	E	F	G	H	I	J
1	Orlyplein Green Roof model 2015									
2		Initial water level								
3		Max Capacity								
4										
5	Day	Max. Capacity	Storage	water in the soil	notes	liquid water	FC im mm	PWP in mm		
6	01-01-15	110	110	50		60	47.1			
7	02-01-15	110	110	50		60	47.1			
8	03-01-15	110	110	50		60	47.1			
9	04-01-15	110	110	50		60	47.1			
10	05-01-15	110	109.688	50		59.688	47.1	15.7	2.9	0.1648
11	06-01-15	110	109.5232	50		59.5232	47.1	15.7	3.2	0.2472
12	07-01-15	110	110	50		60	47.1	15.7	4.2	0.3296
13	08-01-15	110	110	50		60	47.1	15.7	6.8	0.0824
14	09-01-15	110	110	50		60	47.1	15.7	9.8	0.1648
15	10-01-15	110	110	50		60	47.1	15.7	9.2	0.1648
16	11-01-15	110	110	50		60	47.1	15.7	6.6	0.3296
17	12-01-15	110	109.5704	50		59.5704	47.1	15.7	9	0.1648
18	13-01-15	110	110	50		60	47.1	15.7	8.3	0.0824
19	14-01-15	110	110	50		60	47.1	15.7	4.4	0.2472
20	15-01-15	110	110	50		60	47.1	15.7	7.7	0.0824
21	16-01-15	110	110	50		60	47.1	15.7	5.1	0.3296
22	17-01-15	110	110	50		60	47.1	15.7	2.7	0.4944
23	18-01-15	110	109.6056	50		59.6056	47.1	15.7	2.5	0.0824
24	19-01-15	110	110	50		60	47.1	15.7	0.2	0.1648
25	20-01-15	110	109.8352	50		59.8352	47.1	15.7	0.6	0.1648
26	21-01-15	110	109.6704	50		59.6704	47.1	15.7	-0.3	0.2472

	A	B	C	D	E	F
217	31-07-03	110	24.28856422	24.28856422	0	
218	01-08-03	110	23.34999479	23.34999479	0	
219	02-08-03	110	22.57482983	22.57482983	0	add water
220	03-08-03	110	22.04409912	22.04409912	0	add water
221	04-08-03	110	21.32082098	21.32082098	0	add water
222	05-08-03	110	20.6667889	20.6667889	0	add water
223	06-08-03	110	20.12867442	20.12867442	0	add water
224	07-08-03	110	19.67866295	19.67866295	0	add water
225	08-08-03	110	19.22938242	19.22938242	0	add water
226	09-08-03	110	18.89534085	18.89534085	0	add water
227	10-08-03	110	18.60198561	18.60198561	0	add water
228	11-08-03	110	18.33643257	18.33643257	0	add water
229	12-08-03	110	18.10272422	18.10272422	0	add water
230	13-08-03	110	17.85417714	17.85417714	0	add water
231	14-08-03	110	17.66490408	17.66490408	0	add water
232	15-08-03	110	17.50852312	17.50852312	0	add water
233	16-08-03	110	17.34210315	17.34210315	0	add water
234	17-08-03	110	17.22031149	17.22031149	0	add water
235	18-08-03	110	17.26796416	17.26796416	0	add water
236	19-08-03	110	17.69067327	17.69067327	0	add water
237	20-08-03	110	17.54135236	17.54135236	0	add water
238	21-08-03	110	17.44382447	17.44382447	0	add water
239	22-08-03	110	17.3139991	17.3139991	0	add water
240	23-08-03	110	17.32609895	17.32609895	0	add water
241	24-08-03	110	17.24958885	17.24958885	0	add water
242	25-08-03	110	17.20379481	17.20379481	0	add water
243	26-08-03	110	17.08553519	17.08553519	0	add water
244	27-08-03	110	17.02400666	17.02400666	0	add water
245	28-08-03	110	16.96922747	16.96922747	0	add water
246	29-08-03	110	18.32305606	18.32305606	0	add water
247	30-08-03	110	23.7566344	23.7566344	0	

Screen dump 34: A column titled as “notes” was formatted to display “add water” command based on the values in the substrate when compared with the 22mm



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
349	10-12-15	110	109.588	50		59.588	47.1	15.7	6.5	0.1648	0.1648	0.1648	2.3	2.3
350	11-12-15	110	110	50		60	47.1	15.7	7.7	0.0824	0.0824	0.0824	3.2	3.2
351	12-12-15	110	110	50		60	47.1	15.7	8.2	0.1648	0.1648	0.1648	6.2	6.2
352	13-12-15	110	110	50		60	47.1	15.7	7	0.2472	0.2472	0.2472	1	1
353	14-12-15	110	110	50		60	47.1	15.7	7.2	0.1648	0.1648	0.1648	0	0
354	15-12-15	110	109.8352	50		59.8352	47.1	15.7	7.2	0.2472	0.2472	0.2472	0.3	0.3
355	16-12-15	110	109.888	50		59.888	47.1	15.7	11.6	0.0824	0.0824	0.0824	3.7	3.7
356	17-12-15	110	110	50		60	47.1	15.7	12.8	0.3296	0.3296	0.3296	1	1
357	18-12-15	110	110	50		60	47.1	15.7	11.4	0.2472	0.2472	0.2472	-0.1	-0.1
358	19-12-15	110	109.6528	50		59.6528	47.1	15.7	12.1	0.1648	0.1648	0.1648	0	0
359	20-12-15	110	109.488	50		59.488	47.1	15.7	11.4	0.1648	0.1648	0.1648	0.5	0.5
360	21-12-15	110	109.8232	50		59.8232	47.1	15.7	9.9	0.2472	0.2472	0.2472	5.2	5.2
361	22-12-15	110	110	50		60	47.1	15.7	12.3	0	0	0	2.8	2.8
362	23-12-15	110	110	50		60	47.1	15.7	10	0.3296	0.3296	0.3296	1.1	1.1
363	24-12-15	110	110	50		60	47.1	15.7	9.4	0.3296	0.3296	0.3296	0.9	0.9
364	25-12-15	110	110	50		60	47.1	15.7	9.2	0.1648	0.1648	0.1648	1.2	1.2
365	26-12-15	110	110	50		60	47.1	15.7	12.9	0.3296	0.3296	0.3296	0	0
366	27-12-15	110	109.6704	50		59.6704	47.1	15.7	11.8	0.0824	0.0824	0.0824	0.2	0.2
367	28-12-15	110	109.788	50		59.788	47.1	15.7	9.1	0.412	0.412	0.412	0	0
368	29-12-15	110	109.376	50		59.376	47.1	15.7	7.6	0.1648	0.1648	0.1648	0.2	0.2
369	30-12-15	110	109.4112	50		59.4112	47.1	15.7	7.4	0.3296	0.3296	0.3296	0	0
370	31-12-15	110	109.0816	50		59.0816			7.6	0.3296	0.3296	0.3296	1.50	1.5
371					=COUNTIF(E6:E370,"add water")									

Screen dump 35: Count if formula is used to indicate the reduction in days as water is added to the system

This procedure was repeated on the permavoid data and on Laurens van de Werken model. Results are presented in section 4.8 in results and discussion chapter

Chapter 4: findings and discussion

4.1 Preliminary Logical Modification- Water Content Below Zero

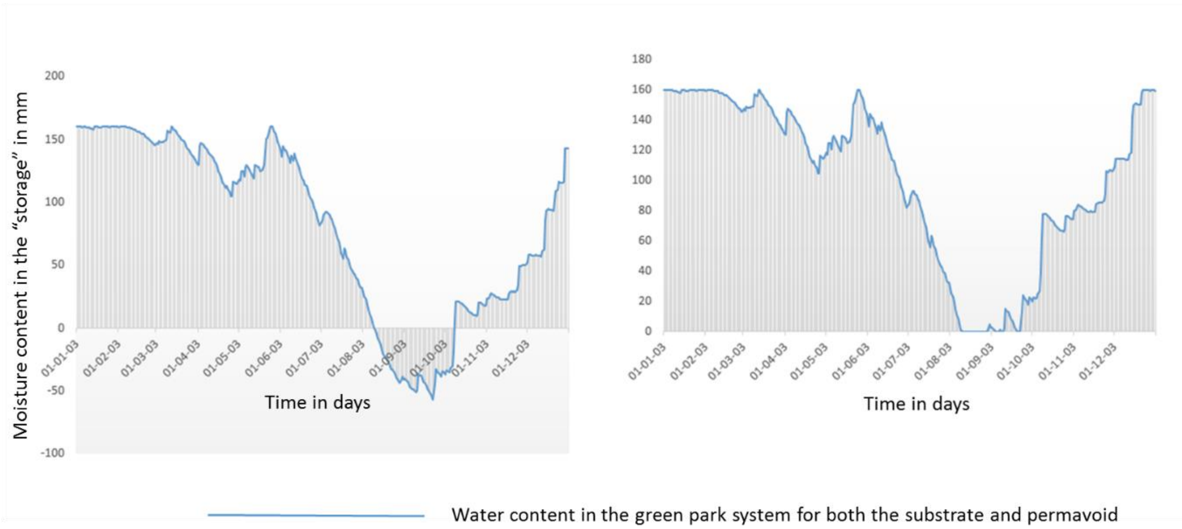


Figure 15: the difference between the “storage” water level before (left) and after (right) modeming the “storage formula

As mentioned in the previous chapter, van de Werken model contained formula that allowed water to evapotranspire from a roof which was devoid of water. Thus, negative values apeared in the model, representing the water level in the storage. This was unrealistic because the lowest value that GRS can hold is zero water. The secound graph in figure 15 presents the water level in “storage” after the modification.

With this modification, the model became more closely to present and simulates the real moisture setuation in the GRS, but it is still difficult to predict and study the water behaviour in the system espically when its asosiated with the cange in P and ET values. Thus, the need for a graph the moisture content in the substrate and the water in the storage emerged.

4.2 Dividing the Stored Water into Realistic Compartments

After dividing the water content into the amount mentioned by (Newman A. et al 2016), records from 2000 to 2015 were graphed as shown in figure15 It was preferable to discuss three years with different rain patterns to discuss about because of war limit restriction. By investigating the wet year (2012), normal year (2008) and a dry year (2003) it was found that the 2008 and 2003 graphs present a shift when comparing water in soil and water in storage. The shift in the days where moisture content is start to respond to the absence of the rain is observed more in the permavoid graph. On the other had the recovery is faster in the substrate moisture content even if the amount of storage water is low. The reason behind this behaviour is the capillary fibres which leads the storage to act as a second stage receptor during rain events after the substrate is saturated and as a donor during dry days. This means that plants growth will not be affected with water storage. Keeping plants alive increases water retention and insure green roof sustainability. (Hakimdavar et al. 494-508)

Figure 16: Graphs of years 2000 to 2015 presenting the moisture content in substrate (blue line in mm), permavoid (red line in mm) field capacity (green line in mm) and permanent wilting point (purple line in mm). the X access presents is time in days and the Y access is the moisture content in the "storage" in mm

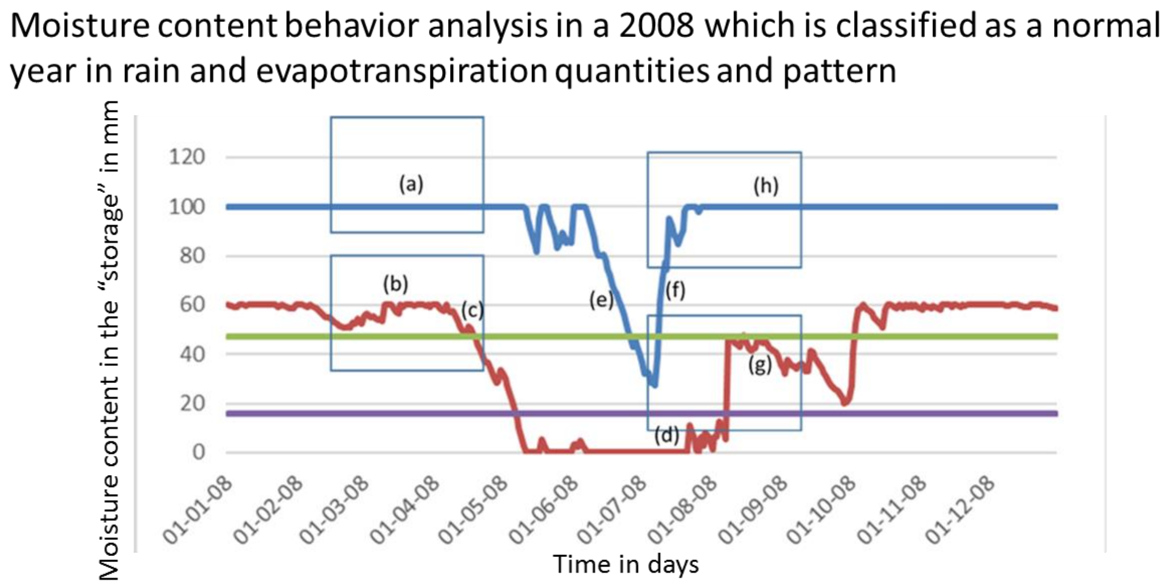


Figure 17: 2008 graph presenting the moisture content in substrate (blue line in mm), permavoid (red line in mm) field capacity (green line in mm) and permanent wilting point (purple line in mm).

Observing figure 17 which presents a normal year (2008)

- (a) the substrate is acting as primary receiver for rain events water. It reaches to the substrate saturation point and pass the water to the permavoid as a second receiver
- (b) water level increases in the storage which makes the substrate in stable saturation level
- (c) rain events stop. The water in the substrate is still constant at 100 mm but the water level in the permavoid starts to decrease because it is acting as a donor to the substrate and ET is evaporating water from the substrate.
- (d) as water moves through the capillary fibers, the permavoid gets empty because no recharging from the substrate.
- (e) water level in the substrate start to decrease because of ETa process. the water level reach to the (water available to plants) area
- (f) rain events start again, and the substrate acts as a primary receiver. Water level increases till it reaches to the saturation point
- (g) as the first part of the system reach to the saturation point. Water passes to the permavoid and water level increases.
- (h) the substrate stays saturated and pass excess water to the permavoid as long as rain events continues

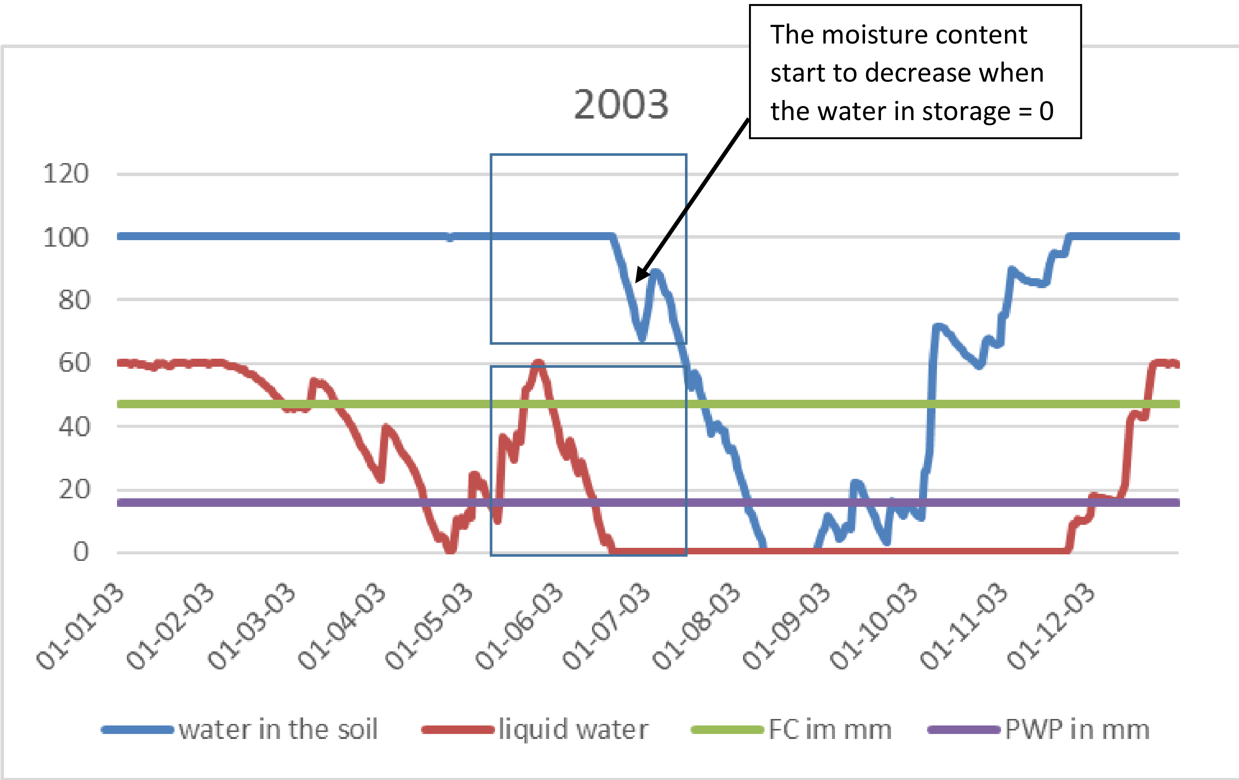


Figure 18 Moisture content behavior analysis in a 2003 which is classified as a dry year in rain and evapotranspiration quantities and pattern

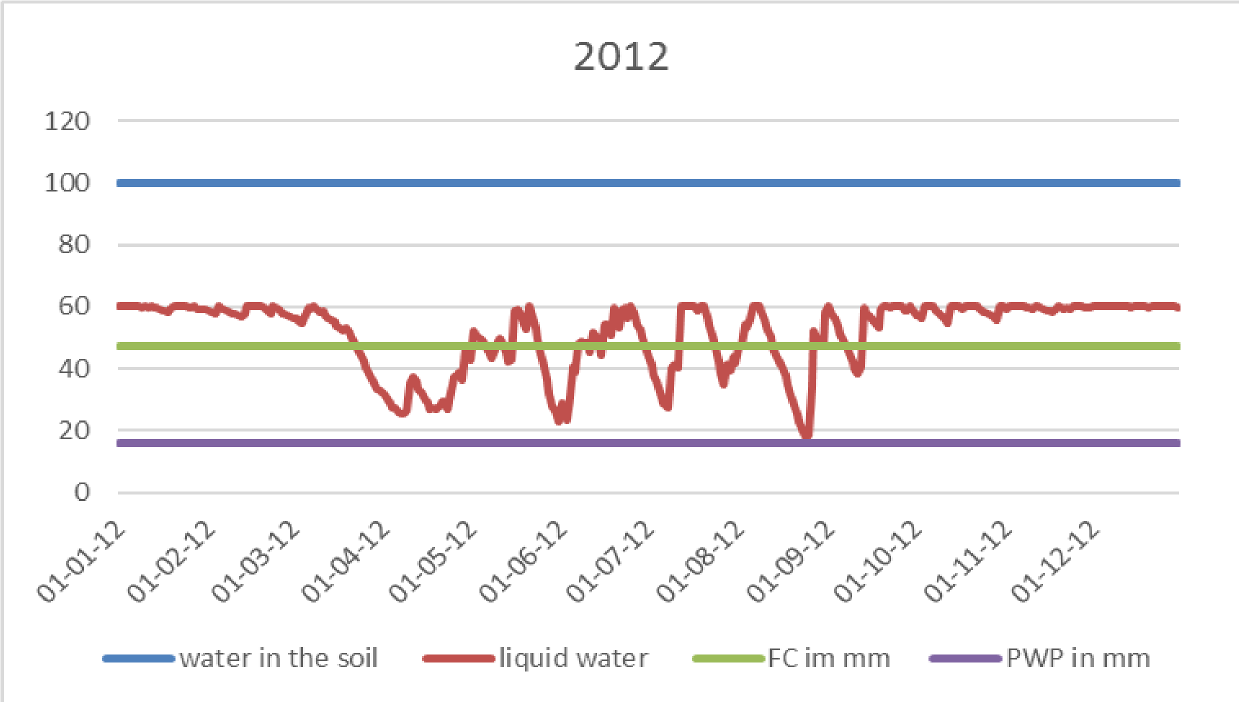


Figure 19: Moisture content behavior analysis in a 2012 which is classified as a wet year in rain and evapotranspiration quantities and pattern

This was supported by (Newman A. et al 2016) study which compared the performance of a model used capillary fibres system with a standard green roof installation. The graph presented in figure 19 suggests that using a capillary fiber to feed the system with water, helps to maintain consistent soil moisture content during from August to September including dry periods essentially the continuity of feeding the substrate with water is due to the presence of water in the permavoid, regardless the actual amount of moisture in the substrate, which does not occur in the traditional green roof system.

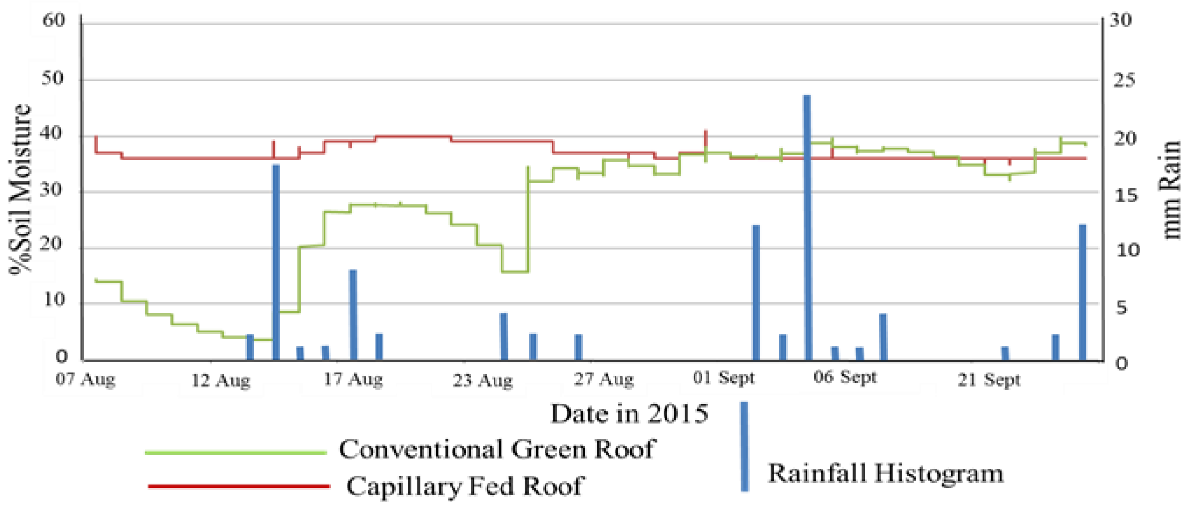


Figure 20: the graph is comparing moisture content of a green roof of capillary system and a typical green roof

4.3 substrate physical characteristics lab experiments

the previous section presented how important to understand water movement to benefit from the system to the maximum stage. The movement of water from and to the substrate can be affected by the natural and physical elements occurring in the system such as precipitation, evapotranspiration, temperature, and particle size in the substrate. Performing the physical analysis on substrate in the lab, analyzing the data that requested from (Permavoid Ltd) and examining this information in the two models resulted the following information

Soil type	Loamy sand
Filed capacity	74.1 mm
Moisture content	34.0 mm
Permanent wilting point	15.7 mm

In green roof system, it is important for plants to stay healthy, at the same time water should move from substrate to permavoid in an adequate rate. Organic matter percentage and soil particle size play an important role in achieving the balance between storm water retention and providing a healthy medium or help in minimizing the impact of drought on the plants.

Organic matter effects the physical characteristics of a soil in several ways. Organic matter acts as a glue agent which enhance soil particles of different together which enhance rainwater infiltration and reduces runoff. Additionally, it provides a fertile medium for plants and microorganisms to live. However, the results illustrated that the substrate consists of sandy Lomé which infiltrate water more than 50 mm/h which is a short period of time when compared to other soil texture. Such drainage appears through soil types with large pores such as sandy soils

The joint effect of substrate absorbing rainfall and plants using water is influenced by field capacity and permanent wilting point. Stormwater retention is suggested to be affected by substrate's capability to absorb and store water (substrate field capacity) and supply it to plants till water reach to permanent wilting point. Both FC and PWP are affected by the growing media composition. It is important to understand the availability of water to keep the "roof park" alive, which emphasis on the importance to update the model with FC and PWP values as it is presented in the nest sections.

Based on the physical analysis, it is worth mentioning that these substrate tests revealed an error in the model. The model calculated 100 mm as a substrate water holding capacity, which is actually the saturation level of the substrate. The 100 mm will be reduced to the field capacity after 2 to 3 days and excess water transferred to the permavoid for storage. Although The graph presented by (Newman et al 2016) illustrated that the water level in the system is between 40 to 50 mm ,(see figure20) the model is setting 100 mm as usual substrate field capacity. The process of mitigating this problem is explained in more detail in sections 4 .6 and 4.7

4.4 Sensitivity analysis

Since GRS is responding naturally to the change in evapotranspiration, soil particle size, wind speed, temperature and precipitation along with other natural factors affecting the water navigation in the GRS, it was essential to perform sensitivity analysis, in order to define how significant is the effect if the change occur on some factors such as P and ET on green roof.

The sensitivity analysis was performed on the three selected years. The result of sensitivity analysis reflected that GRS responds to change in evapotranspiration and precipitation differently according to the rain pattern of the year. For example, the number of days that the substrate contained no water were equal to 27 days in 2003 but the substrate preserved sufficient amount of water in 2008 and 2012. When the evapotranspiration was increased by 0.1 mm, dry days increased by 3 to 8 days in year 2003, whereas in the wet year (2012), only small amount of change occurred when the ET increased to 1mm (Figure 21). Similar situation occurred when precipitation values were increased by 0.1mm. The only difference was that the number of substrate dry days decreased from 3 to 8 in 2003, as precipitation increased by 0.1mm. (figure 22). To interpret the charts presented in the in this section, it is worth noting that precipitation has a positive effect on the GRS drying the dry year which means that an increase in P value would decrees the dry days. The opposite effect was of increasing ET values on number of dry days

This test studies the effect of one variable at a time, which means that precipitation equals zero when evapotranspiration value is changed. Additionally, the change in the variable was from 0 to (+/-1) mm. In reality, both variables might change in value and percentage, and since net inflow of GRS = precipitation – evapotranspiration, a sensitivity analysis table was established to present the difference in the net inflow if value of P and ET changed from 0 to (+/-1) mm. Table 3. For example, a change in precipitation that equals to -0.5mm and in evapotranspiration that equals to 0.9mm results a change of 1.4 mm in the net inflow of GRS. Theoretically, +/- 1mm change in P and ET is not the case. These values are really low when compared to the model even it is a dry year. studies presenting change in these two variable as percentage. Based on that, a sensitivity analysis table was established for the three years to present the amount of changing in net inflow if P and ET changed as a value from 0% to (+/-10%) tables 4 to 6.

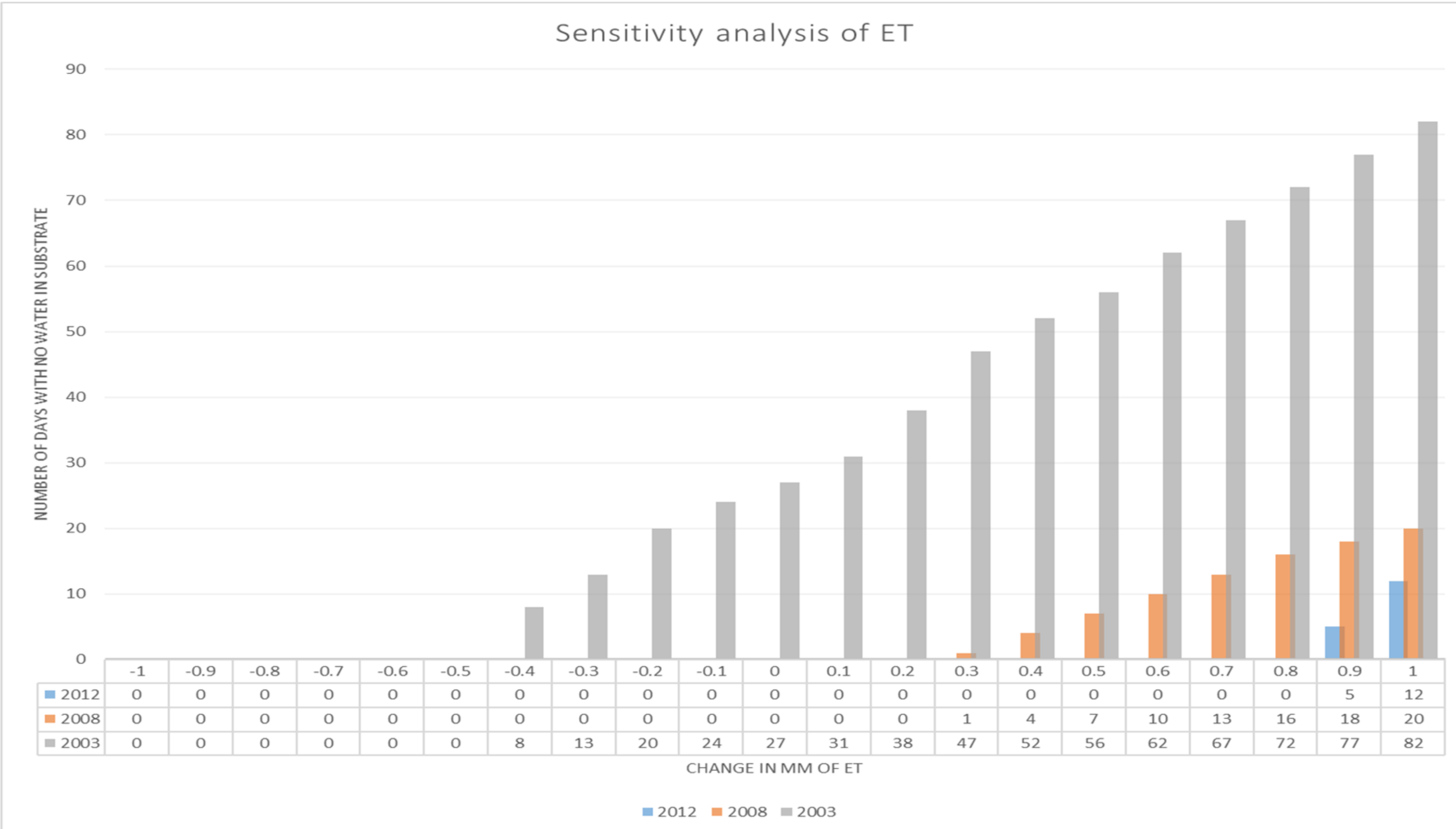
The staked chart reveals that dry year is highly affected by minimum change in the precipitation and evapotranspiration as compared to the normal-pattern year. Thus, unlike year 2003 when the effect was noticeable, this was highly negligible in year 2008. Moreover, the effect of the two variables was minimal in the wet year 2012. This reflect that the rain pattern in the three years and solar radiation that accelerate ET process have an effect on the moisture content of GRS especially when the substrate is consisting of high percentage of sand particles.

Table 3 Sensitivity analysis table for the tow variables affecting the net inflow (-1 – 0 – 1)

These values representing Evapotranspiration →

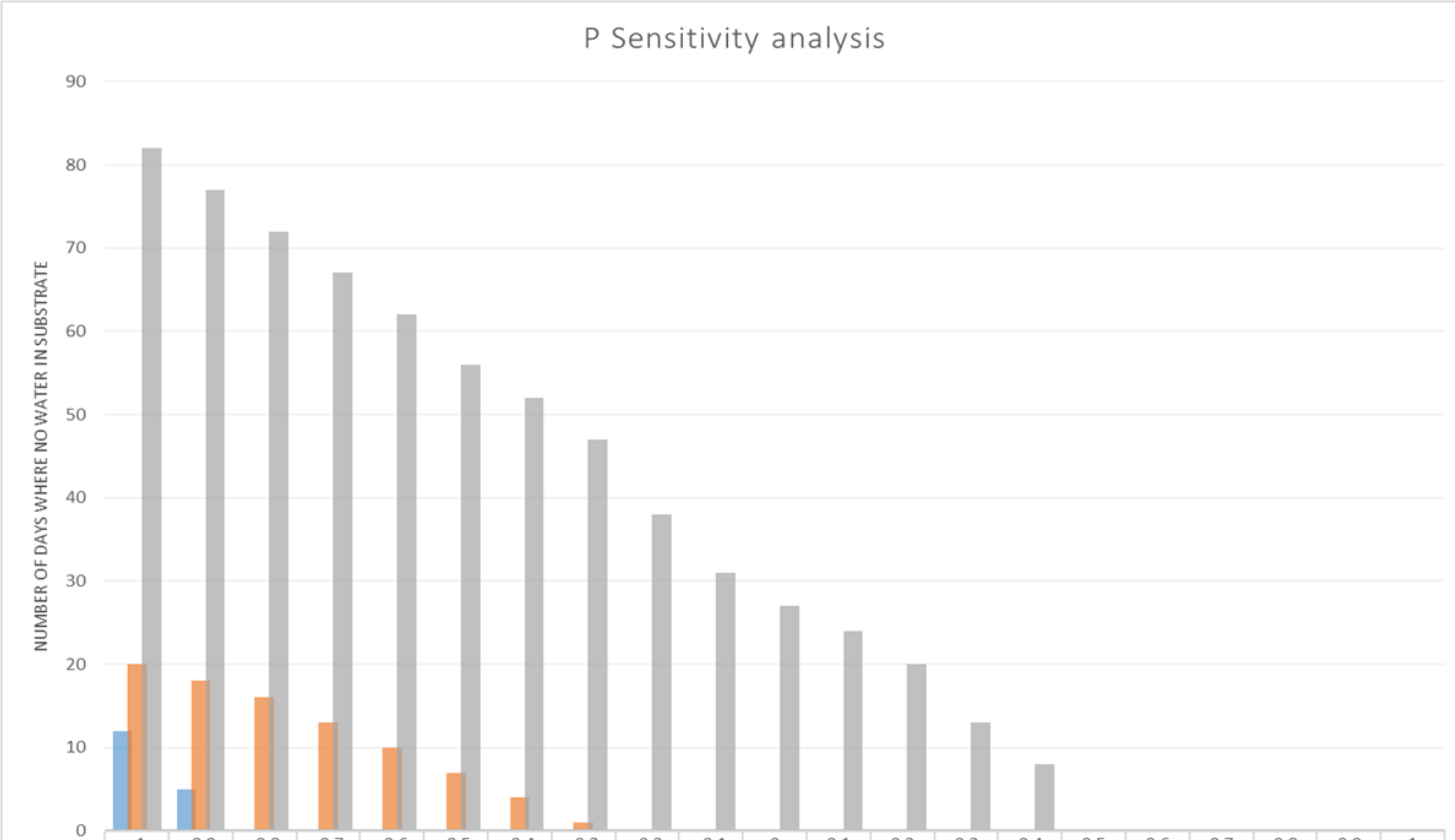
These values representing precipitation ↓

	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1
1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1	-1.1	-1.2	-1.3	-1.4	-1.5	-1.6	-1.7	-1.8	-1.9	-2
0.9	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1	-1.1	-1.2	-1.3	-1.4	-1.5	-1.6	-1.7	-1.8	-1.9
0.8	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1	-1.1	-1.2	-1.3	-1.4	-1.5	-1.6	-1.7	-1.8
0.7	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1	-1.1	-1.2	-1.3	-1.4	-1.5	-1.6	-1.7
0.6	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1	-1.1	-1.2	-1.3	-1.4	-1.5	-1.6
0.5	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1	-1.1	-1.2	-1.3	-1.4	-1.5
0.4	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1	-1.1	-1.2	-1.3	-1.4
0.3	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1	-1.1	-1.2	-1.3
0.2	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1	-1.1	-1.2
0.1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1	-1.1
0	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1
-0.1	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9
-0.2	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8
-0.3	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7
-0.4	1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6
-0.5	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5
-0.6	1.6	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4
-0.7	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3
-0.8	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1	-0.2
-0.9	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	-0.1
-1	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0



	-1	-0.9	-0.8	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	12
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	7	10	13	16	18	20
2003	0	0	0	0	0	0	8	13	20	24	27	31	38	47	52	56	62	67	72	77	82

Figure 21:This graph is presenting number of days where moisture content reached to zero level in the substrate by increasing evapotranspiration by (-/+ 0.1) every test. The most sensitive year to the change in ET was year 2003 (dry year) where the change start to occur at (-0.4). 2008 responded to change in ET at late stage compared to 2003 because 2008 is considered as a normal year in its rainfall and evapotranspiration levels. Finally, 2012 (wet year) respond to the change in ET only when it reached to 1mm and number of days in 2012 where moisture content reached to zero level were very low compared to the dry year.



	-1	-0.9	-0.8	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
2012	12	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	20	18	16	13	10	7	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	82	77	72	67	62	56	52	47	38	31	27	24	20	13	8	0	0	0	0	0	0

Figure 22: This graph is presenting number of days where moisture content reached to zero level in the substrate by decreasing precipitation by (-/+ 0.1) every test. The most sensitive year to the change in P was year 2003 (dry year) where the change start to occur at (0.4). 2008 responded to change in ET at late stage compared to 2003 because 2008 is considered as a normal year in its rainfall and evapotranspiration levels. Finally, 2012 (wet year) respond to the change in ET only when it reached to (-1mm) and number of days in 2012 where moisture content reached to zero level were very low compared to the dry year.

Table 4: Sensitivity analysis table for the tow variables affecting the net inflow till +/- 10% for 2012

These values representing Evapotranspiration →

These values representing precipitation ↓

	10%	9%	8%	7%	6%	5%	4%	3%	2%	1%	0%	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%	-10%
10%	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061	-0.069	-0.076	-0.084	-0.092	-0.099	-0.107	-0.115	-0.122	-0.13	-0.137	-0.145	-0.153
9%	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061	-0.069	-0.076	-0.084	-0.092	-0.099	-0.107	-0.115	-0.122	-0.13	-0.137	-0.145
8%	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061	-0.069	-0.076	-0.084	-0.092	-0.099	-0.107	-0.115	-0.122	-0.13	-0.137
7%	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061	-0.069	-0.076	-0.084	-0.092	-0.099	-0.107	-0.115	-0.122	-0.13
6%	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061	-0.069	-0.076	-0.084	-0.092	-0.099	-0.107	-0.115	-0.122
5%	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061	-0.069	-0.076	-0.084	-0.092	-0.099	-0.107	-0.115
4%	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061	-0.069	-0.076	-0.084	-0.092	-0.099	-0.107
3%	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061	-0.069	-0.076	-0.084	-0.092	-0.099
2%	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061	-0.069	-0.076	-0.084	-0.092
1%	0.069	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061	-0.069	-0.076	-0.084
0%	0.076	0.069	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061	-0.069	-0.076
-1%	0.084	0.076	0.069	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061	-0.069
-2%	0.092	0.084	0.076	0.069	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053	-0.061
-3%	0.099	0.092	0.084	0.076	0.069	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.053
-4%	0.107	0.099	0.092	0.084	0.076	0.069	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046
-5%	0.115	0.107	0.099	0.092	0.084	0.076	0.069	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038
-6%	0.122	0.115	0.107	0.099	0.092	0.084	0.076	0.069	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031
-7%	0.13	0.122	0.115	0.107	0.099	0.092	0.084	0.076	0.069	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023
-8%	0.137	0.13	0.122	0.115	0.107	0.099	0.092	0.084	0.076	0.069	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015
-9%	0.145	0.137	0.13	0.122	0.115	0.107	0.099	0.092	0.084	0.076	0.069	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008
-10%	0.153	0.145	0.137	0.13	0.122	0.115	0.107	0.099	0.092	0.084	0.076	0.069	0.061	0.053	0.046	0.038	0.031	0.023	0.015	0.008	0

Table 5: Sensitivity analysis table for the tow variables affecting the net inflow, +/- 10% for 2008

These values representing Evapotranspiration →

These values representing precipitation ↓

	10%	9%	8%	7%	6%	5%	4%	3%	2%	1%	0%	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%	-10%
10%	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062	-0.069	-0.077	-0.085	-0.092	-0.1	-0.108	-0.115	-0.123	-0.131	-0.138	-0.146	-0.154
9%	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062	-0.069	-0.077	-0.085	-0.092	-0.1	-0.108	-0.115	-0.123	-0.131	-0.138	-0.146
8%	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062	-0.069	-0.077	-0.085	-0.092	-0.1	-0.108	-0.115	-0.123	-0.131	-0.138
7%	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062	-0.069	-0.077	-0.085	-0.092	-0.1	-0.108	-0.115	-0.123	-0.131
6%	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062	-0.069	-0.077	-0.085	-0.092	-0.1	-0.108	-0.115	-0.123
5%	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062	-0.069	-0.077	-0.085	-0.092	-0.1	-0.108	-0.115
4%	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062	-0.069	-0.077	-0.085	-0.092	-0.1	-0.108
3%	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062	-0.069	-0.077	-0.085	-0.092	-0.1
2%	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062	-0.069	-0.077	-0.085	-0.092
1%	0.069	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062	-0.069	-0.077	-0.085
0%	0.077	0.069	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062	-0.069	-0.077
-1%	0.085	0.077	0.069	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062	-0.069
-2%	0.092	0.085	0.077	0.069	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054	-0.062
-3%	0.1	0.092	0.085	0.077	0.069	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046	-0.054
-4%	0.108	0.1	0.092	0.085	0.077	0.069	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038	-0.046
-5%	0.115	0.108	0.1	0.092	0.085	0.077	0.069	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031	-0.038
-6%	0.123	0.115	0.108	0.1	0.092	0.085	0.077	0.069	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023	-0.031
-7%	0.131	0.123	0.115	0.108	0.1	0.092	0.085	0.077	0.069	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015	-0.023
-8%	0.138	0.131	0.123	0.115	0.108	0.1	0.092	0.085	0.077	0.069	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008	-0.015
-9%	0.146	0.138	0.131	0.123	0.115	0.108	0.1	0.092	0.085	0.077	0.069	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0	-0.008
-10%	0.154	0.146	0.138	0.131	0.123	0.115	0.108	0.1	0.092	0.085	0.077	0.069	0.062	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0

Table 6: Sensitivity analysis table for the tow variables affecting the net inflow, +/- 10% for 2003

These values representing Evapotranspiration

These values representing precipitation

	10%	9%	8%	7%	6%	5%	4%	3%	2%	1%	0%	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%	-10%
10%	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186	-0.209	-0.233	-0.256	-0.279	-0.302	-0.326	-0.349	-0.372	-0.395	-0.419	-0.442	-0.465
9%	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186	-0.209	-0.233	-0.256	-0.279	-0.302	-0.326	-0.349	-0.372	-0.395	-0.419	-0.442
8%	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186	-0.209	-0.233	-0.256	-0.279	-0.302	-0.326	-0.349	-0.372	-0.395	-0.419
7%	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186	-0.209	-0.233	-0.256	-0.279	-0.302	-0.326	-0.349	-0.372	-0.395
6%	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186	-0.209	-0.233	-0.256	-0.279	-0.302	-0.326	-0.349	-0.372
5%	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186	-0.209	-0.233	-0.256	-0.279	-0.302	-0.326	-0.349
4%	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186	-0.209	-0.233	-0.256	-0.279	-0.302	-0.326
3%	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186	-0.209	-0.233	-0.256	-0.279	-0.302
2%	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186	-0.209	-0.233	-0.256	-0.279
1%	0.209	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186	-0.209	-0.233	-0.256
0%	0.233	0.209	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186	-0.209	-0.233
-1%	0.256	0.233	0.209	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186	-0.209
-2%	0.279	0.256	0.233	0.209	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163	-0.186
-3%	0.302	0.279	0.256	0.233	0.209	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14	-0.163
-4%	0.326	0.302	0.279	0.256	0.233	0.209	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116	-0.14
-5%	0.349	0.326	0.302	0.279	0.256	0.233	0.209	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093	-0.116
-6%	0.372	0.349	0.326	0.302	0.279	0.256	0.233	0.209	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07	-0.093
-7%	0.395	0.372	0.349	0.326	0.302	0.279	0.256	0.233	0.209	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047	-0.07
-8%	0.419	0.395	0.372	0.349	0.326	0.302	0.279	0.256	0.233	0.209	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023	-0.047
-9%	0.442	0.419	0.395	0.372	0.349	0.326	0.302	0.279	0.256	0.233	0.209	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0	-0.023
-10%	0.465	0.442	0.419	0.395	0.372	0.349	0.326	0.302	0.279	0.256	0.233	0.209	0.186	0.163	0.14	0.116	0.093	0.07	0.047	0.023	0

4.5 Examining Uncertainty in the Rainfall Data

the previous secton interpret how natural variable can increase or decrease number of days where the moisture content equels zero . because GRS is depending on raine events for irrigation, it was esential to study the error in rain events. 10% is the highies persntage that was studired in section 4.4. The question is what if 10% of the time a predicted rain event did not occur? How would the green roof react?

Following the process of testing uncertainty in the Rainfall Data presented in chapter 3, the results were as follows:

Table 7: Number of days where the soil moisture content is equal to & below the wilting point when rainwater is erroneously dumped from the system for 10% of rain events

Year	**small values (5 mm to 6.5 mm)**	**Mixed values odd months (random selection from 5 mm to 40 mm)**	**Mixed values even months (random selection from 5 mm to 40 mm)**	**High values (≥ 25mm)**
2012	0	0	0	12
2008	7	11	22	123
2003	74	101	98	121

Table 8: Number of days where the soil moisture content in the substrate is equal to zero when rainwater is erroneously dumped from the system for 10% of rain events

Year	**small values (5 mm to 6.5 mm)**	**Mixed values odd months (random selection from 5 mm to 40 mm)**	**Mixed values even months (random selection from 5 mm to 40 mm)**	**High values (≥ 25mm)**
2012	0	0	0	5
2008	0	5	11	81
2003	32	75	63	56

Further to the observations presented in section 4.5, it was found that in 2003, the days where moisture content was ≤ PWP (15 .8 mm) changed from 50 to 74 days even when the change in precipitation values were in the small values set. This refer to that the change in the numbers of small value affected soil moisture significantly. Additionally, there was no significant change in number of days that the substrate moisture content was lower than PWP value, when the test was performed using random mixed values in odd and even months, and only high precipitation values through the year. This conclude that because 2003 is a dry year, it is sensitive to any change in the variable even if the values were from low range. The same situation appeared in the result of 2003 in table 7 when comparing the results of the substrate moisture content equals to zero in table 8

As might be expected with the results of 2008, since it is classified as a normal year with normal averages of evapotranspiration and precipitation, the change in days where substrate moisture content reached to wilting point or to zero increased gradually as the precipitation values that used in the test increased.

To the contrary, 2012 results presented an opposite situation to 2003. The only affect that appeared on substrate moisture content when the change in precipitation values were in the high values set. Since 2012 classified as wet year, the GRS contained a sufficient amount of water where even the random values on odd and even months show no effect on the moisture content. This illustrate that in the case of a wet year, the water in the permavoid might need to be drained to maximize the water retention process during rain events. Graphs in images from 23 to34 presents the changes in the three years as the test was performed.

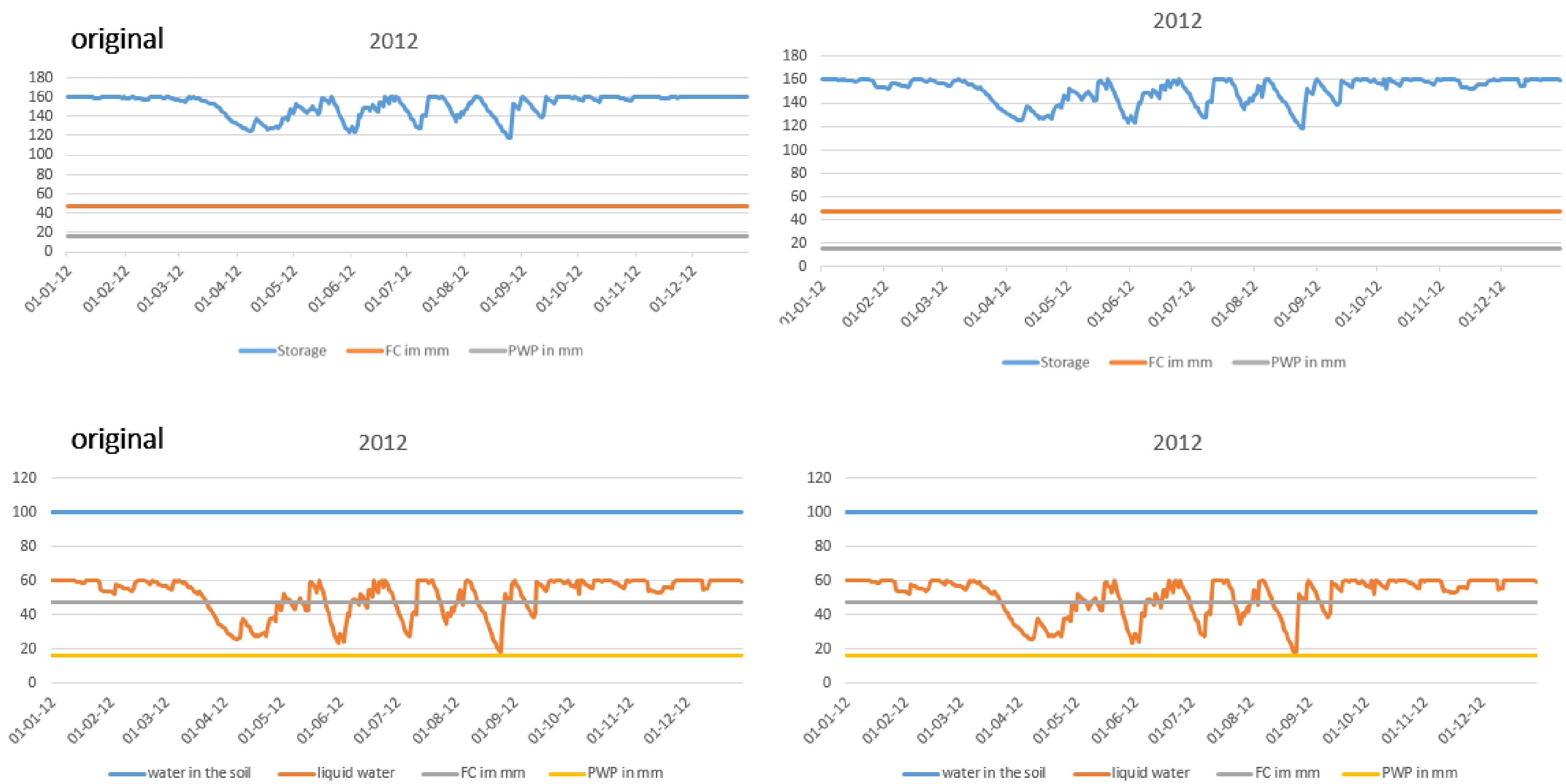


Figure 23: these graphs represent 2012 (wet year) and its response to the change in precipitation values in examining the uncertainty in rainfall data. The two graphs that positioned on the left side are presenting the original condition of 2012. By change the precipitation values using small range of rain fall in mm, the graph showed no change in the substrate (water in soil) moisture content or the liquid water (permavoid) because of high rainfall records. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm

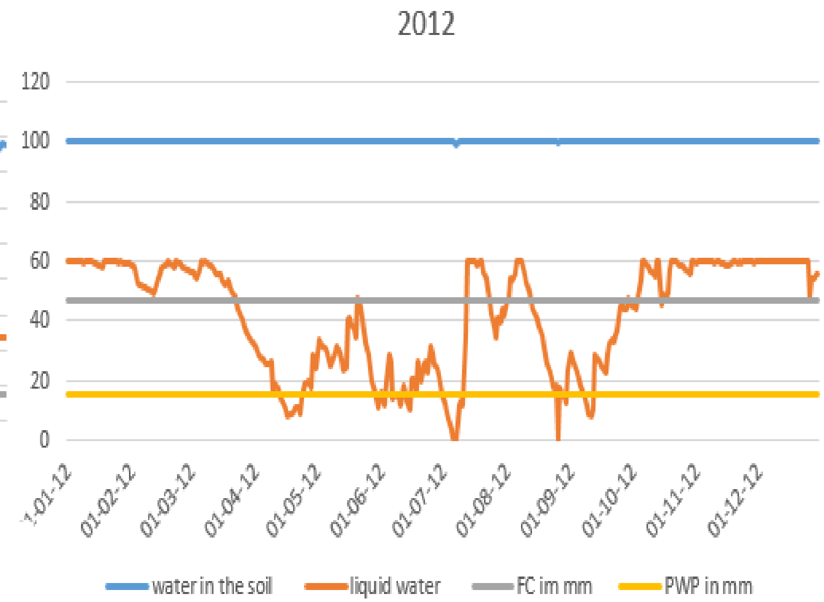


Figure 24: These graphs represent 2012 (wet year) and its response to the change in precipitation values in examining the uncertainty in rainfall data. By change the precipitation values using random values congaing high and small range of rain fall in mm and the change was in the even months, the graph showed a change in the liquid water (permavoid) moisture content where it reached to permanent wilting point. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm

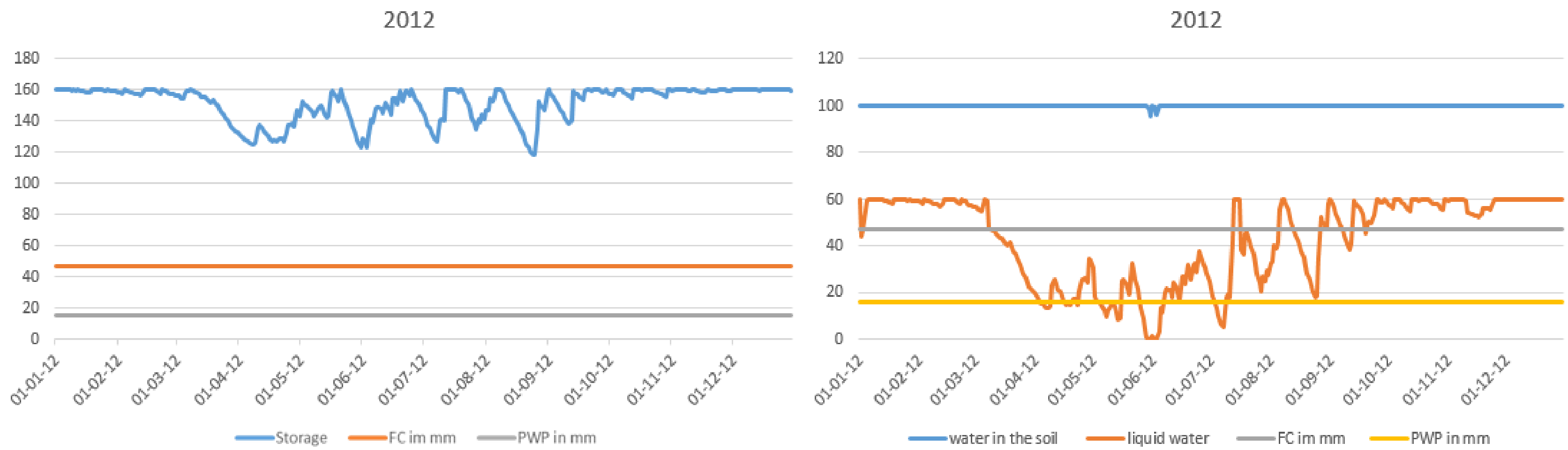


Figure 25: These graphs represent 2012 (wet year) and its response to the change in precipitation values in examining the uncertainty in rainfall data. By change the precipitation values using random values congaing high and small range of rain fall in mm and the change was in the odd months, the graph showed a change in the liquid water (permavoid) moisture content where it reached to permanent wilting point. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm

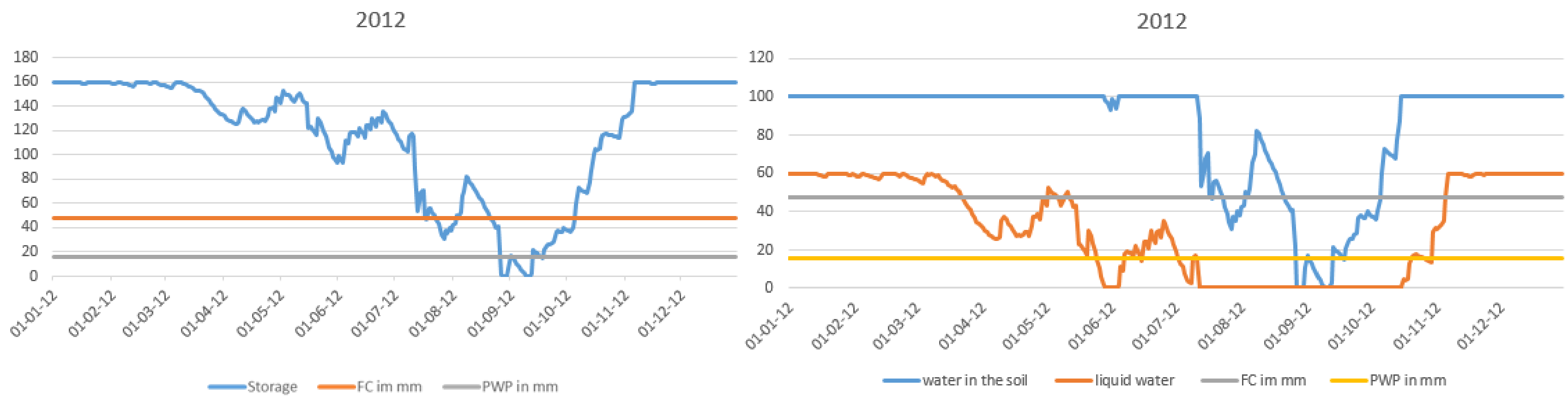
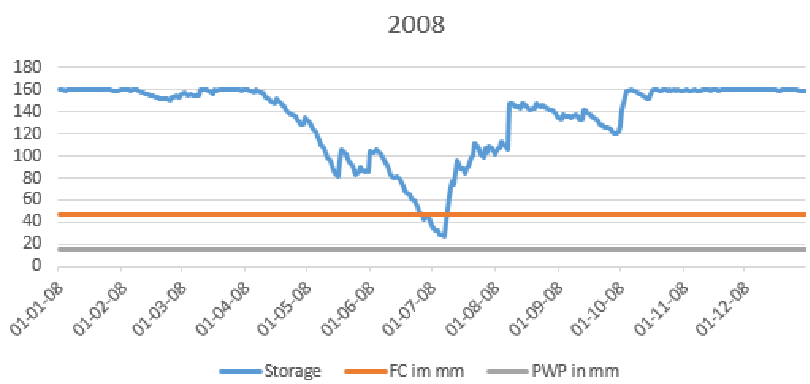


Figure 26: These graphs represent 2012 (wet year) and its response to the change in precipitation values in examining the uncertainty in rainfall data. By change the precipitation values using only high range of rain fall in mm and the change was in the odd months, the graph showed a change in the water in soil (substrate) and liquid water (permavoid) moisture content where it reached below permanent wilting point between September and October. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm

Figure 27: these graphs represent 2008 (normal year) and its response to the change in precipitation values in examining the uncertainty in rainfall data. The two graphs that positioned on the left side are presenting the original condition of 2008. By change the precipitation values using small range of rain fall in mm, the graph a moderate change in the substrate (water in soil) moisture content and a significant change in the liquid water (permavoid) because of normal rainfall records of 2008. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm



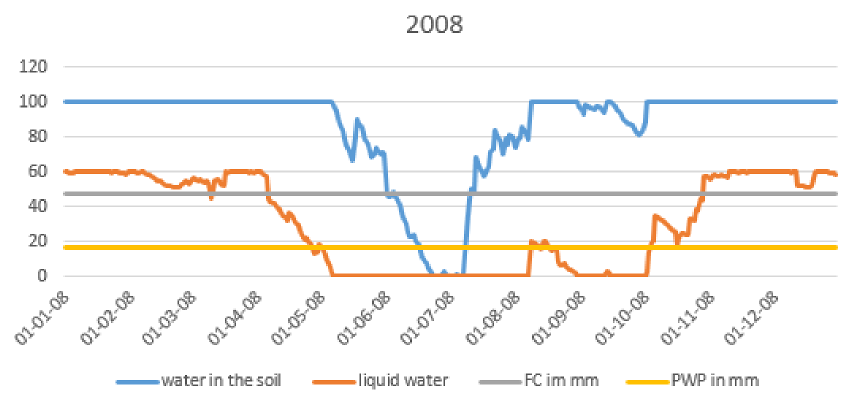


Figure 28: These graphs represent 2008) and their response to the change in precipitation values in examining the uncertainty in rainfall data. By change the precipitation values using random values congaing high and small range of rain fall in mm and the change was in the even months, the graph showed a change in the substrate (water in soil) and liquid water (permavoid) moisture content where it reached to permanent wilting point. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm

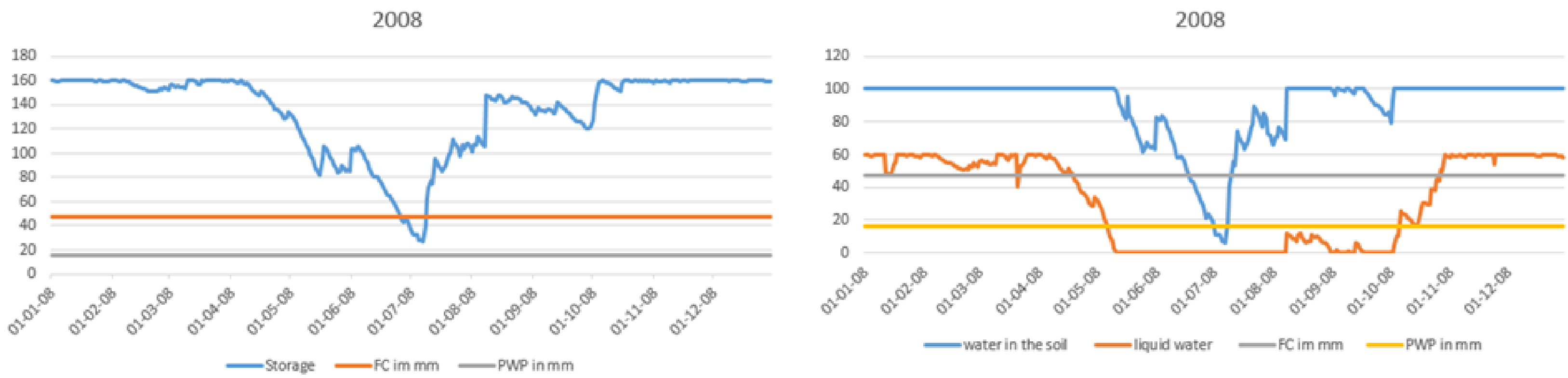
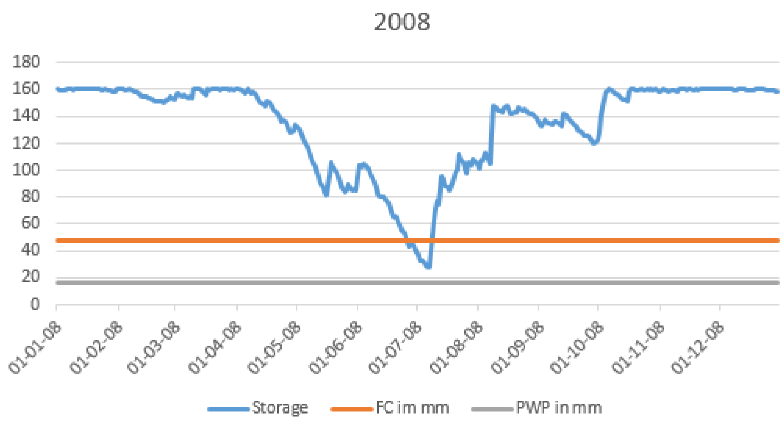


Figure 29: These graphs represent 2008) and their response to the change in precipitation values in examining the uncertainty in rainfall data. By change the precipitation values using random values congaing high and small range of rain fall in mm and the change was in the even months, the graph showed a change in the substrate (water in soil) and liquid water (permavoid) moisture content where it reached to permanent wilting point. Comparing these graphs with figure 28, it was found that there is no significant change ig the test was on even at odd months, the change in the moisture content of the system will be the same. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm



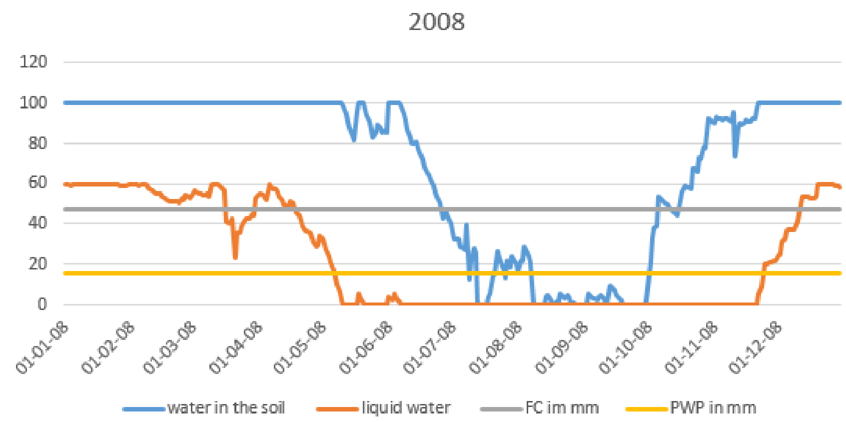


Figure 30: These graphs represent 2008) and their response to the change in precipitation values in examining the uncertainty in rainfall data. By change the precipitation values using high range of rain fall in mm and the change was in random months, the graph showed a significant change in the substrate (water in soil) and liquid water (permavoid) moisture content where it reached to permanent wilting point. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm

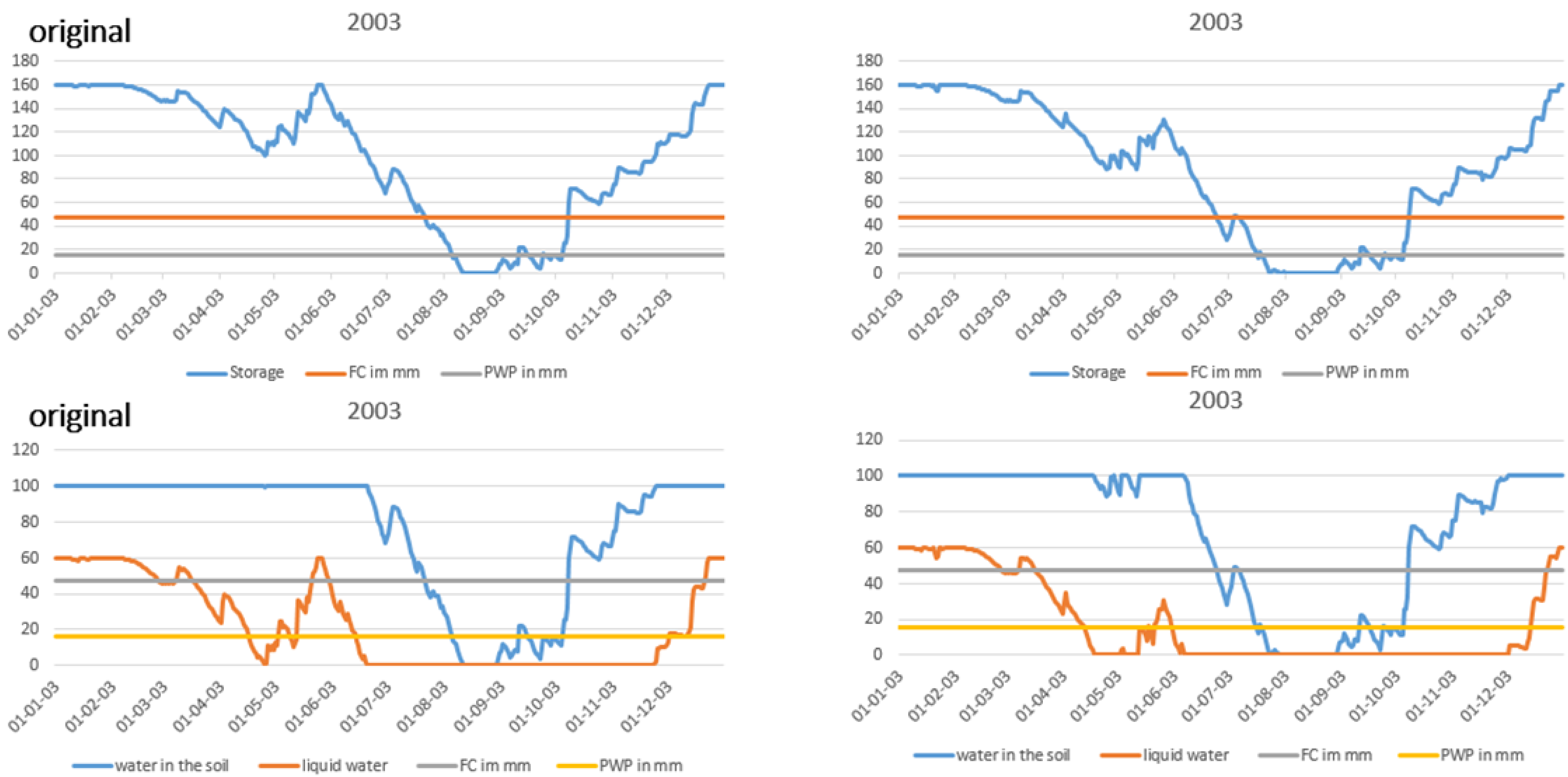


Figure 31: these graphs represent 2003 (dry year) and its response to the change in precipitation values in examining the uncertainty in rainfall data. The two graphs that positioned on the left side are presenting the original condition of 2003. By change the precipitation values using small range of rain fall in mm, the graph a moderate change in the substrate (water in soil) moisture content and a significant change in the liquid water (permavoid) this significance of responding to change in small values is due to the low rain fall amount in 2003. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm

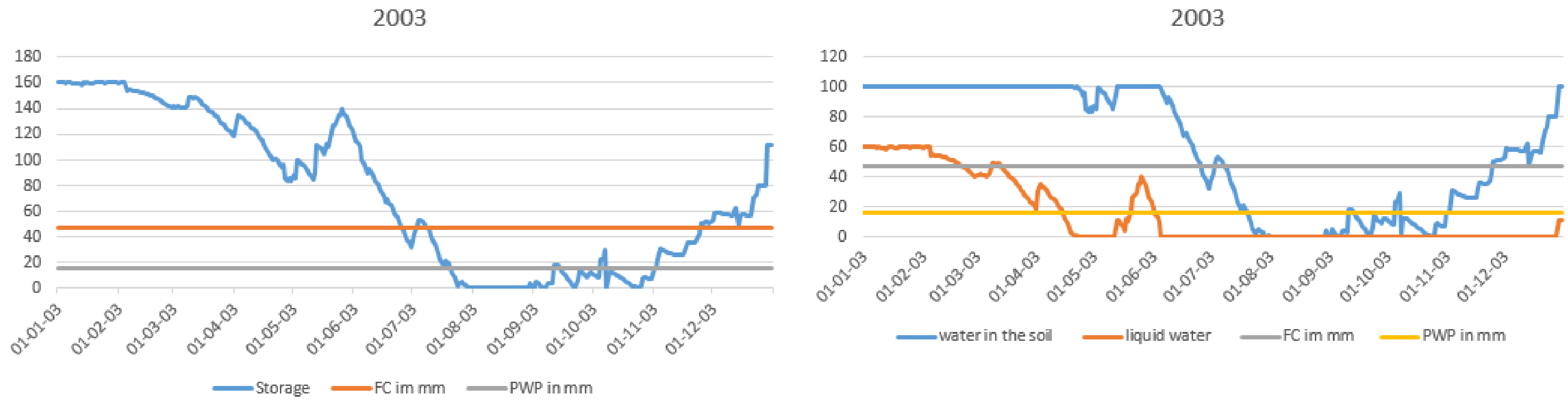
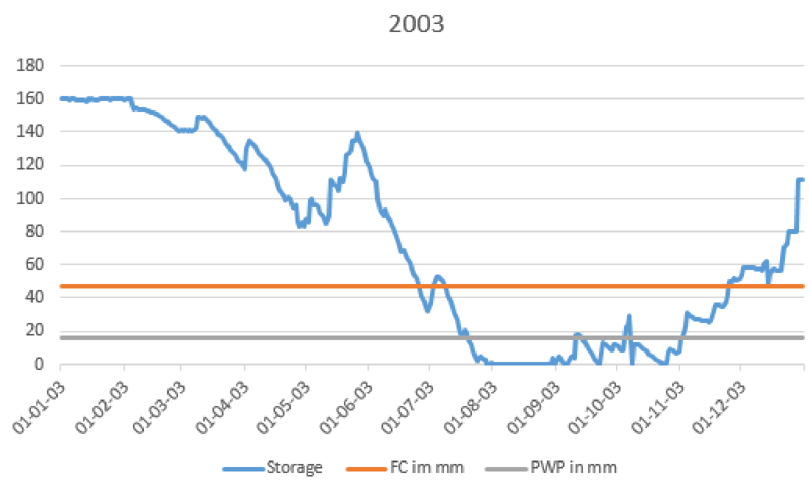


Figure 32: these graphs represent 2003 (dry year) and its response to the change in precipitation values in examining the uncertainty in rainfall data. By change the precipitation values using random high and low range of rain fall in mm in even months, the graph a moderate change in the substrate (water in soil) moisture content and a change in the liquid water (permavoid) significantly. this significance of responding to change in random values is due to the low rain fall amount in 2003. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm



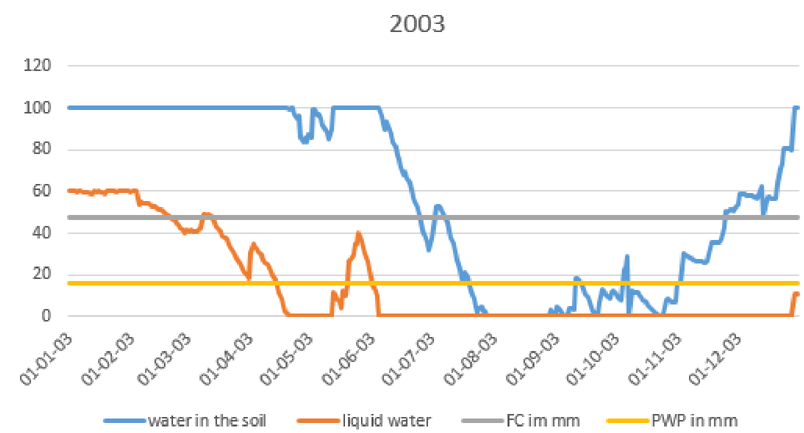


Figure 33: these graphs represent 2003 (dry year) and its response to the change in precipitation values in examining the uncertainty in rainfall data. By change the precipitation values using random high and low range of rain fall in mm in odd months, the graph a moderate change in the substrate (water in soil) moisture content and a change in the liquid water (permavoid) significantly. this significance of responding to change in random values is due to the low rain fall amount in 2003. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm

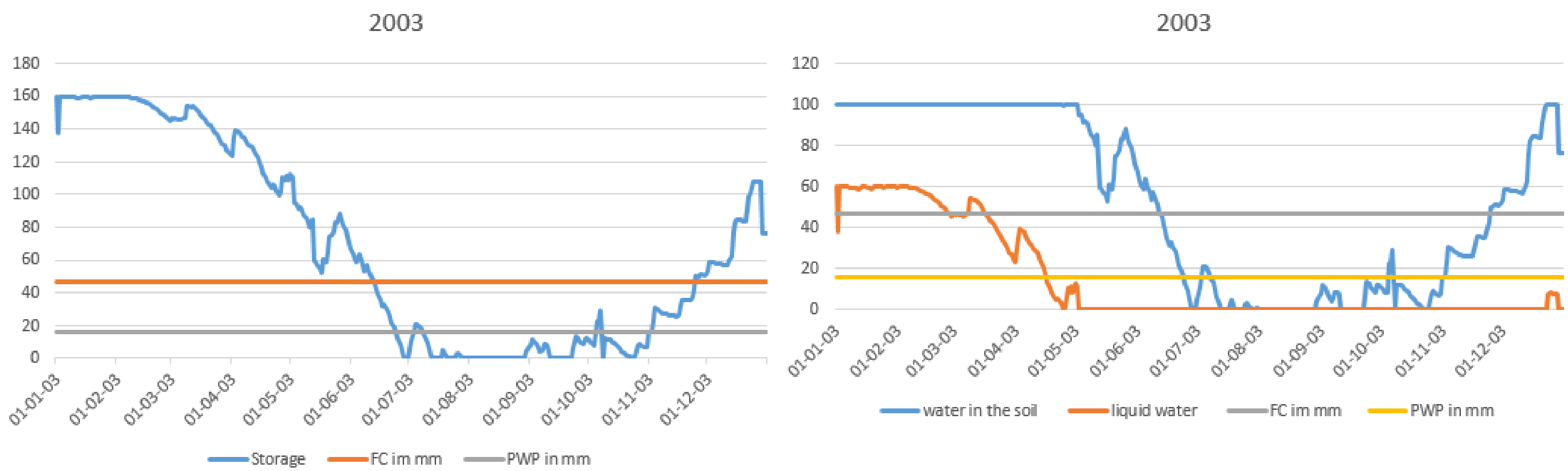


Figure 34: these graphs represent 2003 (dry year) and its response to the change in precipitation values in examining the uncertainty in rainfall data. By change the precipitation values using random high range of rain fall in mm in odd months, the graph a moderate change in the substrate (water in soil) moisture content and a change in the liquid water (permavoid) significantly. this significance of responding to change in high values is due to the low rain fall amount in 2003. Figures 32 o 34 presents significant change no mater what the range of values used in the test. This sensitivity in response is because 2003 is classified as dry year. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm

4.6 Calculating actual evapotranspiration from potential evapotranspiration

The key to a successful improvement and application of SuDS-type approaches can be achieved by understanding the hydrological performance of the different variables in the system. A lot of studies proved the efficiency of Green roofs in managing runoff to some extent. Thus they have received high level of attention in last 15 (yearsPalla et al, 2010) and (Stovin et al.2012).

As mentioned earlier in section 3.8, vegetation has a positive impact on water retention and a good control on storm water runoff. Since green roof modeling is essential to understand the hydraulic behavior of the system, the required data that should be input for this kind of model are the precipitation, actual evapotranspiration, time, an estimation of the system substrate maximum and minimum retention capacity (field capacity and permanent wilting point). It is worth mentioning that many studies focused on ET behavior in relation to moisture content, which is considered as an essential parameter in green roof retention and modelling.

It was difficult to conduct study the hydraulic behavior of green park and perform analysis on van de Werken model Even with the pre-modification and analysis. The model presented water in storage based on potential evapotranspiration and substrate saturation point of 100 mm which is temporary because the moisture content falls to the field capacity after 24 hours from the last rain events for a substrate of sandy lome to 47 mm

The solution was to update the model and introduce actual evapotranspiration and adjusts the field capacity. The next figure presents a graph of 2003 based on van de Werken model before and after update

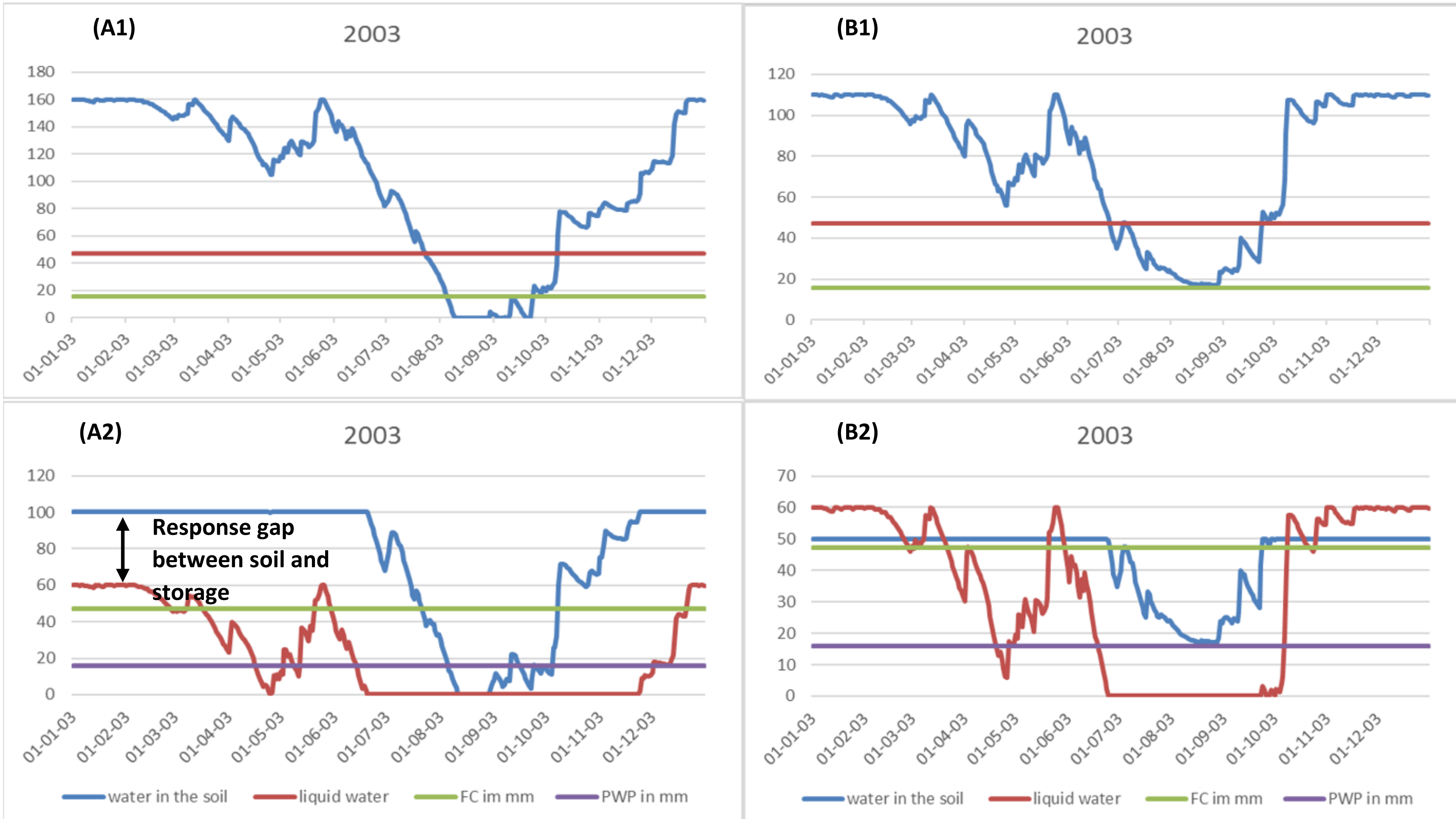


Figure 35:Graphs of 2003 presenting the moisture content in substrate (blue line in mm), permavoid (red line in mm) field capacity (green line in mm) and permanent wilting point (purple line in mm). the graphs that are positioned on the left are presenting van de Werken model, where the ones positioned on the right are presenting the modified model which monitors the moisture content in substrate and permavoid at the same time. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm

4.6.1 Preliminary observations

By comparing A2 and B2, the following was noticed

- The line presenting moisture content in the soil in (B2) does not exceeds PWP line. While in (A2) the moisture content in the soil exceeds PWP line for almost 50 days. The reason behind this behavior is that van de Werken model based on ETp tends to overestimate the ET once the permavoid is empty. In contrast to ETa, ETp is not limited to the system moisture content (h), field capacity (h fc) or permanent wilting point (h pwp).
- The number of days when water reaches or approaches the wilt point in van de Werken model are 50 days
- These graphs presents that permavoid contain no water longer in van de Werken model (A2) when compared with adjusted model (B2). this illustrate that less water need to recharge the green park when using the modified model.
- There is no gap between "water in soil" line and "liquid water" line in the adjusted model (B2). this means that the time that the system responds to rain events is immediate. the substrate passes water to the permavoid once it's reached to the field capacity.

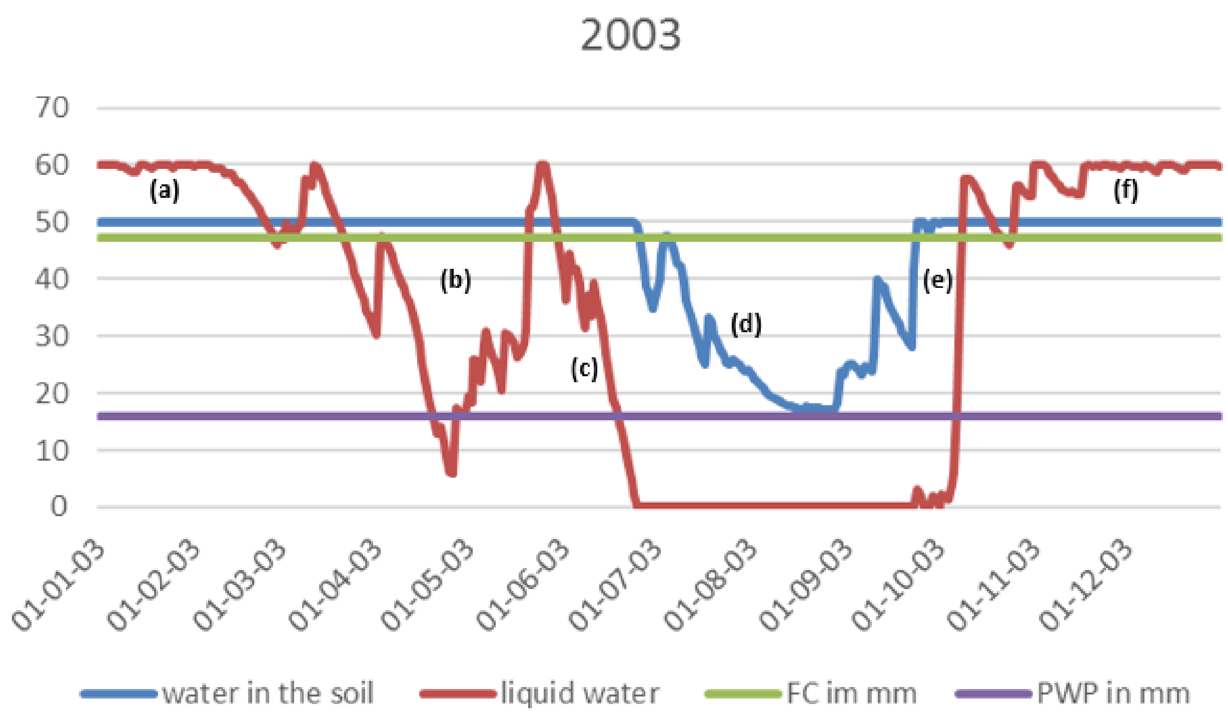


Figure 36: Graphs of 2003 presenting the moisture content in substrate (blue line in mm), permavoid (red line in mm) field capacity (green line in mm) and permanent wilting point (purple line in mm). the graphs are presenting the modified model which monitors the moisture content in substrate and permavoid at the same time. The graph presenting *Moisture content behaviour analysis in a 2003 which is classified as a dry year in rain and evapotranspiration quantities and pattern. the X access presents is time in days and the Y access is the moisture content in the "storage" in mm*

Secondary observations

By adopting the correction in van de Werken model and adjusted to the experiments results and the additional information about the modeled green park. The resulted graph heled in understanding the real time hydraulic behavior of green park during different seasons. Additionally, the adjusted model reflected more realistic information based on scientific information about natural systems and metrological data. The final graph illustrated the follows:

a) Rain events were present at the beginning of 2003. during rainfall event, the substrate preserved rainfall water until the field capacity was reached (water retention). Rain events continued and further moisture is added to the substrate, which might have enhanced runoff. The excess water from the substrate drained vertically down to the permavoid as a response to gravitational force. Once the permavoid was saturated, water starts to leave the system to the drainage system
b) Dry days occurred between rainfall events. The permavoid started to recharge substrate. At this stage Eta=ETp and the park the storage capacity was restored by evapotranspiration (ET). Since evapotranspiration depends on sessions, meteorological conditions, plant species and substrate's moisture content, ET values will vary throughout the year.
c) Dry period started and water level in permavoid starts to decrease as the water passes to the substrate and the water in the substrate was stable at field capacity and ETa = ETp. Once the water level in the "storage" became zero, moisture content in the substrate started to decrease as $ETa = ETp * (h-h_{WP} / h_{FC} - h_{WP})$.
d) moisture content in the substrate continued to decrease until moisture content is $\leq h_{WP}$, where at this stage ETa=0
e) rain events started and the substrate acted as primary receiver. Moisture content was increasing and $ETa = ETp * (h-h_{WP} / h_{FC} - h_{WP})$ until the moisture content reached field capacity level.
f) Rain events continued and further moisture is added to the substrate, which might have enhanced runoff and ETa = ETp.

In summary, this section has highlighted the link between evapotranspiration, moisture content and retention capacity. Relatively simple methods and assumptions were used evaluate P and ET. Although the results of previous sections demonstrated that van de Werken model was based on un calibrated ET data in which added uncertainty in model output, the adjustment and adding ETa equation with its conditions lead to reasonable predictions when it comes to extensive green roof.

It is clear that this model need to be refine and modified further more in order to understand and present the change in ET that is associated with plant species as well as the types of substrate Likewise, the relation between saturation level, field capacity and permanent wilting point with substrate characteristics such as substrate depth, water retention and release properties. This model imitates hydrological ideologies that are widely discussed in many researches, including the dependency of actual ET rates on the substrate moisture content. (e.g. Kasmin et al., 2010) which would enable the runoff retention effects to also be well represented in this model.

4.7management of water with a float valve or moisture content meter – developing models for tracking water status and green roof system hydrological Performance

A study by M. Uhl and L. Schiedt (2008) highlighted the importance of vegetation in storm water retention. The importance to control green parks irrigation during dry seasons is an essential step that has to be modeled and controlled through the green roof system (Lambrinos J. 2015). previous sections in this chapter presented number of days that the substrat's moisture content decreased to the permanent wilting point value that can last for almost a month.

Developing the model to predict when to "add water" to the system and what is the amount that should be added was important to preserve the vegetation in green roofs and parks, at the same time to get the flexibility to grow different variety of plants which preserve biodiversity to certain limit in cities.

After adjusting the model to interoperate ETa and field capacity with two sub-storages in GRS, the model was developed for tracking water status and green roof system hydrological Performance. The results of this modification is presented in table 9 and figure 37

Table 9: This table represent a comprising between managing water in green park using van de Werken model and the adjusted model.

Management of water with a float valve - van de Werken model		
24 mm recorded when the dry days = 0	The substrate moisture content reached to the 20% above the wilting point for 61 days	Total amount of water = 61 *24 = 1464 mm
24 mm recorded when the dry days = 0	The permavoid water level reached to the 20% above the wilting point for 200 days	Total amount of water = 200 *24 = 4800 mm
Management of water with a float valve - The adjusted model		
24 mm recorded when the dry days = 0	The substrate moisture content reached to the 20% above the wilting point for 28 days	Total amount of water = 28 *24 = 672 mm
24 mm recorded when the dry days = 0	The permavoid water level reached to the 20% above the wilting point for 133 days	Total amount of water = 133 *24 = 3192 mm

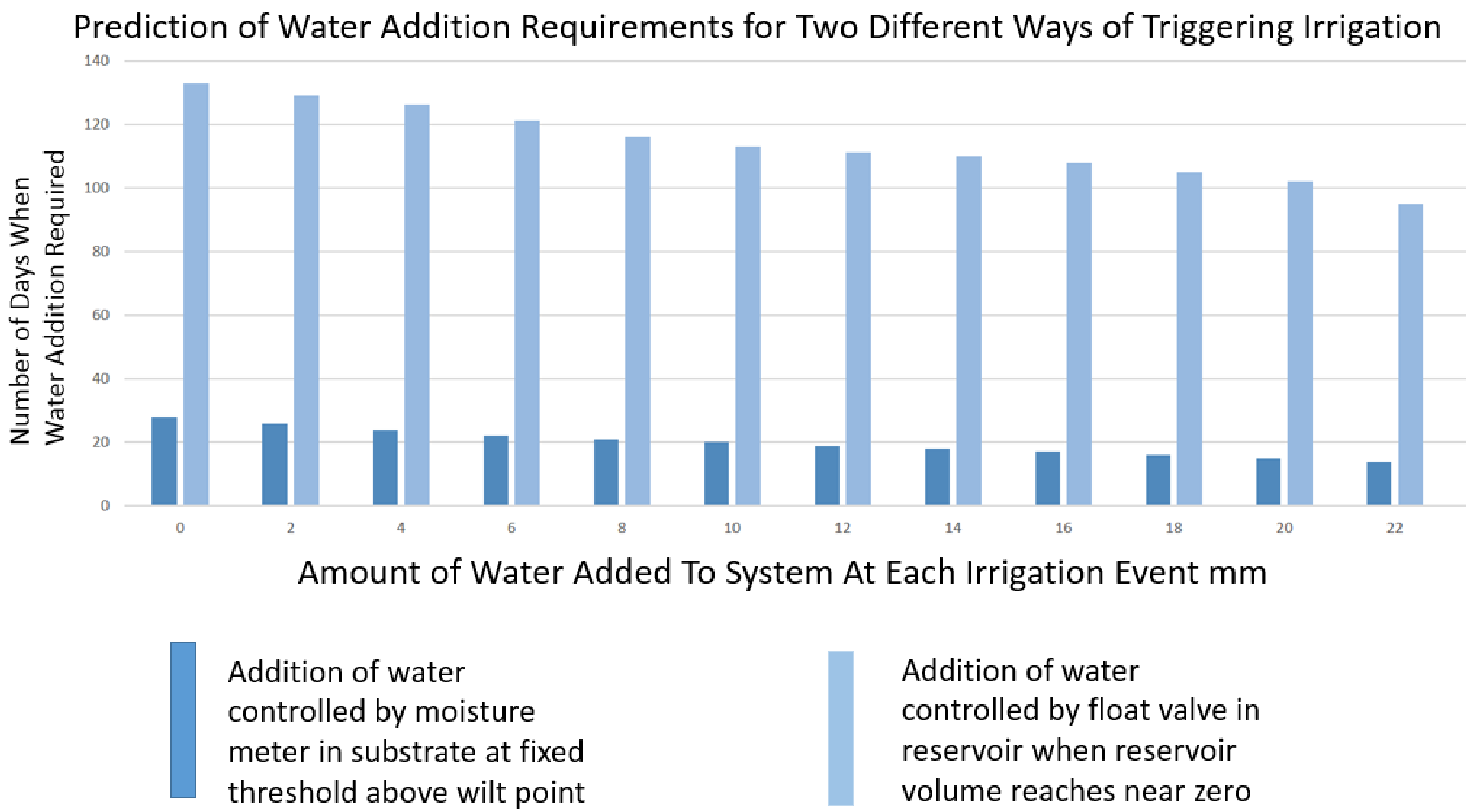


Figure 37: Effect of controlling water addition by electronic (water content monitor in substrate) compared to mechanical (float valve in reservoir) control. Modeled for different values of water addition at each irrigation event.

The results present the amount of water that should be added in order to preserve vegetation and substrate moisture content when water content is close to permanent wilting point in a dry year. Both models gave a record of "zero" days when 24 mm of water added. The question is there any difference in the amount of water added to the system id the model monitoring the substrate or the permavoid? management of water with a float valve in van de Werken model presented that the substrate in the system was in water shortage for two months when compared with the modified model and the "storage was in the limits of 23 mm for 2/3 of the year. This is because van de Werken model based on ETp which is not considering substrate moisture content. However, the adjusted model show less days where moisture content was less than 1/5 of the water available for plants. The calculation in the adjusted model based on ETa which is linked with moisture content levels in the system. The figures and the table presents that the better option is to monitor water content in the substrate using the adjusted model. only 17% of the water needed to manage the roof park. Since water is a valuable natural resource, it is important to manage it especially in a dry year where water is needed in all fields and sectors.

The adjustments that were introduced to the model in the previous section incorporate into the model the ability to model the effects of a real time control system which would dump water from the storage voids in advance of a predicted storm event. This would reduce the total water entering a watercourse during the course of a rain event and thus reduce pluvial flooding. Moreover, it triggers the moisture content and recharge the system with water once moisture content reaches the borders of PWP. the system can perform to the optimum level in mitigating storm water by retention and keep vegetation healthy

In Summary, the model described in this project encompasses four stages as shown in figure 38. Many studies described the hydrological processes mentioned above. The general performance of green roofs and parks are widely understood. Additionally, Jarret and Berghage (2008) and Kasmin et al. (2010) have established that applications of models that study some combined storage systems in order to retain water and delay runoff for a time, can control and narrow green roof studies pattern to focus on specific variables such as ET, P and waive radiation, and crop factor. These models also, helps in understanding per significant rain event retention and to assess overall volumetric performance, in order to utilize green park water management facility to the maximum level. The modification on this model helped in understanding and model green roof irrigation requirements to avoid potential drought risk. (Miller, 2003; Bengtsson et al., 2005; Jarret and Berghage, 2008; Palla et al., 2010; Stovin et al., 2012)

Figure 38: four stages of modification that occurred on the model in order to study he hydrological behavior of green park and managing the moisture content of the system

Chapter 5: conclusion

In summary, green roofs benefit the environment in many ways. Most of the studies emphasize on storm water retention. However, few studies looked at the mechanism of passive irrigation of the vegetation on green roof. This study examined the hydrological performance of the green roof and developed a model to predict the moisture content of it.

The actual evapotranspiration equation has 3 status introduced to the model. Because ETa is controlled by the moisture content of the system, development of the model enabled the prediction of actual days when the system has no water in it.

In the future, this model can be improved through studying actual evapotranspiration and implement different equations to calculate the rate of ET by using other meteorological variables such as temperature, energy waves, humidity, wind speed and precipitation. Another way to develop this model is to calculate the rate of water movement from permavoid to growing medium as this will ensure adequate amount of moisture content.

There are number of lessons that can be learned from this paper. Firstly, we need to implement our knowledge of soil and water properties in predicting storage capacity and permanent welting point. Secondly, we need to make a lot of effort to make sure that the data is correct so that it does not affect model development. Lastly, it is important to have scientific way of thinking to help in troubleshooting problems occurring during building scientific models.

Reference

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Appendix

Coventry University

Certificate of Ethical Approval

Applicant:

Tasneem Abdullah

Project Title:

An Integrative Approach towards Optimizing Hydrological Performance of Green Roofs Technology: the reflect of accuracy of logical meteorological data modelling on Green Roofs sustainability

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Low Risk

Date of approval:

31 May 2016

Project Reference Number:

P42527

Coventry University ETHICS

Low Risk Research Ethics Approval

Project Title

An Integrative Approach towards Optimizing Hydrological Performance of Green Roofs Technology: the reflect of accuracy of logical meteorological data modelling on Green Roofs sustainability

Record of Approval

Principal Investigator

I request an ethics peer review and confirm that I have answered all relevant questions in this checklist honestly.	X
I confirm that I will carry out the project in the ways described in this checklist. I will immediately suspend research and request new ethical approval if the project subsequently changes the information I have given in this checklist.	X
I confirm that I, and all members of my research team (if any), have read and agreed to abide by the Code of Research Ethics issued by the relevant national learned society.	X
I confirm that I, and all members of my research team (if any), have read and agreed to abide by the University's Research Ethics, Governance and Integrity Framework.	X

Name: Tasneem Abdullah ....

Date: 23/03/2016...

Student's Supervisor (if applicable)

I have read this checklist and confirm that it covers all the ethical issues raised by this project fully and frankly. I also confirm that these issues have been discussed with the student and will continue to be reviewed in the course of supervision.

Name: Mark Bateman ....

Date: 31/05/2016...

Reviewer (if applicable)

Date of approval by anonymous reviewer: 31/05/2016

Low Risk Research Ethics Approval Checklist

Project Information

Project Ref	P42527
Full name	Tasneem Abdullah
Faculty	Faculty of Engineering, Environment and Computing
Department	Geography, Environment & Disaster Manager
Supervisor	Mark Bateman
Module Code	M70GED
EFAAF Number	
Project title	An Integrative Approach towards Optimizing Hydrological Performance of Green Roofs Technology: the reflect of accuracy of logical meteorological data modelling on Green Roofs sustainability
Date(s)	02/05/2016 - 15/08/2016
Created	23/03/2016 14:24

Project Summary

Few studies were published, focusing on increasing the ability of the green roof in managing rainstorm water and how to maintain these green roofs making them sustain. Since water availability is essential to vegetation life cycle in the green roofs, this study will focuses on designing a model that has the ability to model the effects of discharging water from the green roof storage voids in advance of a predicted storm event. This would reduce the total water entering a watercourse during the course of a rain event and thus reduce pluvial flooding. The issue is whether this would have a bad effect on the availability of water to prevent plants to reach the wilting point if the weather were to be badly predicted. A number of scenarios and models will be generated which would simulate various degrees of accuracy of the rainfall predictions and then trying to get a handle on how good the weather data needs to be to avoid both unexpected discharge of water and loss of plant viability.

Names of Co-Investigators and their organisational affiliation (place of study/employer)	
Is the project self-funded?	NO
Who is funding the project?	
Has the funding been confirmed?	NO
Are you required to use a Professional Code of Ethical Practice appropriate to your discipline?	NO

Have you read the Code?	NO

Project Details

What is the purpose of the project?	The aim of this research is to investigate the ability to model the effects of a real time control of meteorological predicted storm events and its effect on the hydrologic performance of green roofs and their sustainability during a period of time. The objective of this study 1.To identify and investigate appropriate, practical and affordable alternative storm water management technologies that can be applied in urban environments 2.To evaluate the different identified and proposed mathematical models that are used to study the hydrologic performance of green roofs in terms of their ability to indicate and improve storm water management in urban areas; i.e. model the impact of draining water from green roofs on the vegetation in green roof. 3.To develop practical and user-friendly model that can present the effect of dump water from the storage voids in advance of a predicted storm event on the sustainability of the green roof vegetation before reaching to the wilting point
What are the planned or desired outcomes?	Based on the research methodology and procedure employed, the desired outcome of this project is to design a model that acts as a good tool to manage water storage in green rooftops for to sustain and reduce rainstorm water runoff effectively, by using real time metrological and precipitation data. This model should carry the ability to model wide range of data for different rainstorm duration, quantity and in seasons.
Explain your research design	The project will be based on secondary data and by developing mathematical model and equations, the secondary data will be used to rune these models and equations. Changing modeling

	parameters, different scenarios will be build and different results will be generated. These results will be compared and discussed based on previous literature review and discussions. The project design framework will base on the following components:: 1.Gathering Information needed from previous models and published research 2.Data collection and modeling 3.Measurement and scaling procedures 4.Data analysis procedures	
Outline the principal methods you will use	The methodology will based on extensive literature and theoretical review, which will focus on a wide range of studies done on the advantages of implementing green roofs as part of storm event management, different developed mathematical models in studying the green roof hydrologic behavior in managing rain storms. The modelling exercise will study the potential performance of the system installed in the green roof with respect to providing sufficient storage for the study periods of the year. The general water balance equation will be used to study and model the hydrological behavior of the system ET = P - Q +/- ?S; where: - ET is the evapotranspiration, P is the precipitation, Q is the amount of discharge (runoff) and ?S represents the change in water storage. This model will be developed to have the ability to model the effects of a real time control system which would dump and drain water from the storage voids in advance of a predicted storm event. This would reduce the total water entering a watercourse during rain events and thus reduce pluvial flooding.	
Are you proposing to use an external research instrument, validated scale or follow a published research method?		NO
If yes, please give details of what you are using		
Will your research involve consulting individuals who support, or literature, websites or similar material which advocates, any of the following: terrorism, armed struggles, or political, religious or other forms of activism considered illegal under UK law?		NO

Are you dealing with Secondary Data? (e.g. sourcing info from websites, historical documents)	YES
Are you dealing with Primary Data involving people? (e.g. interviews, questionnaires, observations)	NO
Are you dealing with personal or sensitive data?	NO
Is the project solely desk based? (e.g. involving no laboratory, workshop or off-campus work or other activities which pose significant risks to researchers or participants)	YES
Are there any other ethical issues or risks of harm raised by the study that have not been covered by previous questions?	NO
If yes, please give further details	

External Ethical Review

Question		Yes	No
1	Will this study be submitted for ethical review to an external organisation? (e.g. Another University, Social Care, National Health Service, Ministry of Defence, Police Service and Probation Office)		X
	If YES, name of external organisation		
2	Will this study be reviewed using the IRAS system?		X
3	Has this study previously been reviewed by an external organisation?		X

Risk of harm, potential harm and disclosure of harm

Question		Yes	No
1	Is there any significant risk that the study may lead to physical harm to participants or researchers?		X
	If YES, please explain how you will take steps to reduce or address those risks		
2	Is there any significant risk that the study may lead to psychological or emotional distress to participants?		X
	If YES, please explain how you will take steps to reduce or address those risks		
3	Is there any risk that the study may lead to psychological or emotional distress to researchers?		X
	If YES, please explain how you will take steps to reduce or address those risks		
4	Is there any risk that your study may lead or result in harm to the reputation of participants, researchers, or their employees, or any associated persons or organisations?		X
	If YES, please explain how you will take steps to reduce or address those risks		
5	Is there a risk that the study will lead to participants to disclose evidence of previous criminal offences, or their intention to commit criminal offences?		X
	If YES, please explain how you will take steps to reduce or address those risks		
6	Is there a risk that the study will lead participants to disclose evidence that children or vulnerable adults are being harmed, or at risk or harm?		X
	If YES, please explain how you will take steps to reduce or address those risks		
7	Is there a risk that the study will lead participants to disclose evidence of serious risk of other types of harm?		X
	If YES, please explain how you will take steps to reduce or address those risks		
8	Are you aware of the CU Disclosure protocol?	X	

Online and Internet Research

Question			Yes	No
1	Will any part of your study involve collecting data by means of electronic media (e.g. the Internet, e-mail, Facebook, Twitter, online forums, etc)?			X
	If YES, please explain how you will obtain permission to collect data by this means			
2	Is there a possibility that the study will encourage children under 18 to access inappropriate websites, or correspond with people who pose risk of harm?			X
	If YES, please explain further			
3	Will the study incur any other risks that arise specifically from the use of electronic media?			X
	If YES, please explain further			
4	Will you be using survey collection software (e.g. BoS, Filemaker)?			X
	If YES, please explain which software			
5	Have you taken necessary precautions for secure data management, in accordance with data protection and CU Policy?			X
	If NO please explain why not	Because the project is based on secondary data and literature study.		
	If YES Specify location where data will be stored			
	Planned disposal date			
	If the research is funded by an external organisation, are there any requirements for storage and disposal?			
	If YES, please specify details			

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