Project Title: **Engineering Analysis and Management of Water flow in Domestic Housing: The problem of Guttering and Resource Reusability**

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Summary

Urban drainage patterns are altered by increasing urbanization and soil sealing, leading to increased flood risk and diminish of aquifer recharge. It is the moment to take a holistic view, and improve the stormwater management.

Two cases of study have been researched in two publics' institutes in a Mediterranean city. The aim is to implement several SuDS (Sustainable Drainage Systems), making simulations with the SWMM (Stormwater Management Model) software to realize about of how feasible it might be. In the Case study 1 has been implement a sustainable green roof and in the Case of study 2, the harvest and redirection of the runoff from the two rooftops.

The results have been successful, since the peak runoff has been reduced using the green roof, and the irrigation studio allows keep it with the maximum efficiency and minimum maintenance assured. On the other hand, it has been possible to see how much water can be harvested and reuse it, and how much water is redirected to the aquifer or the river because the tank is full, so is returned to the natural cycle water.

In conclusion, the outcomes show that the project is viable with a minim inversion, as well as it is sustainable and can reduce and adapts climate change. This model has infinity of possibilities and can be adapted to many cases and see the behaviour of the whole system.

Definitely, in the future, this model will be necessary.

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Nomenclature

AFP	Air Filled Porosity
AW	Available Water
CE	European Community
Cr	Runoff Coefficient
CSOs	Combined Sewer Overflows
CTE	Building Technical Code
DST	Decision Support Tool
ET_L	Landscape Evapotranspiration
FC	Field Capacity
FEDER	European Funds for Regional Development
IES	Secondary Education Institute
IVIA	Valencian Institute for Agricultural Research
K_d	Density Coefficient
K_L	Landscape Coefficient
K_{mc}	Microclimate Coefficient
K_S	Species Coefficient
LCM	Landscape Coefficient Method
LID	Low Impact Development
LPS	Litters Per Second
MED	Development of the European Mediterranean cities
PVC	Polyvinyl Chloride
RWH	Rainwater Harvesting
SOM	Soil Organic Matter
SuDS	Sustainable Drainage Systems
SWMM	Stormwater Management Mode
US EPA	United State Environmental Protection Agency
WHC	Water Holding Capacity
WP	Wet Point
WUCOL	Water Use Classification of Landscape Species

Chapter 1. Introduction

Since the industrial revolution in the 18st century, the world has quickly developed without looking back to think about the consequences from this behaviour. Right now more than half of human population, 3.3 billion people, live in urban areas. By 2030, this is expected to increase to almost 5 billion. Many of the new urbanites will be poor. Their future, the future of cities in developing countries, the future of humanity itself, all depend very much on decisions made now in the preparation for this growth.

Cities in the 21st century face the enormous challenge of catalyzing, intensifying and accelerating sustainable urban transformations. It is important to approach this challenge under a holistic view, since the world works like an indivisible machine. For this reason, we must consider the resource management and climate mitigation and adaptation from where born the problem, the cities.

Urban drainage patterns are altered by increasing urbanization and soil sealing, leading to increased flood risk and diminish of aquifer recharge (European Commission, 2012). Traditional practice in many countries considers urban stormwater as a waste product instead of a precious resource, and its rapid conveyance and discharge contributes to the degradation of receiving waterways: combined sewer overflows (CSOs), diffuse pollution, etc. (Andrés-Doménech et al., 2010; Campbell et al., 2004).

In response, a relatively new and flexible approach to urban stormwater management has emerged that makes a switch from piped engineered systems to practices and systems that use and enhance natural processes (infiltration, evapotranspiration, filtration, retention, reuse) to mimic the predevelopment hydrology of the site. Known under different names across the globe, the term Sustainable Drainage Systems (SuDS) is used throughout the present project to refer to this approach. SuDS currently in use include green roofs, rain gardens, permeable pavements, infil-tration basins and daylighting of culverted water bodies; they can be combined with conventional techniques (pipes) and retrofitted into existing drainage systems.

EU Ministers responsible for Urban Development have highlighted the “need to promote a smarter, more sustainable and socially inclusive urban development in European urban areas, cities and towns”, undertaking “a genuine ‘green, ecological or environmental’ regeneration” that includes ‘re-greening’ the existing city, what offers excellent opportunities for creating new businesses and jobs, better places to live in and more social integration (European Commission, 2010).

In the Spanish framework, some references promote a urban development that reduces runoff and make use of rainwater harvesting techniques as strategies for reducing the effects of floods and droughts (Cabrera and Babiano, 2007; Madrid City Council, 2006; Puertas et al., 2008; Rueda, 2009; Xunta de Galicia, 2009). In terms of water management, recent national legislation (R.D.1290/2012) recognizes the law of regulation, amongst others, in relation to combined sewer overflows (CSOs), needed to achieve a good ecological status of the water bodies, as re-quired by the EU Water Framework Directive (Directive 2000/60/CE). In terms of urban runoff, it highlights the need to take stormwater out of combined sewers, specifying the use of best available (and affordable) practices and technical knowledge The legislation requires future technical rules to be developed, and it would be desirable that they embody recent European guidelines for water management which promote the use of SuDS (European Commission, 2012). This would be aligned with R.D.233/2013, which opens the door to co-finance urban interventions that fall under the SuDS approach (e.g. the sustainable management of urban runoff and the use of green roofs).

The present project will be developed in a Mediterranean city, where the climate change is a fact, with long dry periods and rainy season on autum. In this moment, the experience in Spain is limited to two study cases, Benaguasil and Xativa, where the SuDS have been implemented with great success. Both cities are inside of the European program called E2stormed, and are a reference for the stormwater management currently. Some examples from these SuDS are the Underground-concrete rainwater harvesting tank in the Benaguasil Youth Center (Figure 1-1) and the Green Roof in the Gonzalbes Vera public school in Xativa (Figure 1-2):

Figure 1-1: *Rainwater harvesting tank in the Benaguasil Youth*

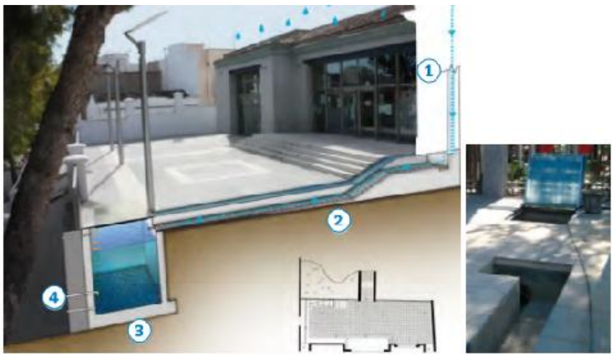


Figure 1-2: *Green Roof in the Gonzalbes Vera public school in Xativa*

Chapter 2. Objectives

The main objective of this project is to design several SuDS in a Mediterranean city and demonstrate their effectiveness both from the technical-economic and environmental perspective. Thus fulfilling with European regulation (CE, 2012) and International (USEPA, 2008) to do a Sustainable Stormwater Management, being more respectful of the environment and more flexible and energy efficient.

The general aims would be:

- Design and assessment of a green roof by means of SWMM model.
- Reduce stormwater inflow into sewer systems.
- Recharge of aquifers.
- Reduce energy consumption for air conditioning of buildings (insulation).
- Reduce the effect of "heat island" of urban environments.
- Landscape integration of infrastructure

The specific aims are:

- Select the specific places where would be better to implement the SuDS.
- Get the current data the quantity and quality of the rainfall water in this city.
- Design the SuDS.
- Rainfall-runoff simulation for single event and long-term (continuous) simulation of runoff quantity from specific urban area.
- Make an economic study to know the viability of the project.

Chapter 3. Literature Review

The stormwater sustainable management is a relative new topic, but in the few last years there have been many studies made about that.

The key study in which one has been based this project has been the book *"El agua en Benaguasil, un viaje en el tiempo"* (Water in Benaguasil, a journey in time), realized to disseminate the activities performed in the framework of the E2STORMED project in the Spanish municipality. The 140 pages of this book, introduces the link of Benaguasil with water and the hydraulic solutions developed within E2STORMED to save rainwater.

The E2STORMED program (Improving energy efficiency in the water cycle in Mediterranean cities through the use of innovative technologies for the management of rainwater) is a project partly funded by FEDER (European Funds for Regional Development) and approved within the MED (Development of the European Mediterranean cities) program. The project started in January 2013 and will end in June 2015. It is a transnational cooperation project with partners from 6 Mediterranean countries and partner of UK.

Another well support to get a general point of view about this topic has been the book: "*Toward a Sustainable Water Future: Visions for 2050*". This book showcases the opinions of more than 50 experts who draw an optimistic picture of environmental and water resource conditions and issues midway through the 21st century. These authorities—distinguished professionals in environmental and water resources engineering, ecology, economics, and law—describe the pathways that could transform today's visions into future reality. Each chapter addresses a specific issue in water resources planning and policy, education, or science and technology and identifies the steps to shape a future of water security and sustainability.

Chapter 4. Methodology

The city chosen to develop this project has been Quart de Poblet, a Mediterranean town with 28.780 population located to 4.9 km from Valencia (Spain). The main reason to choose this one has been that is the town where I have grown up. I have seen on occasion how the rainfall caused overflow of sewer and flood the down zone of the town. In the last years I have seen the town has began improving these facilities, urbanism and environment always under a landscape integration view. The Turia River passes for this city and it is our responsibility to take care the aquifers and rainfall quality that finish in there. Looking to the future I hope it is reference in the management water and energy efficient.

Figure 4-1: *Location of Quart de Poblet (from Google maps)*

The rainfall and temperature average daily in the year 2014 according to "IVIA" (Valencian Institute for Agricultural Research) has been shown below as an example:

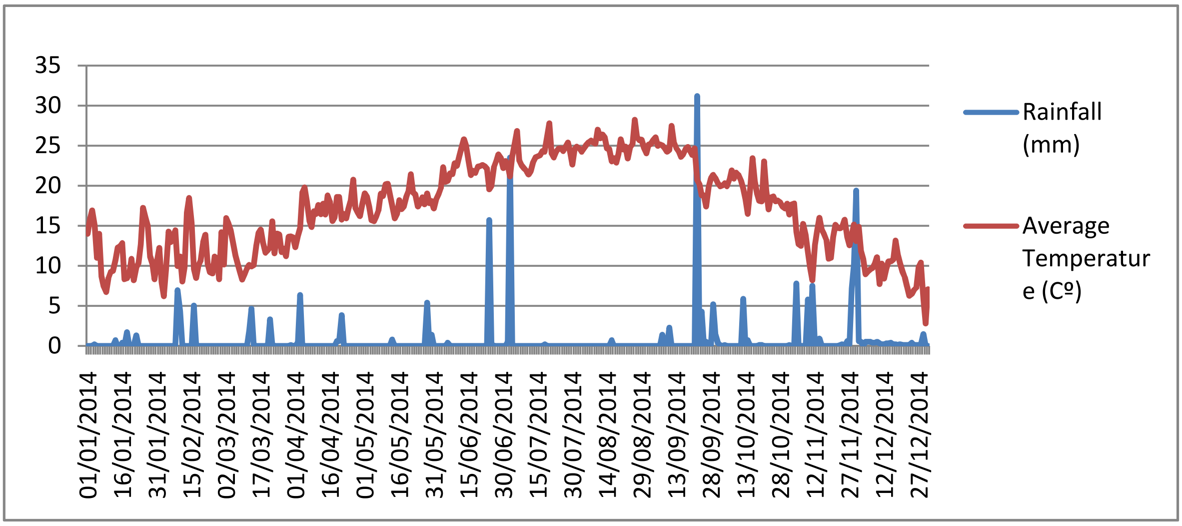


Figure 4-2: *Rainfall and Temperature data in Betera (from http://www.ivia.gva.es/)*

4.1 Case study 1: La Senda Institute of Secundary Education

The first case study is La Senda Institute of Secondary Education, located in the more down area of Quart de Poblet (for location see Figure 4-3). It was built in 1990 and was designed for about 500 students and staff and occupies approximately 6.000 m^2, of which, the main build has $1391m^2$.

Figure 4-3: *Location of IES La Senda (from Google maps)*

This site has been chosen for three main reasons: firstly, its ability to raise the awareness of SuDS to pupils from an early age. Secondly, reduce the volume of runoff and reduce peak flows. And thirdly for provide thermal insulation, so it can reduce heating and cooling costs. To achieve this goals, the SuDS chosen has been a green roof that consists basically in cover the roof with vegetation and a growing medium, planted over a waterproofing membrane.

The effectiveness of this SuDS has been demonstrated in the AQUAVAL study in a public school in Xativa. Monitoring results from the green roof retrofitted in Xàtiva guided the design and operation of a green roof retrofitted later in Benaguasil as part of the E2STORMED European project. For instance, in order to minimize the leaching of nutrients, the substrate composition used in this second green roof was different: with soil of lower nutrient content and the use of controlled release fertilizers. In terms of operation, irrigation is now controlled by the soil moisture and vegetation water demand instead of being periodically activated. The Benaguasil green roof is currently being monitored for its hydrology coupled with energy consumption observations (Alfonso et al., 2015).

➢ Design of guttering

The guttering has been design according to CTE (Building Technical Code), a Spanish mandatory standard. In the 4.2 point (Dimensioning of the drainage of rainwater) describe the steps to follow to each case. The calculations were done for a rainfall of 100 mm/h the nominal diameter depend of the surface and the slope of the guttering.

In this case there are two surfaces, the normal roof surface and the green roof surface. The water flow from the Roof 2 (J2), get the water of Roof 1 and finish in the Tank. The height of the junctions (J) and the size and length of the gutters (Tubes) are shown below:

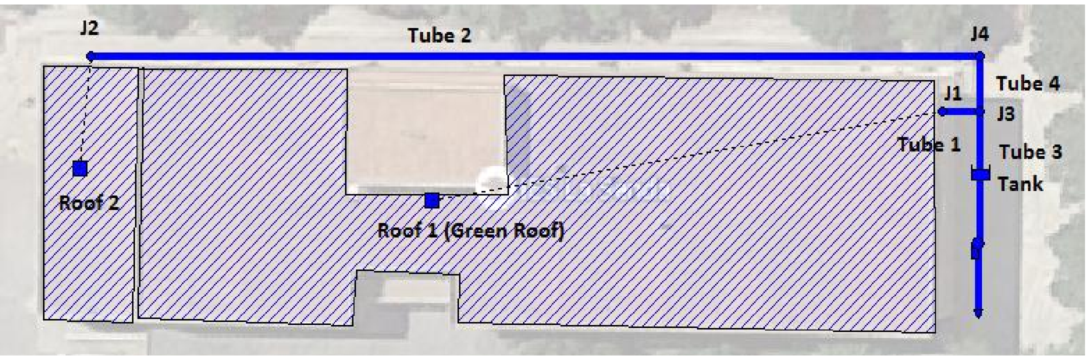


Figure 4-4: *Scheme of hydraulic of the Case study 1 (from SWMM)*

Junction	Height (m)
J1	10
J2	10
J3	8
J4	8.5
Tank	0

Tube	Diameter (mm)	Length (m)
Tube 1	110	2
Tube 2	150	75
Tube 3	125	8
Tube 4	150	5

Table 4-1: *Measures of junctions and gutters*

These measures will be tested with the SWMM on several heavy rainfalls but should be right because the calculated has been done with a rainfall of 100 mm/h as it is specified before.

The material used has been PVC because have good qualities with a reasonable price.

➢ Design of the green roof:

With all that we know today, our floor will be a light mixture including organic substrate and volcanic gravel and silica sand to ensure the drainage capacity of the soil. An impermeable barrier layer and roots avoids protecting the floor structure from moisture and roots of vegetation. This vegetation consists of a mixture of drought-resistant, rustic plants, perennial vegetation, with minimal maintenance requirements and irrigation and resistant to a wide range of temperatures, especially at high thermometric values.

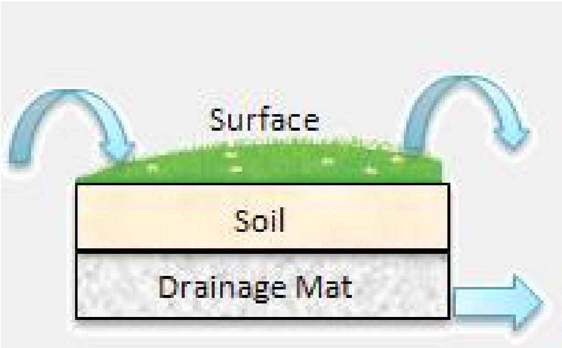


Figure 4-5: *green roof structure (from SWMM)*

1118.7 m^2 of the roof will retrofitted with a green roof. The soil of the vegetated roof is a lightweight substrate made from recycled brick, compost and medium clay soil. The depth of substrate is 200 mm and it has a high total porosity value, comprising a reasonable balance of air-filled and capillary porosity and indicates a high drainage rate for a growing medium (see the property in Table 4-2).

INTENSIVE SUBSTRATE PROPERTY	
Air filled porosity (AFP)	50% vol.
Maximum water holding capacity (WHC)	33.5% vol.
Soil Organic Matter (SOM)	9.2%
Saturated hydraulic conductivity	3 mm/min, 194 mm/hr
pH value	av. 8.47
Electrical conductivity	0.78 g/l
Density Driest days in Summer	870 (kg/m^3)
Density Fully Maximum water capacity	1170(kg/m^3)
Density Fully Saturated Design maximum	1445(kg/m^3)

Table 4-2: *Intensive Substrate Characteristics (green roof)*

The green roof will be planted with some varieties of Sedum (see Table 4-3 to know the density and the Landscape Coefficient (K_L) of each type). The Sedum species have demonstrated the right behaviour in hard weather conditions and they are prefects to make a sustainable green roof.

% Plant Used	**Sedum Species**	**K_L**	**Photo**
25	Sedum Acre	0.25	
20	Sedum Sediforme	0.25	
30	Sedum floriferum	0.25	
25	Sedum Reflexum	0.25	

Table 4-3: *Sedum species (green roof)*

- <u>Maintenance of the green roof:</u>

The type of vegetation used has been chosen because it needs minimal maintenance, but it will be important keep it alive in dry periods. For this reason, a water tank will be placed to tap water runoff from the cover to irrigate the green roof. For that purpose, an irrigation unit with a pump is required to convey the water from the tank to the green roof in specific pressure conditions. In periods that the rainwater will not be enough to keep the tank full with water, a water supply network will be installed after of the pump working through an electro valve. The electro valve will open when the tank is empty and the pump stopped working.

The irrigation system will be scheduled to operate as efficient as possible. The water use efficiency can be achieved by supplying only the amount of water sufficient to meet plant needs. There are lots studies about this field but we will use the Landscape Coefficient Method (LCM) together with the WUCOLS III

(Water Use Classification of Landscape Species). The specific LCM is shown below:

The Landscape Evapotranspiration Formula

Water needs of landscape plantings can be estimated using the landscape evapotranspiration formula:

$$\mathbf{ET_L = K_L \times ET_0}$$

This formula (called the ET_L formula) states that water needs of a landscape planting (landscape evapotranspiration, ET_L) is calculated by multiplying the landscape coefficient (K_L) and the reference evapotranspiration (ET_0).

Reference evapotranspiration (ET_0), is a representation of the environmental demand for evapotranspiration and represents the evapotranspiration rate of a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile (FAO 56 Irrigation and Drainage Study). Depend of the weather conditions in a specific land and it is the sum of the evaporation from the soil and the transpiration from the plant. It is a reflection of the energy available to evaporate water, and of the wind available to transport the water vapour from the ground up into the lower atmosphere. This data have been got from the IVIA website and are between 0.6 and 6.66 (see 4.3 Data Records).

The landscape coefficient (K_L) was derived specifically to estimate water loss from landscape plantings. It has the same function as the crop coefficient, but is not determined in the same way. Landscape coefficients are calculated from three factors: species, density, and microclimate. These factors are used in the landscape coefficient formula as follows:

$$K_L = K_S \times K_d \times K_{mc}$$

These factors are key elements of the landscape coefficient method and the K_L have been obtained and shown in the table 2. Since the species have the same water needs the K_L is a constant: K_L=0.25

The Field Capacity and Wilting Point

After a heavy rain the water comes to occupy all the pores of the soil. Then it said soil is saturated. Then, the water tends to move by gravity to the ground, up to a point where the drain is so small that the water content stabilizes soil.

When this point is reached it is said that the soil is at field capacity (FC). Much of the water retained the FC can be used by plants, but decreases as the water reaches a point where the plant cannot absorb it. In this state it is said that the soil is in the wilting point (WP). The difference between the FC and the wilting point represent the fraction of useful water (available) for crop.

For the substrate chosen the FC is 0.33 and the WP is 0.12 so, the Available Water (AW) is:

FC – WP = AW **0.33-0.12=0.21**

Water Volume and Irrigation Time

The initial phase in the design of a drip irrigation subunit is called agronomic design. In this phase, the number and type of emitters in the subunit are determined. Several authors have proposed methodologies to identify some or all variables involved in the agronomic design of a drip irrigation system (Keller and Karmelli 1974; Zur 1996; Bresler 1978; Bucks et al1980).

According to the design criteria summarized by Arviza (1996) the minimum wetted area must be equal to or greater than a certain percentage of the shaded area (Ps), generally 50%.

The irrigation needs have been calculated with the Excel program to be sure about the outcomes from SWMM. The methodology used is shown below:

<u>Irrigation scheduling with probes</u>

1. The last day an irrigation was done or occurred rain, is detected.
2. It is determined the soil moisture (20 cm depth) of the last day and the current humidity
3. The amount of water to supply is calculated:

$$\Delta_{\theta(\%)} = \theta_{Goal} - \theta_{current}$$

$$V_{(mm)} = \frac{f_{m(\%)} \times z_{(mm)} \times \Delta_{\theta(\%)}}{100 \times 100}$$

Where: $\mathbf{f_m}$ is the wet fraction of soil.
z is the wet soil depth.

The fundaments of the program is to keep a target moisture, when they drop below a certain moisture, in this case the wilting point, the irrigation brings back the target moisture. Of this way the substrate always is in the AW section and the plants keep healthy.

The irrigation time has been calculated for a facility of drip irrigation where each point has a flow of 0.8l/h. The surface to irrigation is 1118.7 m2, since the 10% from total 1243 m2 will impermeable to allow the maintenance and educational visits. If the ground cover (wet area) will be the 30% of 1118.7, that is 335.61 m2 is the total surface to irrigation, and the volume if the high is of 0.2m is 67.12m3. So the water necessary for the plants to grow up healthy will be:

$$V_{wn} = Vplants \times AW$$

$$V_{wn} = 67.12 \times 0.21 = 14.1\ m^3$$

The irrigation time is calculated with the next formula:

$$T(h) = \frac{V_{wn}}{\sum_i^n Q_{dp}}$$

As a summary, below are shown the data used in the Excel logic program:

Surface	1118,7	m^2
Z	0,2	M
Volume	223,74	m^3
% plants	0,3	%
Wet area	0,3	%
FC	0,33	%
WP	0,12	%
AW	0,21	%
Moisture goal	0,2	
Nº dropping points (m^2)	3	
Q dropping point	0,8	(l/h)
Water Needs (average)	**14,10**	**Mm**
FC Agua (top)	22,150	Mm
WP Agua (lower)	8,055	Mm

Table 4-4: *Green Roof's Data summary*

The irrigation has been designed underground to avoid the evaporation and to save the tubes from the sun and increase his time life.

- Other purposes:

The main use of the rainwater harvesting will be the irrigation and washing uses. For that it is necessary a pump which power will be calculate depend of the characteristics of the facilities. Will be possible to work without any pump but only will be possible to irrigation the plants that are lower that the tank, and to get water to wash the staff must go to the tank each time.

The consumption according to studies has been calculated about 900 litters weekly.

The Green Roof will have an educational character, so the secure access for schoolchildren and visitors will be enabled, as well as maintenance personnel. In addition, the Green Roof will be monitored and it will set up the basis for future developments in the process of the paradigm shift leading to a broader uptake of SuDS in Spain.

4.2 Casestudy 2: Riu Turia Instite of Secondary Education

The next case of study has been done in the Riu Turia Institute of Secondary Education (for location see Figure 4-6) which was completely reformed in the 2010 year. This institute occupies approximately 4.000 m2, of which, 2.169 are builds. It makes maximum use of natural light as well as innovative lighting technology and along with natural cooling, energy consumption is significantly reduced compared to traditional air conditioned buildings.

Figure 4-6: *Location of IES Riu Turia (from Google maps)*

This site has been chosen for two main reasons: firstly, its ability to raise the awareness of SuDS to pupils from an early age, as in the Case of Study 1. And secondly, because the IES Riu Turia has many impermeable areas, where we can implement SuDS and to try reproduce the natural water cycle, preventing, reducing or delaying the discharge of runoff generated in the area's network of collectors, allowing them to work properly and preventing floods and dressed in dirty water to the receiving means (Turia River, in this case), and facilitating their adaptation to the effects of climate change (heaviest rains and less annual precipitation are expected).

In this case of study we focus on Rainwater Harvesting (RWH) coming from the impermeable areas (mainly the roofs) and their reuse in some applications. During the twentieth century, in a modern context, the use of techniques RWH declined around the world, to some extent due to the supply through large centralized systems of water supply, which involve the construction of dams, exploitation of groundwater and water supply networks. However, in recent decades there has been an increased interest in the use of water harvesting, see Gould and Nissen-Peterson (1999).

All RWH systems have a number of components in common, that are:

- A collection surface from which the runoff is collected, eg roof surface.
- A system to transport water from the catchment area to the storage tank.
- A reservoir where the water is stored until it is needed.
- A device or installation, depending on the type of water harvesting system for the extraction of water from the reservoir.

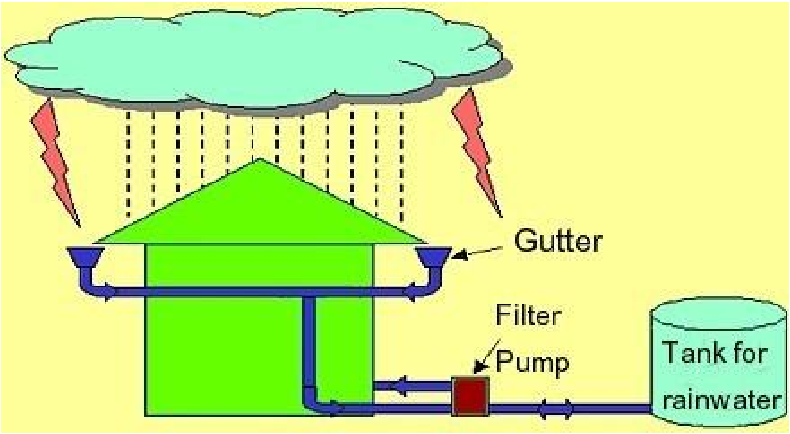


Figure 4-7: *RWH system (from* http://www.nature-education.org/rainwater.html*)*

In this case we already have delimited the roof area, the Roof 1 has 991.38 m^2 and the Roof 2 has 1177.88 m^2 so, the research will follow the next steps:

- Design of guttering:

  The guttering has been design according to CTE (Building Technical Code), a Spanish mandatory standard. In the 4.2 point (Dimensioning of the drainage of rainwater) describe the steps to follow to each case. The calculations were done for a rainfall of 100 mm/h the nominal diameter depend of the surface and the slope of the guttering.

  In this case there are two buildings so two roofs. The Subcatchment areas have been divided in two each one to improve the simulation. Each Subcatchment has a collector with a sloped of about 2%, and for that reason the diameter of the guttering is 200 mm according to the CTE. The runoff water from the Roof 1 is collected by J1 and J2, and both are join in J3 to go down until J7. The runoff from the Roof 2 is collected by J4 and J5, and is join in J6. Then, the runoff water falls and is joined with the runoff from the Roof 1 to go together to the tank by the 250mm diameter guttering. The summary of the height of the junctions (J) and the size and length of the gutters (Tubes) are shown below:

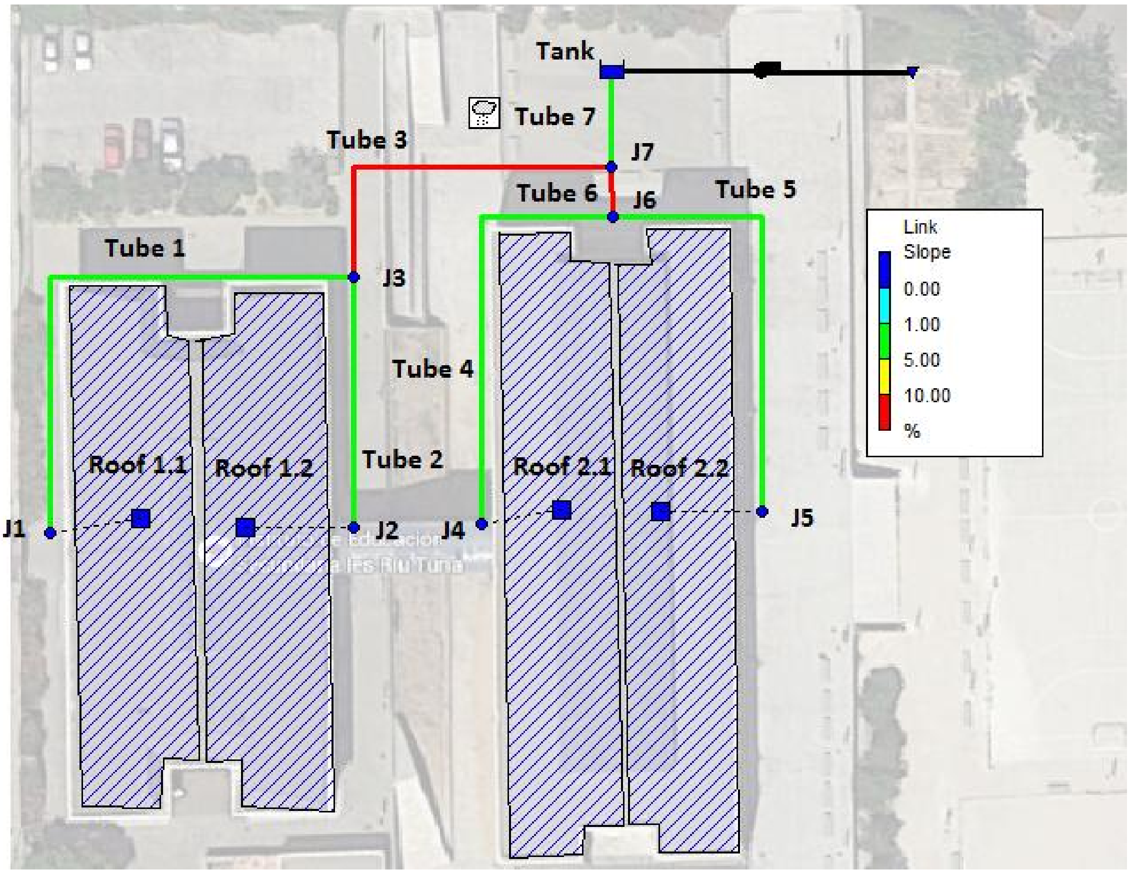


Figure 4-8: *Scheme of hydraulic of the Case study 2 (from SWMM)*

Junction	Height (m)
J1	22
J2	22
J3	20
J4	15
J5	15
J6	13
J7	1
Tank	**0**

Tube	Diameter (mm)	Length (m)
Tube 1	200	150
Tube 2	200	60
Tube 3	200	100
Tube 4	200	80
Tube 5	200	80
Tube 6	200	20
Tube 7	250	40

Table 4-5: *Measures of junctions and gutters*

These measures will be tested with the SWMM on several heavy rainfalls but should be right because the calculated has been done with a rainfall of 100 mm/h as it is specified before.

The material used has been PVC because have good qualities with a reasonable price.

- Precipitation analysis:

  Precipitation is the main input parameter in the design of systems RWH therefore a precipitation analysis is a prerequisite in determining the design parameters, primarily on the storage capacity and the catchment area which are necessary for the system meets the expected requirements.

  The precipitation analysis will be develop with the Storm Water Management Model (see the point 4.4)

- Runoff Coefficient:

  The runoff coefficient (Cr), for any capture rainwater is the ratio of the volume of water that runs off a surface and the volume of water that falls on the surface, at time t.

$$Cr = \frac{Volume\ of\ Runoff}{Volume\ of\ Rainwater}$$

  All calculations relating to the performance of rainwater catchment systems involve the use of a runoff coefficient to take into account of losses due to spillage, leaks, infiltration, catchment surface wetting, and evaporation, which will contribute to reducing the amount of rainwater which actually enters the storage tank.

  For this reason, it is appropriate to consider the runoff coefficient appropriate for this case of study. This is not an easy issue but the study developed by Zhu and Liu (1998) published in the book “Rainwater Harvesting for Agriculture and Water Supply” shows a table of runoff coefficients of different roof catchment land surface in areas with average annual rainfall ranging from 200 to 500mm, which is our case of study.

Material	Runoff Coefficient
Corrugated iron	0.8-0.85
Cement tile	0.62-0.69
Clay tile (machine made)	0.30-0.39
Clay tile (hand-made)	0.24-0.31

Table 4-6: *Runoff Coefficient for different materials.*

- Potential Rainwater Supply from a Simple Roof Catchment:

The potential rainwater supply depends on the amount of rainfall, the area of the catchment, and its runoff coefficient. The more umpredictable and important variable in the calculation is the rainfall, and it will be considered.

$$S = R \times A \times Cr$$

Where:

S = Mean rainwater supply in cubic meters (m3)

R = Mean annual rainfall in millimetres (mm/a)

A = Catchment area in square meters (m2)

Cr = Runoff coefficient

- Dimensions of the tank:

In a harvesting system of rainwater, the tank of catchment is the main construction in the overall system and about relation inversion-benefits. Therefore the volume of catchment tank will be quite big to collect rainwater in episodes of heavy rain for use in times of drought.

There are several authors who have worked on the optimal sizing of tanks for water harvesting, such as Ngigi (1999), Che et al. (2008), Coombes and Kuczera (2003a), Campisano and Modica (2012), among others. But in this case it is a complementary source of non-potable water and the main objective is to collect all the rainwater as much as possible and then study for what applications it can be used (watering gardens, cleaning, toilet, etc).

- <u>Reuse of the rainwater:</u>

The main use of the rainwater harvesting will be the irrigation and washing uses. For that it is necessary a pump which power will be calculate depend of the characteristics of the facilities. Will be possible to work without any pump but only will be possible to irrigation the plants that are lower that the tank, and to get water to wash the staff must go to the tank each time.

The consumption according to studies has been calculated about 2000 litters weekly.

4.3 Data Records

This input is the most important one, since there are a lot of variables that depend on it. The data rainfall used has been got from website IVIA (Valencian Institute of Agricultural Research). IVIA is an autonomous body of the Generalitat Valenciana, attached to the Ministry of Agriculture, Fisheries, Food and Water, created in 1991 by Law 4/1991 of the Generalitat Valenciana. Its aims are to promote scientific research and technological development in the Valencian agri-food sector.

The data is from Bétera, a tiny town to 15km to the west from Quart de Poblet because it is the rain station more close. The file was in Excel format and it has been changed to a format where each line of the file contains the station ID, year, month, day, hour, minute, and precipitation reading in mm, all separated by one or more spaces. After to do that, the file was saved in .dat format to be able to introduce in the SWMM software and implement the case of study.

[Station	Year	Month	Day	Hour	Minute	Rain]
BETERA	2014	1	1	0	0	0
BETERA	2014	1	2	0	0	0
BETERA	2014	1	3	0	0	0
BETERA	2014	1	4	0	0	1.31
BETERA	2014	1	5	0	0	0

It is important remember that, when a rain gage is designated as receiving its rainfall data from a file, the user must supply the name of the file and the name of the recording station referenced in the file. For the standard user-prepared format, the rainfall type (e.g., intensity or volume), recording time interval, and depth units must also be supplied as rain gage properties. For this case, I have chose the volume rainfall type, 24 hours of frequency (daily) and the rainfall units in mm.

Rain Gage RW1

Property	Value
Name	RW1
X-Coordinate	42.323
Y-Coordinate	76.811
Description	
Tag	
Rain Format	VOLUME
Time Interval	24:00
Snow Catch Factor	1.0
Data Source	FILE
TIME SERIES:	
- Series Name	*
DATA FILE:	
- File Name	C:\Users\usuario\Drop
- Station ID	BETERA
- Rain Units	MM

User-assigned name of rain gage

Figure 4-9: *Rain Gage parameters (from* SWMM*)*

To make it as real as possible, the simulation and to know what can happens in the worst case, I have taken three heavy rainfall episodes in half hour format and another by days to make a continuous simulation by two years (2014 and 2015).

The three heavy rainfall episodes chosen are shown below:

<u>Heavy Rain Case 1:</u>

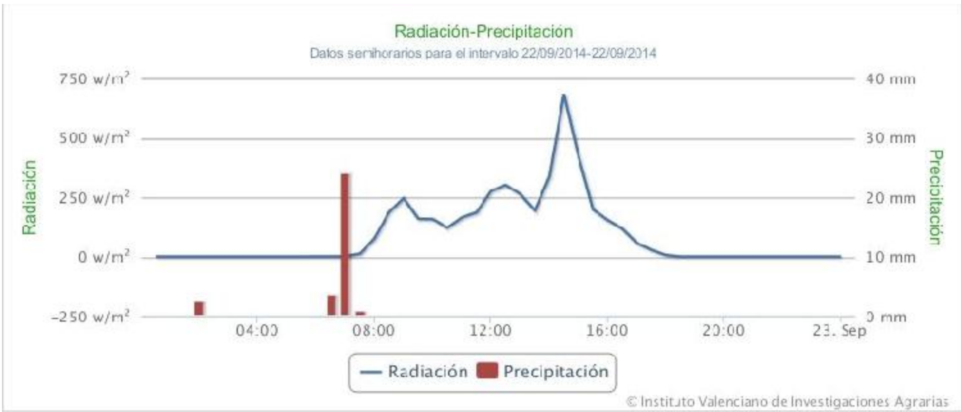


Figure 4-10: *Rainfall Data 22/09/2014 (from* IVIA*)*

At 7 hours in the morning was recorded 24 mm in half hour, it is 48 mm/hour, so it is considered as a heavy rain, almost violent rain (>50mm/hour) according to State Meteorological Agency (AEMET). The total rainfall recorded was of 29 mm.

Heavy Rain Case 2:

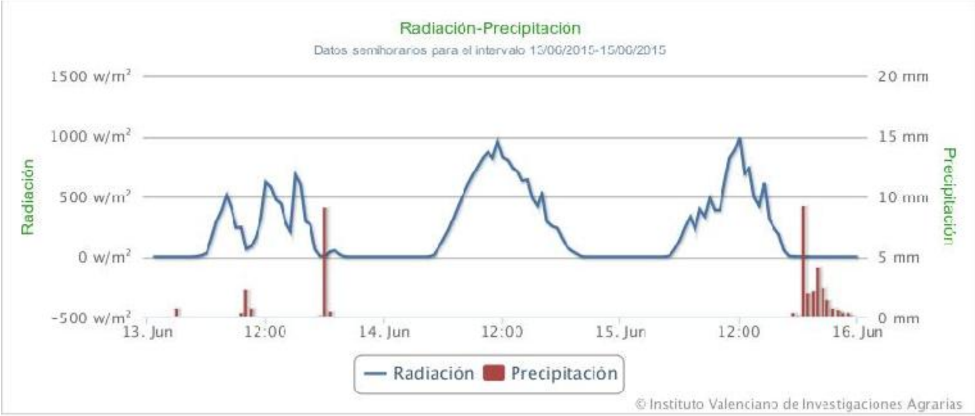


Figure 4-11: *Rainfall Data since 13/06/2015 to 15/06/2015 (from* IVIA*)*

In this case are recorded two heavy rains in a short time period (three days), the first one of 18.2 mm/hour and the second one of 18.4 mm/hour. The total rainfall recorded in this period was of 31mm.

Heavy Rain Case 3:

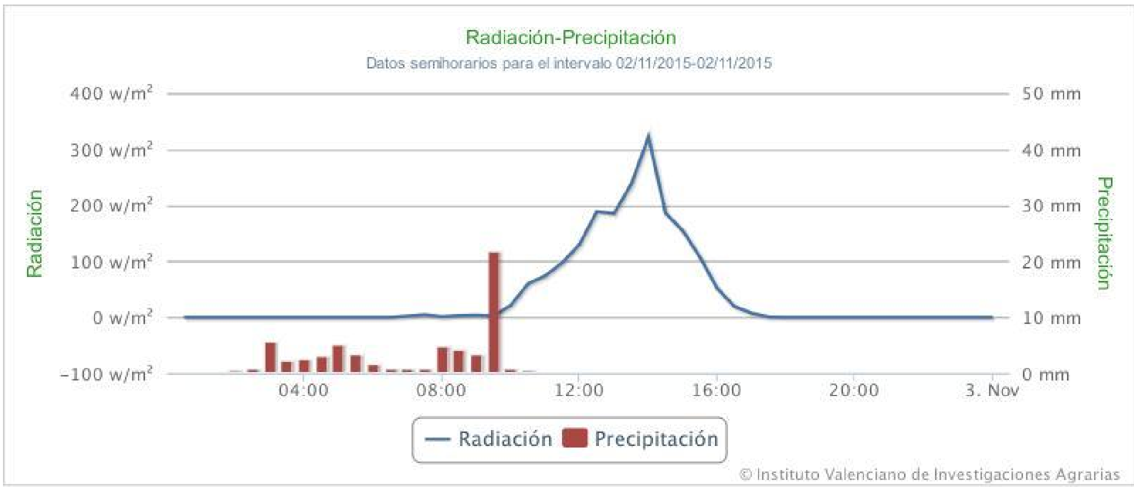


Figure 4-12: *Rainfall Data 02/11/2015 (from* IVIA*)*

This case is the most hart one since, was recorded 53mm in 9 hours with a peak of 21.6 mm in half hour.

The same way that with the daily rainfall data, the Excel files have been changed to a .dat format, and the frequency selected to 30 minutes.

Evapotranspiration data:

This file has daily data about rainfall and it also has the average temperature and the Reference Evapotranspiration (ETo), data that are necessaries to implement the project as real as possible. Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process.

The Evapotranspiration data are between 0.6 and 6.8 mm (see Figure 4-13), depend of the year stations, temperature, weather, moment of the day, etc. This data will be necessary to know the specific irrigation necessities of the green roof, and keep the humidity conditions in the Available Water range (Between the Field Characteristics point and the Wilting Point).

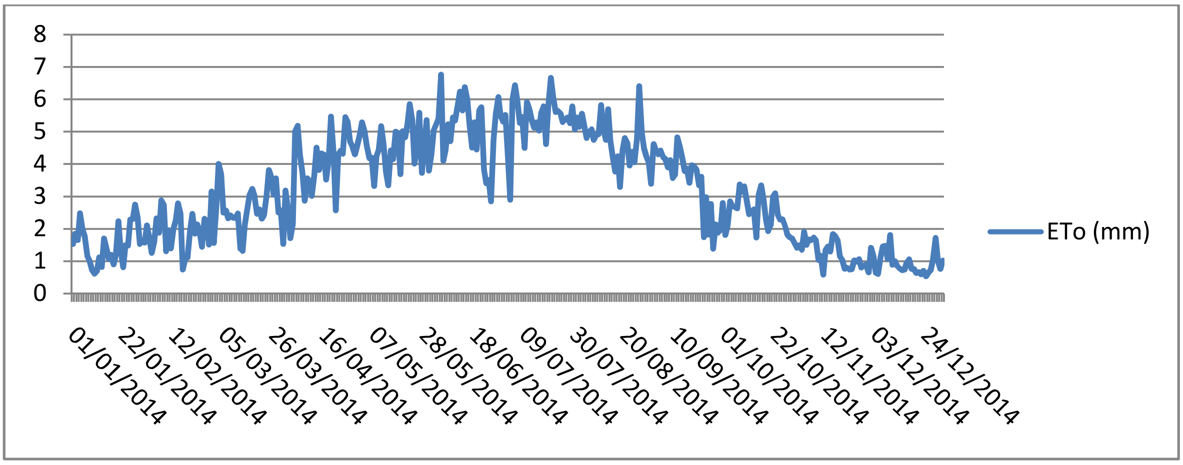


Figure 4-13: *Evapotranspiration daily data (from* IVIA*)*

4.4 Used Tool/ Software

For simulate both cases of study, we will use the Storm Water Model Management (SWMM). SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps

Below (Figures 4-14 and 4-15) I am going to show you the processes that SWMM models using the objects mentioned previously and how they are tied to one another:

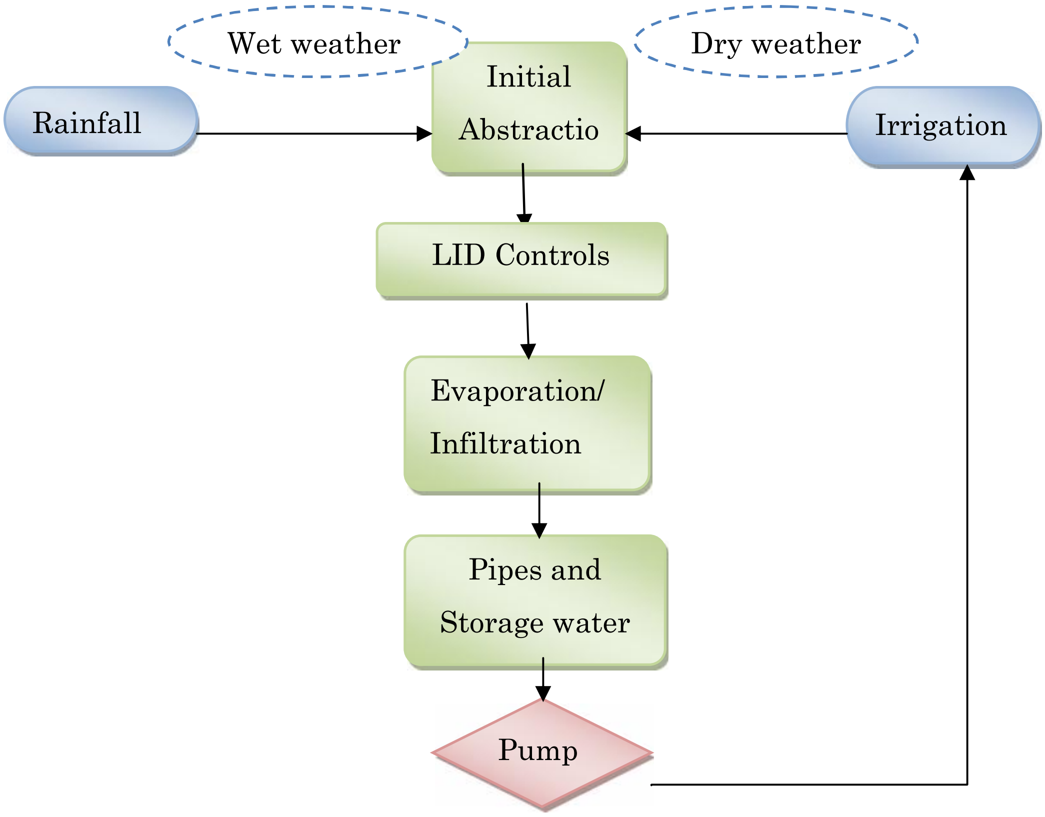


Figure 4-14: *Processes modeled by SWMM for IES La Senda*

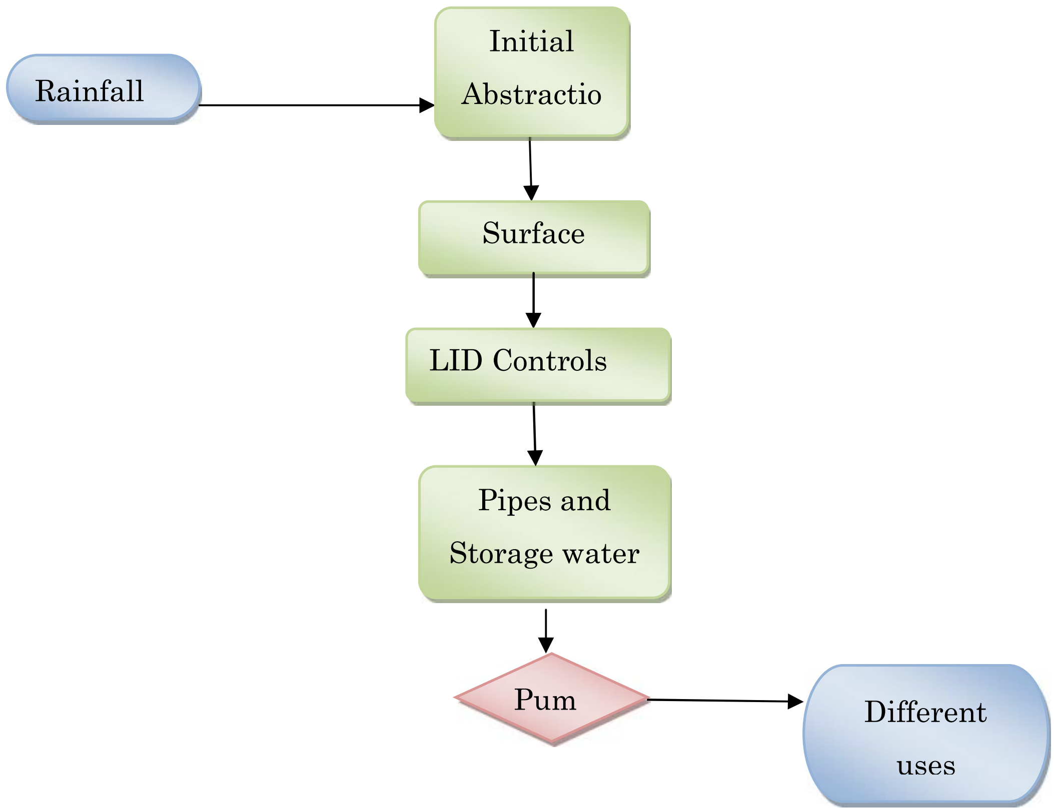


Figure 4-15: *Processes modeled by SWMM for IES Riu Turia*

LID Representation

Low Impact Development (LID) controls are represented by a combination of vertical layers whose properties are defined on a per-unit-area basis. This allows LIDs of the same design but differing area coverage to easily be placed within different subcatchments of a study area. During a simulation SWMM performs a moisture balance that keeps track of how much water moves between and is stored within each LID layer.

Green Roof

Green Roof is a variation of a bio-retention cell that have a soil layer laying atop a special drainage mat material that conveys excess percolated rainfall off of the roof. Below each layer is defined:

- The Surface Layer corresponds to the ground (or pavement) surface that receives direct rainfall and runon from upstream land areas, stores excess inflow in depression storage, and generates surface outflow that either enters the drainage system or flows onto downstream land areas.

- The Soil Layer is the engineered soil mixture used in bio-retention cells to support vegetative growth. It can also be a sand layer placed beneath a pavement layer to provide bedding and filtration.
- The Drainage Mat Layer is a mat or plate placed between the soil media and the roof in a green roof whose purpose is to convey any water that drains through the soil layer off of the roof.

Rooftop Disconnection

Rooftop Disconnection has downspouts discharge to pervious landscaped areas and lawns instead of directly into storm drains. It can also model roofs with directly connected drains that overflow onto pervious areas. Below each layer is defined:

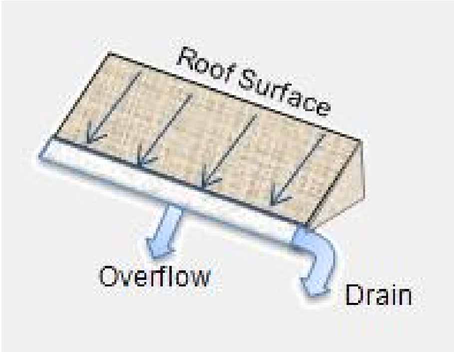


Figure 4-16: *Rooftop Disconnection (from SWMM)*

- The Surface Layer corresponds to the ground (or pavement) surface that receives direct rainfall and runon from upstream land areas, stores excess inflow in depression storage, and generates surface outflow that either enters the drainage system or flows onto downstream land areas.
- The Drain System conveys water out of the gravel storage layer of bio-retention cells, permeable pavement systems, and infiltration trenches (typically with slotted pipes) into a common outlet pipe or chamber. For rain barrels it is simply the drain valve at the bottom of the barrel while for rooftop disconnection it is the roof gutter and downspout system.

Once defined the key characters and objects of the SWMM, the next step is to introduce the parameters for the both model of study and start the run of the simulation.

Like I have mentioned before, in the first moment, it will be run the three heavy run case to decide the size of the pipes and of the tank, and avoid the overflows. Then, it will be run the continuous simulation for a two years period.

Chapter 5. Results Presentations

After making the simulations with the SWMM, has been possible to record the data about quantity of the runoff, as well as the correct size of the guttering and the tank. Moreover, have seen the specific necessities of irrigation for the green roof to achieve a maintenance as efficient as possible. Let's go see the outcomes to each study case:

5.1 Study case 1: La Senda Institute of Secondary Education

5.1.1 Heavy rain simulations

The heavy rainfall simulations were successful, that means that the "continuity error" is lower than 10 and the simulation can be considered right (see Figure 5-1). The most important data records are shown below:

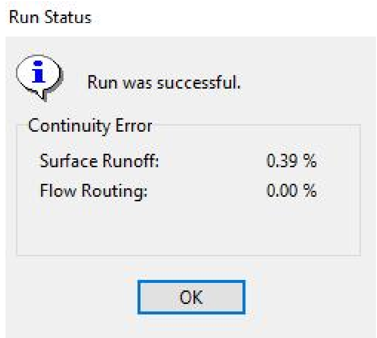


Figure 5-1: *Run Status (from SWMM)*

With the *Heavy rain case 1* has been possible to see that the sizes (diameter) of gutter are right, since this one is the heavier rain with 48 l/m^2 in an hour. In no one of tubes the capacity is upper than 15%.

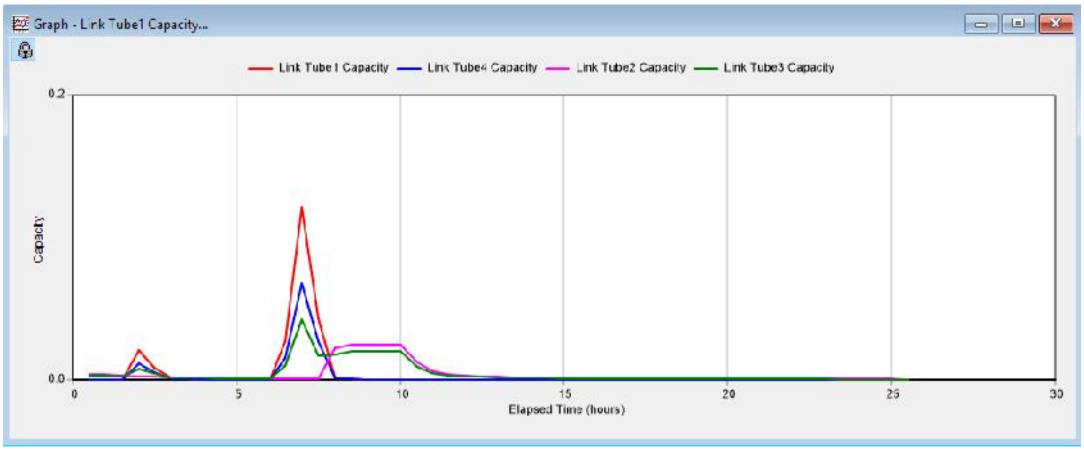


Figure 5-2: *Link tube capacity (from SWMM)*

In the same case is possible to observe the different behaviours between the normal roof and the green roof when the water runoff goes over these.

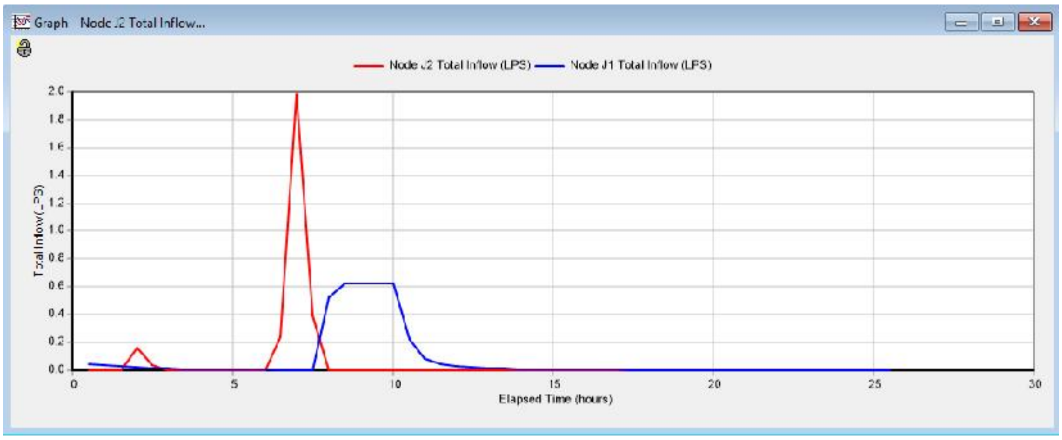


Figure 5-3: *Runoff peak to both roofs Heavy Rain Case 1 (from SWMM)*

Another parameter important is the velocity in the tubes, those velocities must not be more of 4 m/s.

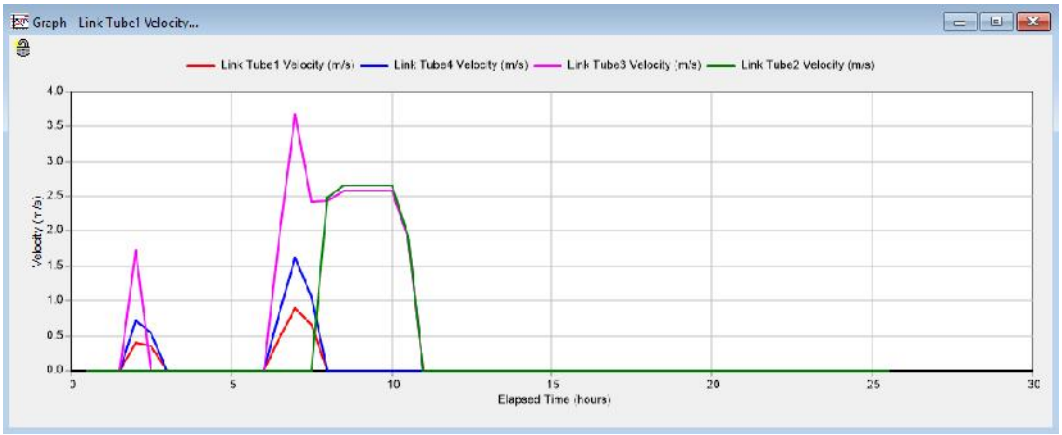


Figure 5-4: *Tubes velocity (from SWMM)*

In the Figure 22 is possible to see that in no one link are overcome the 4 m/s, despite that in the Tube 2 and 3 than velocity is close because they are a vertical links.

In the *Heavy rain case 3* is interesting highlight the rainfall quantity drop in only 9 hours (53mm/m^2) and the behaviour of the different roofs.

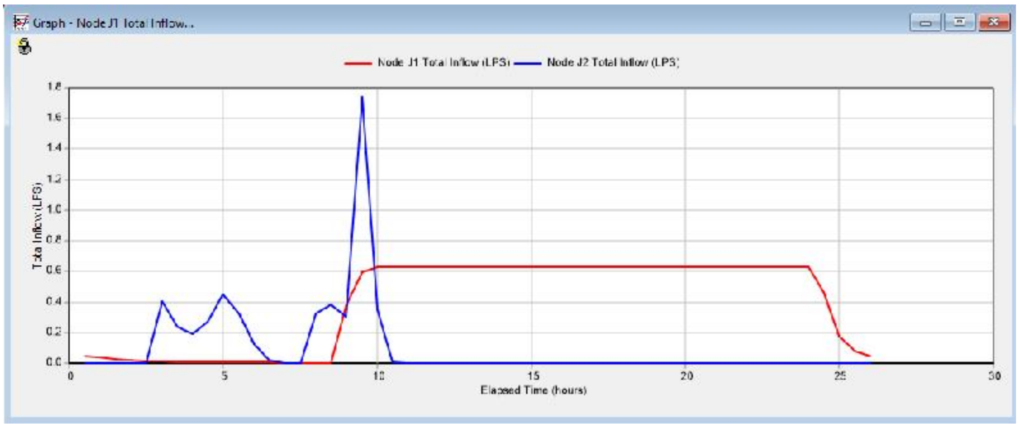


Figure 5-5: *Runoff peak to both roofs Heavy Rain Case 3 (from SWMM)*

In the Figure 23 is possible to see again the behaviour to use a green roof instead the normal roof in relation to the peak flow. Using the green roof the rainfall is harvested in the first moment and filtered slowly during several hours.

The Figure 24 shows the summary results from the two roofs, the Roof 1 surface (Green Roof) is bigger and the total runoff is higher too. In this table is possible to see the exact peak runoff data that has been shown in the figure 23.

Summary Results

Topic: Subcatchment Runoff — Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff LPS	Runoff Coeff
Roof1	53.00	0.00	0.29	0.00	29.15	0.04	0.63	0.550
Roof2	53.00	0.00	0.16	0.00	53.15	0.01	2.03	1.003

Figure 5-6: *Subcach. Runoff Summary Results; Heavy Rain Case 3 (from SWMM)*

As an example about how work in the scream of the program, see the Figure 5-7.

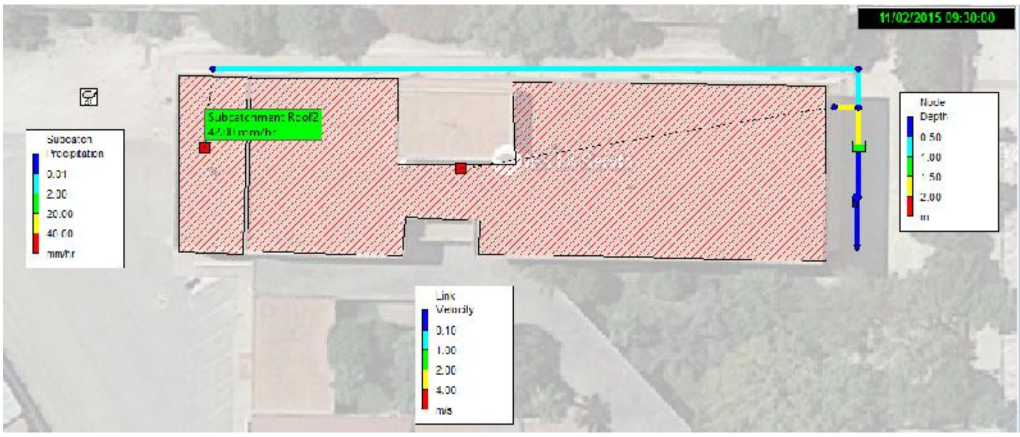


Figure 5-7: *Example how the program works; Heavy Rain Case 3 (from SWMM)*

5.1.2 Long-Term Simulation

In the summary results of the Subcatchment runoff is possible to see the total precipitation, the total evaporation, the total runoff and the runoff coefficient between others, to each roof of the years 2014 and 2015 is possible to see below:

Summary Results

Topic: Subcatchment Runoff — Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff LPS	Runoff Coeff
Roof1	518.33	0.00	340.85	0.00	168.47	0.21	0.52	0.325
Roof2	518.33	0.00	73.96	0.00	446.40	0.08	0.12	0.861

Figure 5-8: *Summary results Subcat. Runoff 2014 & 2015 (from SWMM)*

Summary Results

Topic: Subcatchment Runoff — Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff LPS	Runoff Coeff
Roof1	212.66	0.00	140.60	0.00	50.63	0.06	0.32	0.238
Roof2	212.66	0.00	34.41	0.00	179.28	0.03	0.06	0.843

Figure 5-9: *Summary results Subcat. Runoff 2014 (from SWMM)*

Summary Results

Topic: Subcatchment Runoff — Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff LPS	Runoff Coeff
Roof1	304.87	0.00	200.25	0.00	95.61	0.12	0.52	0.314
Roof2	304.87	0.00	39.31	0.00	266.54	0.05	0.12	0.874

Figure 5-10: *Summary results Subcat. Runoff 2015 (from SWMM)*

Of this way, it is possible to see the different between two consecutive years and get the average for implement it in any year. From the total runoff, one amount is harvested to reuse it according to the demand. The water quantity used each week is about 0.9 m3 (take 0.9 m3), and the remainder is returned to the natural water cycle. Below (Table 5-1) is possible to see the yearly average runoff to each case and the percentage that supposes.

Total Runoff (litters)	143000	100%
Total Runoff reused (litters)	47700	33%
Total Runoff returned to the natural water cycle (litters)	95300	67%

Table 5-1: *Runoff destination yearly average (from Excel logical program)*

According to the demand and precipitation records, the tank chosen has been of the 9.000 litters. Below (Figure 5-11) is possible to see the volume fluctuating of the tank considerate a weekly consume of 900 litters to cleaners labours and irrigation when will be necessary. The plot is about two years (2014 and 2015) and in any case the tank is empty completely.

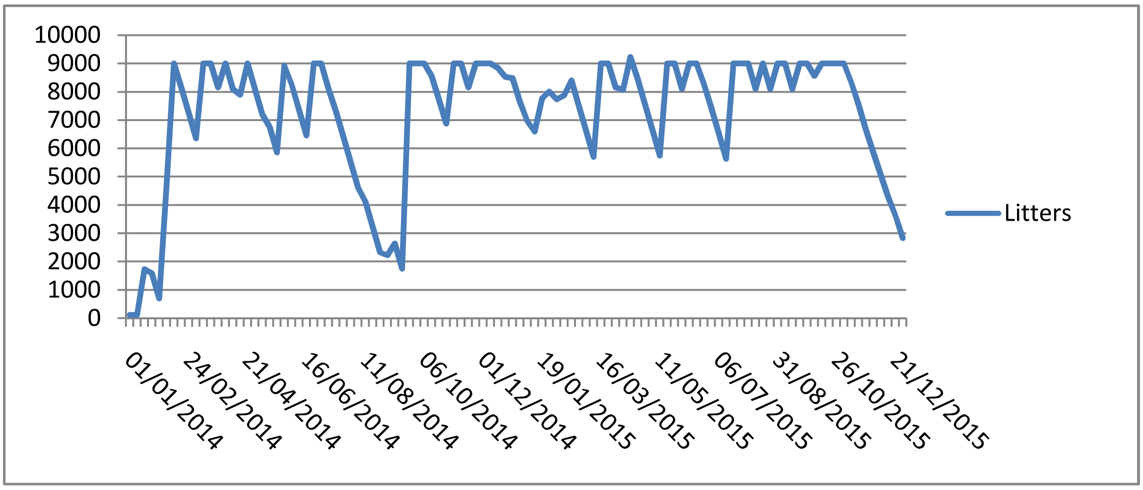


Figure 5-11: *Fluctuating volume from the tank in 2014 & 2015 (from Excel)*

According to the parameters about the soil, evapotranspiration (ET_0) and weather data has been possible to make an irrigation scheduling with probes in the Green Roof (see Figure 5-12).

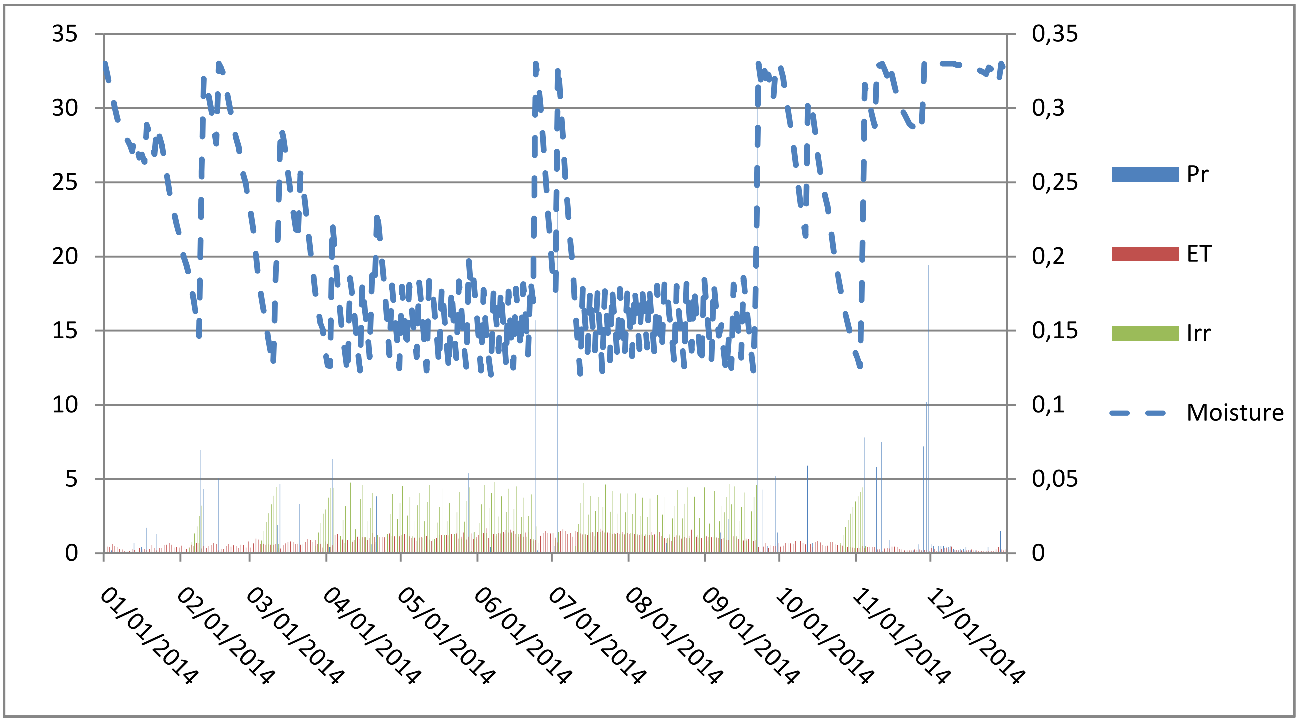


Figure 5-12: *Irrigation scheduling with probes in the Green Roof, 2014. (from Excel)*

In the next plot (Figure 5-13) is shown the irrigations times (fractions hours) with the irrigation quantity (mm). It is according to the methodology used.

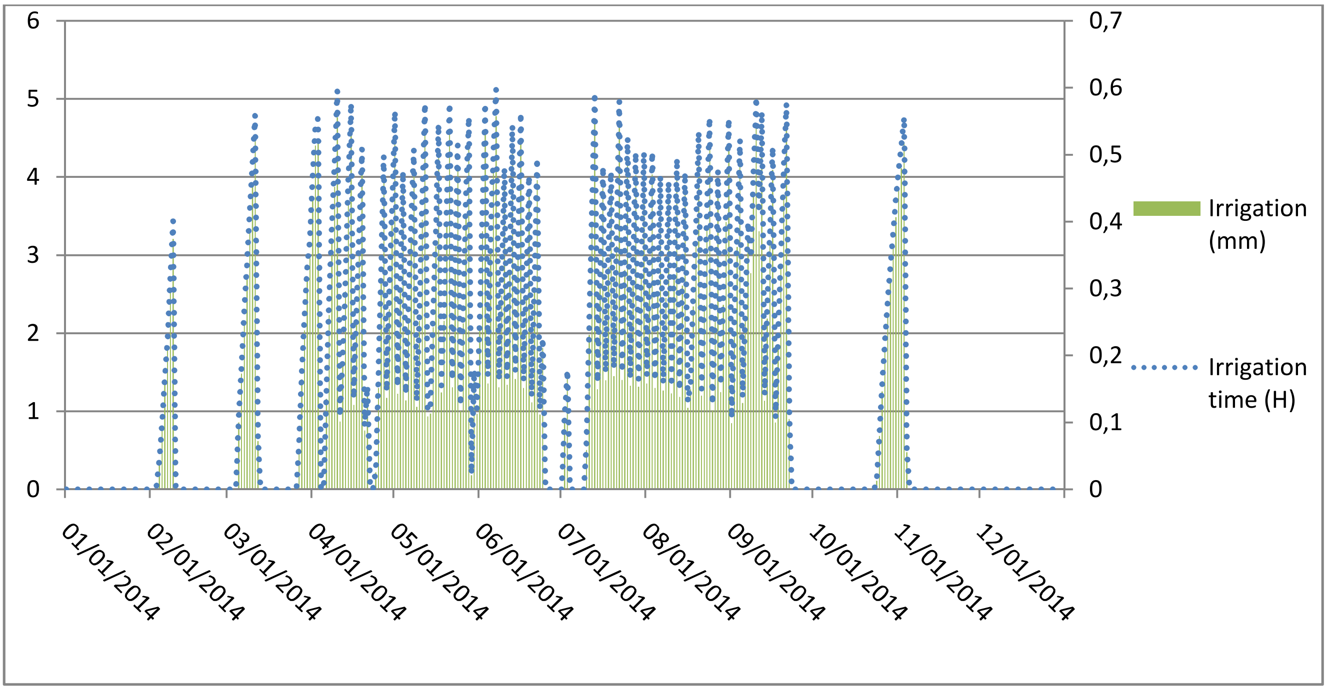


Figure 5-13: *Irrigation quantity and time in the Green Roof, 2014. (from Excel)*

5.2 Study case 2: La Riu Turia Institute of Secondary Education

5.2.1 Heavy rain simulations

The simulations have been done, being aware that the continuity error in the run status must not be higher than 10%. These have been acceptable, so the more important outcomes are shown below:

The *Heavy rain case 1* is the heavier rain with 48 l/m^2 in an hour, so it is pefect to see the capacity of the gutters.

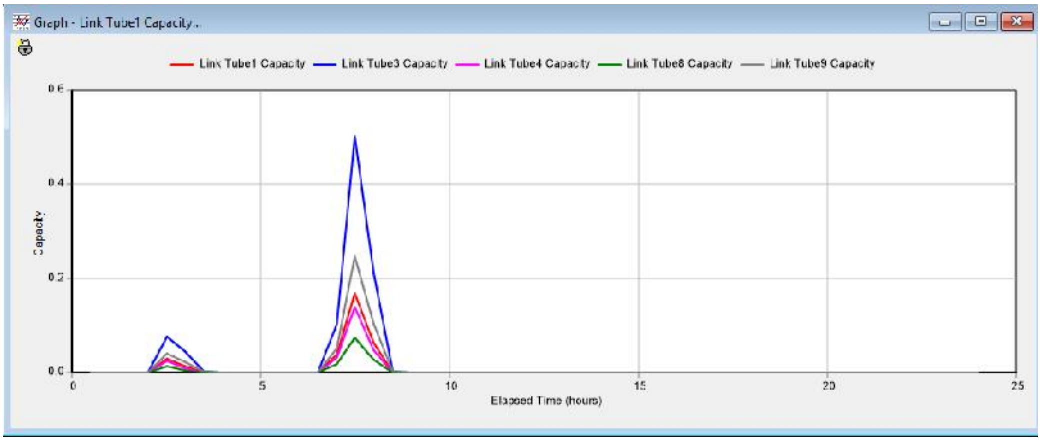


Figure 5-14: *Link tube capacity (from SWMM)*

Another important parameter is the velocity into the gutters and it is shown below:

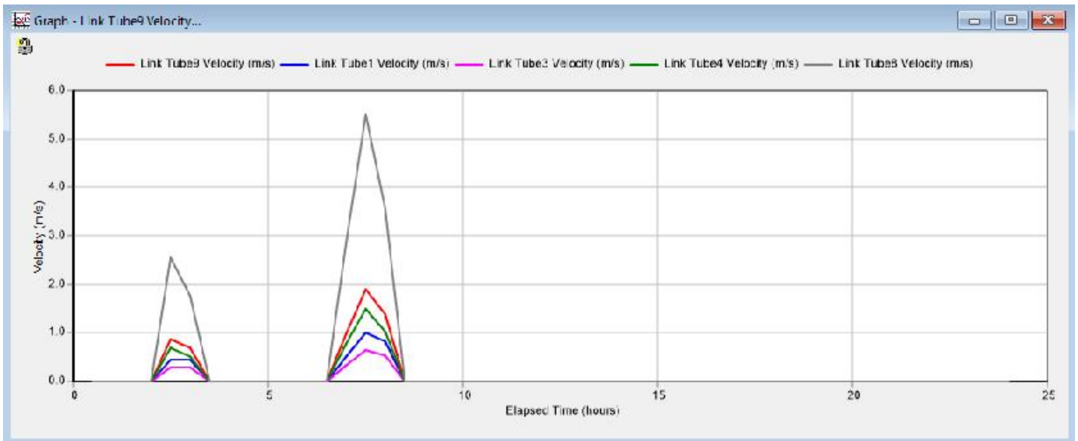


Figure 5-15: *Tubes velocity (from SWMM)*

Below (Figure 111) is shown the Heavy Rain Case 1 plot between the tank depth and link pump where is possible to see the overflow when the tank is filled. At 7 a.m. fell 24 litters in a half hour and was too much water to be harvested, so the excess rainfall was conducted to the Turia River.

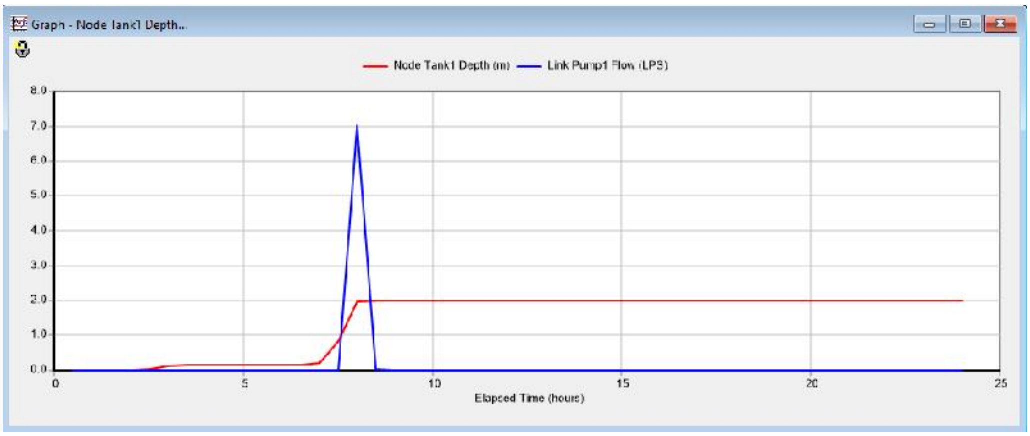
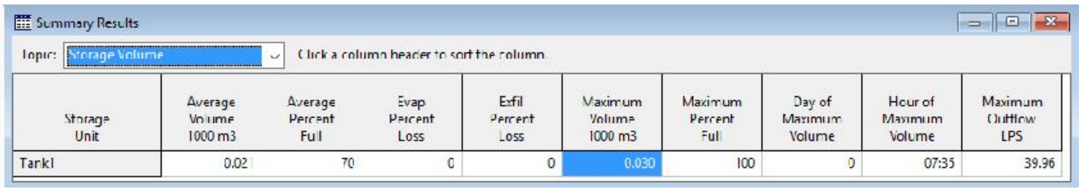


Figure 5-16: *Tank depth VS Link pump flow; Heavy Rain Case 1 (from SWMM)*

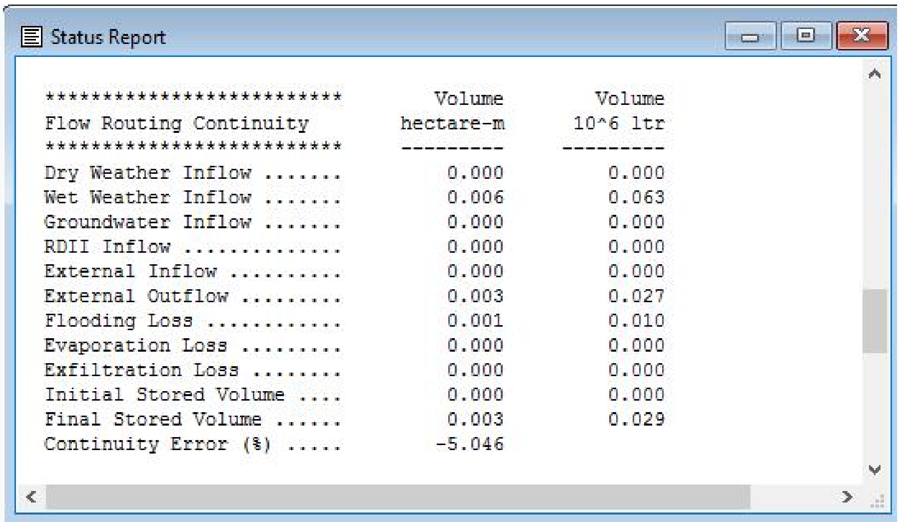
The amount runoff in only one session was 63. But the Tank only has capacity to store 30 m^3 so the rainfall harvest was 29 m^3, and the overflow was exactly 27 m^3. Another runoff were losses on the system (continuity errors: -5.04). See Figure 15:


Summary Results

Topic: Storage Volume   Click a column header to sort the column.

Storage Unit	Average Volume 1000 m3	Average Percent Full	Evap Percent Loss	Exfil Percent Loss	Maximum Volume 1000 m3	Maximum Percent Full	Day of Maximum Volume	Hour of Maximum Volume	Maximum Outflow LPS
Tank1	0.02	70	0	0	0.030	100	0	07:35	39.96

Figure 5-17: *Storage Volume; Heavy Rain Case 1 (from SWMM)*


Status Report

```
**************************        Volume         Volume
Flow Routing Continuity       hectare-m      10^6 ltr
**************************     ---------      ---------
Dry Weather Inflow .......         0.000          0.000
Wet Weather Inflow .......         0.006          0.063
Groundwater Inflow .......         0.000          0.000
RDII Inflow ..............         0.000          0.000
External Inflow ..........         0.000          0.000
External Outflow .........         0.003          0.027
Flooding Loss ............         0.001          0.010
Evaporation Loss .........         0.000          0.000
Exfiltration Loss ........         0.000          0.000
Initial Stored Volume ....         0.000          0.000
Final Stored Volume ......         0.003          0.029
Continuity Error (%) .....        -5.046
```

Figure 5-18: *Report of Flow Routing Continuity; Heavy Rain Case 1 (from SWMM)*

The Runoff Coefficient is more close to 100%. To manual calculation should be applied the runoff coefficient (see 4.2 Runoff Coefficient).

In the Heavy rain case 2 is possible to see the velocities in the Tube 8 and 9 that are both verticals and the velocity is not upper that 4 m/s.

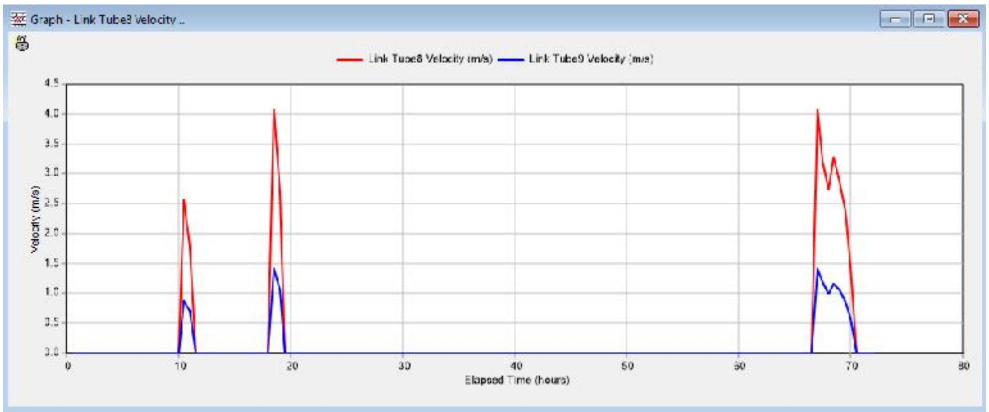


Figure 5-19: *Tubes velocity; Heavy Rain Case 2 (from SWMM)*

But, it is important to say that the rainfall in this case was 18mm/h, not 48 mm/h. And the continuity errors were lesser too: 0.34 (see Figure 165).

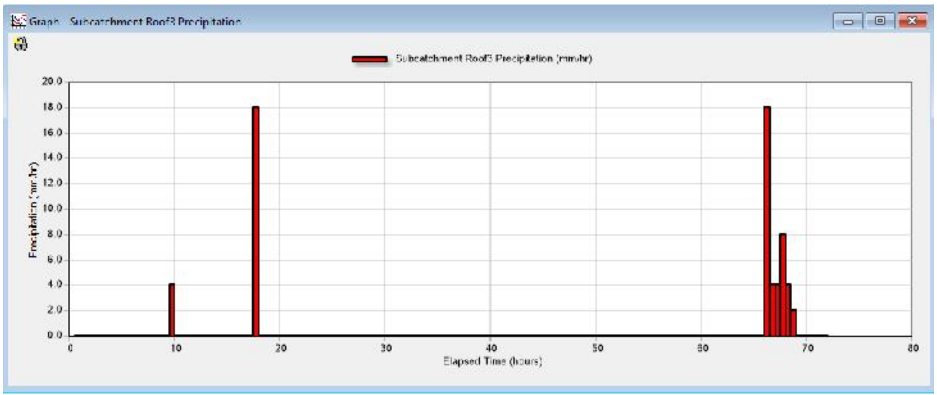
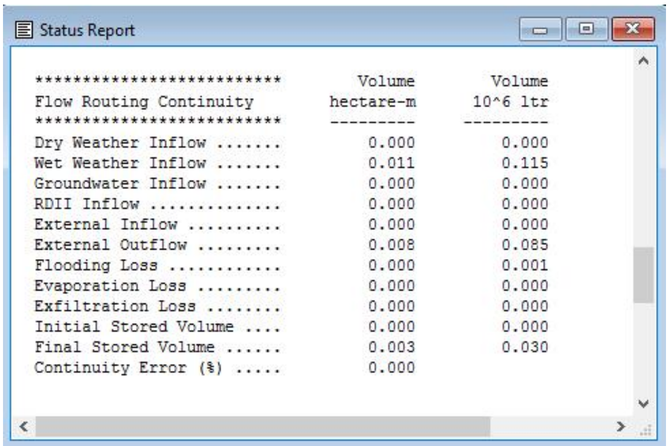


Figure 5-20: *Precipitation; Heavy Rain Case 2 (from SWMM)*

The heavy rain case 3 is the heaviest one, since the precipitation was of 53 mm in 9 hours. Anyway the flow routing continuity was an exit, and the continuity error was 0. On the other hand is possible see in the Figure 155 the total rainfall harvested and the total rainfall come back to the Turia River (85 m^3).



Status Report

Flow Routing Continuity	Volume hectare-m	Volume 10^6 ltr
Dry Weather Inflow	0.000	0.000
Wet Weather Inflow	0.011	0.115
Groundwater Inflow	0.000	0.000
RDII Inflow	0.000	0.000
External Inflow	0.000	0.000
External Outflow	0.008	0.085
Flooding Loss	0.000	0.001
Evaporation Loss	0.000	0.000
Exfiltration Loss	0.000	0.000
Initial Stored Volume	0.000	0.000
Final Stored Volume	0.003	0.030
Continuity Error (%)	0.000	

Figure 5-21: *Report of Flow Routing Continuity; Heavy Rain Case 3 (from SWMM)*

Like an example that how the program works, in the Figure 68 is shown the moment when the maxima precipitation is recorded. Both roofs are red because the runoff is more than 42 mm/h, the tubes (links) represent the velocity, and in the node is possible to see the depth of the tank in this moment.

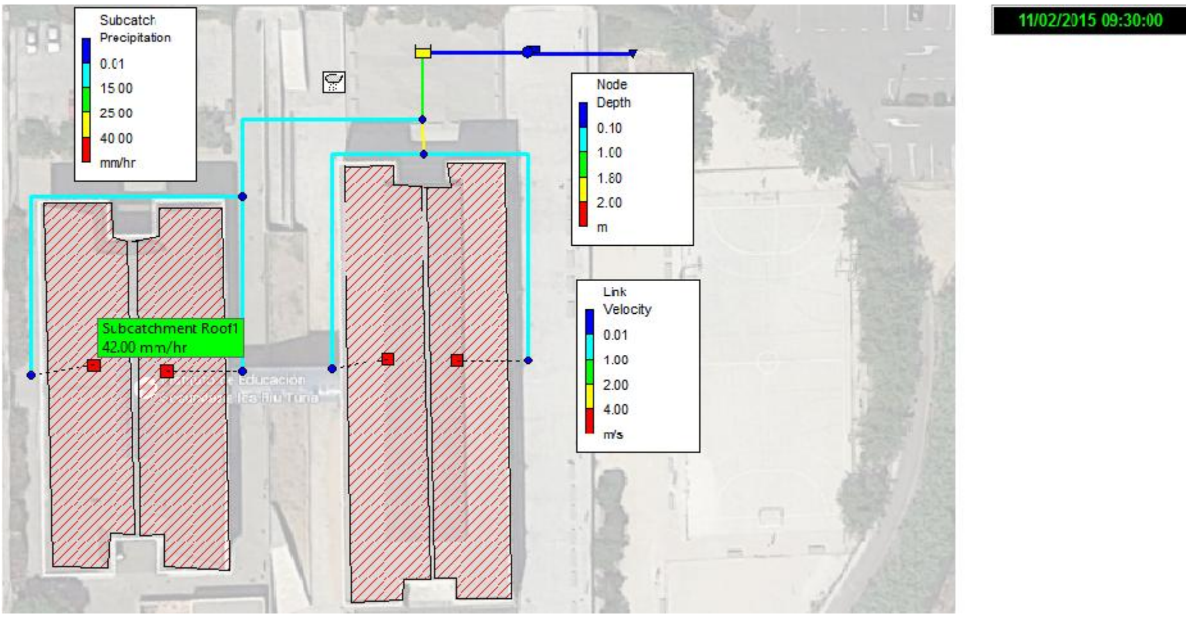


Figure 5-22: *Example how the program works Heavy Rain Case 3 (from SWMM)*

5.2.2 Long-Term Simulations

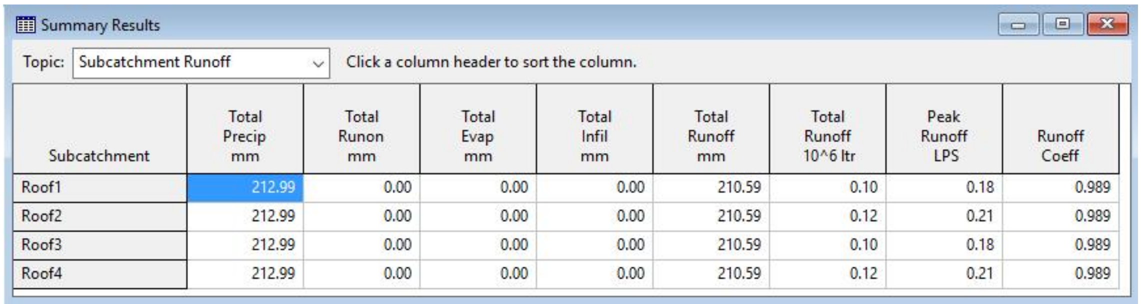
In the summary results of the Subcatchment runoff is possible to see the total precipitation, the total runoff and the runoff coefficient between others, to each roof of the years 2014 and 2015 is possible to see below:

Summary Results

Topic: Subcatchment Runoff — Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff LPS	Runoff Coeff
Roof1	518.71	0.00	0.00	0.00	516.26	0.26	0.34	0.995
Roof2	518.71	0.00	0.00	0.00	516.26	0.30	0.41	0.995
Roof3	518.71	0.00	0.00	0.00	516.26	0.26	0.34	0.995
Roof4	518.71	0.00	0.00	0.00	516.26	0.30	0.41	0.995

Figure 5-23: *Summary results Subcat. Runoff 2014 & 2015 (from SWMM)*

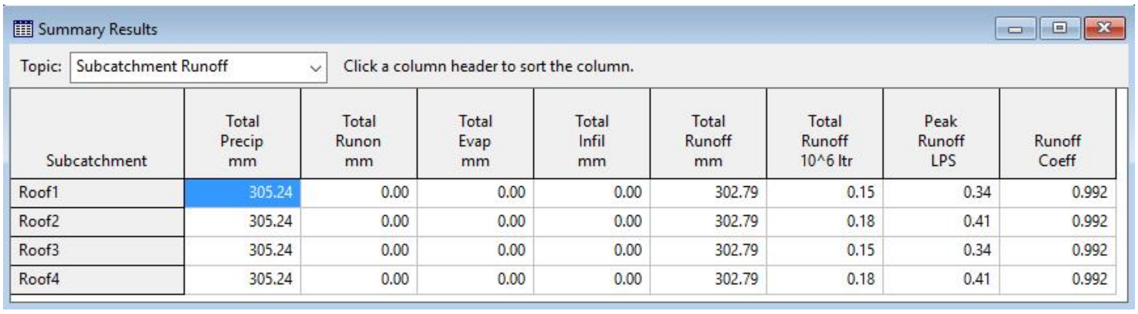


Summary Results

Topic: Subcatchment Runoff — Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff LPS	Runoff Coeff
Roof1	212.99	0.00	0.00	0.00	210.59	0.10	0.18	0.989
Roof2	212.99	0.00	0.00	0.00	210.59	0.12	0.21	0.989
Roof3	212.99	0.00	0.00	0.00	210.59	0.10	0.18	0.989
Roof4	212.99	0.00	0.00	0.00	210.59	0.12	0.21	0.989

Figure 5-24: *Summary results Subcat. Runoff 2014 (from SWMM)*



Summary Results

Topic: Subcatchment Runoff — Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff LPS	Runoff Coeff
Roof1	305.24	0.00	0.00	0.00	302.79	0.15	0.34	0.992
Roof2	305.24	0.00	0.00	0.00	302.79	0.18	0.41	0.992
Roof3	305.24	0.00	0.00	0.00	302.79	0.15	0.34	0.992
Roof4	305.24	0.00	0.00	0.00	302.79	0.18	0.41	0.992

Figure 5-25: *Summary results Subcat. Runoff 2015 (from SWMM)*

Of this way, it is possible to see the different between two consecutive years and get the average for implement it in any year. From the total runoff, one amount is harvested to reuse it according to the demand. The water quantity used each week is about 2 m^3 (take 2 m^3), and the remainder is returned to the natural water cycle. Below (Table 5-2) is possible to see the yearly average runoff to each case and the percentage that supposes.

Total runoff (liters)	590000	100%
Total runoff reused (liters)	106000	18%
Total runoff returned to the natural water cycle (liters)	484000	82%

Table 5-2: *Runoff destination yearly average (from Excel logical program)*

Below (Figure 5-26) is possible to see the volume fluctuating of the tank considerate a weekly consume of 20.000 litters to cleaners labours and irrigation if will be necessary. The plot is about two years (2014 and 2015) and in any case the tank is empty completely.

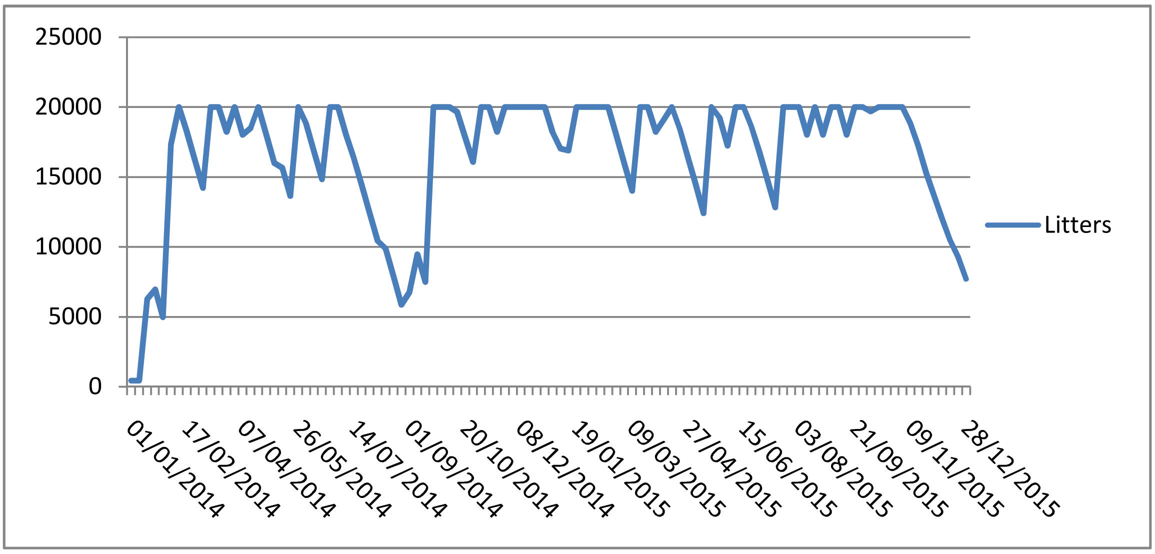


Figure 5-26: *Fluctuating volume from the tank in (2014 & 2015 (from* Excel*)*

Chapter 6. Discussion

The data records shown before, make it possible to realize how powerful the program SWMM is. Every data has been observed and checked with other tools (e.g. Excel program) and they all have full validity.

6.1 Study case 1: La Senda Institute of Secondary Education

The data records from the heavy rains shown before, are only a little bit of all data recorded but there are enough as example about how has been developed the project.

The capacity of guttering according to CTE’s design is correct. Under heavy rains, the capacity is always lower that 20% so the overflow is under control to open gutters. In partially filled vertical pipes, water slides on the inner wall of the pipe, leaving a hole in the center. Pipe works 1/3 full section (it is our case), extends water mode this central hollow sealing diaphragm, resulting in pressure oscillations that can break the water seal or expel water outfalls into storm drains.

The velocity into the gutters is always lower that 4 m/s, so the system works in laminar regime and avoids many problems of overflow or even broke the gutters.

The Figure 23 has shown the peak flow is different between the green roof (Roof 1) and the normal roof (Roof 2). The benefits to use a LID (Low Impact Development) like it is the Green Roof are clear. Using the Green Roof the peak flow is reduced until 0.6 LPS, from 2.1 LPS of the normal roof. Through this method is avoided the possible saturations of the gutters and is reduced the size of the gutters, so the costs are reduced. The rainfall is flowing during hours and, also this water has been filtered and it is harvested or is returned to the river totally clean.

The runoff Coefficient is correct, since it is about 55% to the green roof and about 100% to the normal roof. The runoff coefficient to the green roof is inside the outcome hoped according to the soil properties and depth. The runoff coefficient of the normal roof is not totally correct but in this case has not applied any LID, so the runoff does not follow the "rooftop disconnection rules" like in the Study Case 2. In the reality the runoff coefficient will be close to 95 or 97%.

In the long-term simulation has been possible to see how many runoff is captured for the subcatchments, besides to see how much is harvested or reused, according to usage expectations, and how much is redirection to the natural water cycle (Turia River). Of this way, the runoff data in litters supposed saving money in two different outlooks.

On the one hand, the total water harvesting as yearly average is 47.7 m^3 so, the money saved according to the bill water in Quart de Poblet of 2.4€ per m^3 is in total: 115€. On the other hand, the total water redirection is 95.3 m^3, and that supposed, according to the depuration and sewer cost of 1.2€ per litter, a total of 114€.

The size of the tank has been estimated for keep the water supply for 6 weeks during dry period. According to the simulation for the last two years in any moment the tank has been totally empty, so the service is guaranteed.

The Figure 5-12 shows the irrigation scheduling with probes simulated in a logic Excel program, which is possible to see the specific irrigation needs to keep the sedum species healthy. The moisture is kept about 0.2 and depending of the year period need more or less irrigation to keep the specific moisture.

The irrigation times have been design according to specific criterion shown in the methodology, and the times are never more than 0.6 hours, that is about 36 minutes as maximum. It is important to say that the irrigation is done during periods that the evapotranspiraton is lower, it mean, when the sun goes down. Of this way, the need of water is reduced and the plants have more time to absorb the water.

The economical study is in the Appendix A.1, and the total inversion is 9386€. This includes the gutters, tubes and accessories, the tanks, the pump and everything necessary to make the green roof and the irrigation system to keep it. This budget could be lower because the gutters and tubes are already fits and the pump could be dispensable and use the harvest water for flushing and irrigation.

The first amortization time estimation is of 40 years but that is not totally true since, in this study has not been calculated the electrical saving due to improve of the insulation with the green roof. Further the educational character and other difficult issues calculate its value.

6.2 Study case 2: Riu Turia Institute of Secondary Educaton

The first aim is to check the sizes of gutters are aright. In the Heavy rain case 1 it is possible to see it, since this one is the heavier rain with 48 l/m2 in an hour. None of the tubes capacity is more than 50%.

It´s important to note the velocities don´t work in the tubes more than 4 m/s, for this reason in the Figure 15 is possible to see the evolution of the velocities. In the Tube 8, that is a vertical tube has almost 6 m/s, but in this case it is acceptable.

With this model it´s possible to see the moment when the tank is full and the rainfall starts to overflow. In that cases the runoff will be conduit to the Turia River, very close from Institute, so it´s not necessary to put the water with a pump. The size of tank has been designed to harvest as rainfall as possible in the heavy rain season, since after will come long dry seasons. But the total rainfall in the heavy rains is too much to harvested all it.

The runoff coefficient is about 95% so it is right according to parameters established. In this case is working with the "rooftop disconnection rules" LID, and the parameters are totally correct.

In the long-term simulation it has been possible to see how much runoff is captured for the subcatchments, besides to see how much is harvested or reused, according to usage expectations, and how much is redirection to the natural water cycle (aquifer). Of this way, the runoff data in litters supposed saving money in two different outlooks.

On the one hand, the total water harvesting as yearly average is 106 m^3 so, the money saved according to the bill water in Quart de Poblet of 2.4€ per m^3 is in total: 254€. On the other hand, the total water redirection is 484 m^3, and that supposed, according to the depuration and sewer cost of 1.2€ per litter, a total of 581€.

The size of the tank has been estimated to keep the water supply for 6 weeks during dry period. According to the simulation for the last two years in any moment the tank has been totally empty, so the service is guaranteed.

The economical study is in the Appendix A.2, and the total inversion is 14280€ and includes the gutters, tubes and accessories, the tanks, the pump, etc The first amortization time estimation is of 17 years but, has been calculated other lower budget without take account the gutters and tubes, which are already fits and the pump could be dispensable and use the harvest water for flushing and irrigation. Of this way, the inversion is 8266€ and can be amortized in 10 years. The amortization period is only a reference because this SuDS has infinities of benefits such as, avoid overflows, restore water natural cycle or educational character for the pupils of the educational center.

Chapter 7. Conclusion and Recommendations for Futures Works

This project has examined how to improve energy efficiency in the water cycle through SuDS based essentially replicate as closely as possible the natural hydrologic cycle in the urban spaces. With the use of SuDS has been possible to eliminate the production of runoff, getting detract much of the pollution load of these runoffs, eliminating the need for treatment before discharge to the environment.

SWMM has been the perfect partner to make a simulation of both cases of study as real as possible. It has been demonstrated the power, reliability and flexibility of the software used, since it is possible to simulate quickly and reliably infinity of models that improve energy efficiency in the water cycle.

In short, the uses of SuDS have reduced the energy consume by the next ways:

- Reducing the use of potable water, so the energy consumed in the treatment and purification processes is reduced. The total saving yearly average is shown below (Table 7-1) to each case:

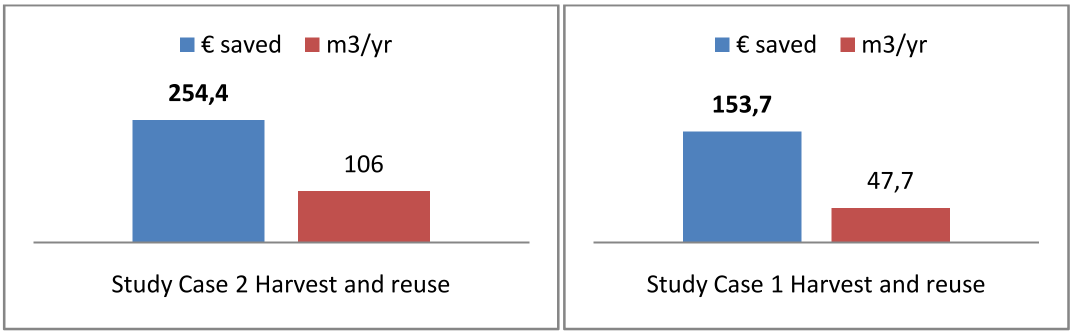


Table 7-1: *Yearly average runoff harvest and reuse (from Excel)*

- Reducing the volume of runoff entering the sewer system and improving the quality of it, so the energy consumed in the plant wastewater treatment is lower. The total saving yearly average is shown below (Table 7-2) to each case:

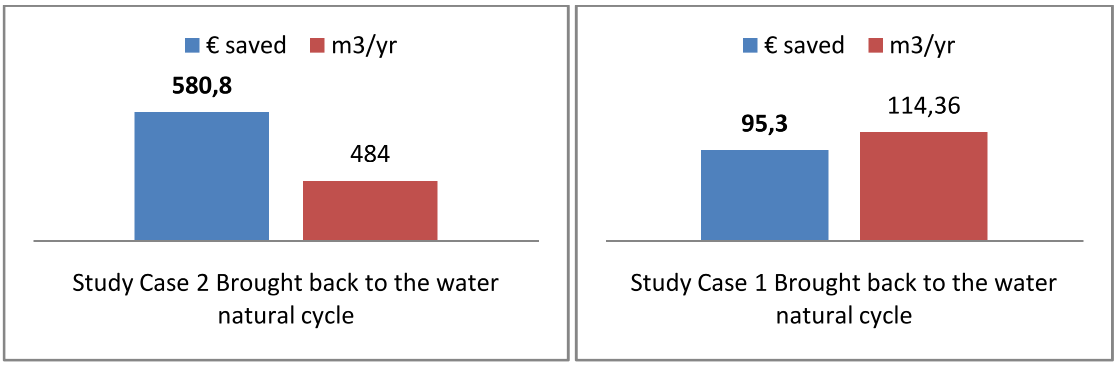


Table 7-2: *Runoff destination yearly average (from Excel)*

- Reducing the temperature in the city, what it is known as “heat island”, to increase green areas like is the green roof in this case.
- The green roof improving the insulation of buildings, so it is reduced energy consumption for air conditioning of buildings.
- For the same retention volume, the use of a conventional drainage system requires treatment and in some cases pumping water stored while SuDS allow infiltration and discharge into the channel, reducing the volume treated and pumped and avoids overflows.
- Provide versatility drainage infrastructure against the effects of climate change.
- Develop municipal policies that integrate environmental considerations into urban water management and legislation, thereby contributing to sustainable development.
- This project promotes the reduction of energy consumption in managing rainwater to make our cities more sustainable because water management in municipalities is usually the business managed by local governments requiring greater energy consumption, representing up 35% of local consumption.
- It will have an educational character, so the secure access for school children and visitors will be enabled, as well as maintenance personnel.

The knowledge about the application of these techniques in Mediterranean countries is very limited. In addition, data on energy consumption in the water cycle are often not readily available. For this reason, it is very difficult for local authorities and decision makers consider energy efficiency aspects when different alternatives are analyzed. On the other hand, water quality in the Turia River, especially after discharges produced during severe precipitation events, is one of the main concerns of local authorities.

Responding to these problems, E²STORMED promotes the use of SuDS to improve energy efficiency in Mediterranean cities, capitalizing on the results of projects and past experiences of the partners (SWITCH and Aquaval European projects among others).

Would be interesting make a viability study using the E²STORMED Decision Support Tool (DST). It is software which supports the decision-making process in urban stormwater management. Using this tool, the advantages and disadvantages of different drainage scenarios can be compared and different decision criteria can be defined to choose the best option for urban stormwater management. The E²STORMED DST encourages making decisions based not only on financial criteria, but also on energy, environmental and social criteria (see Figure 7-1).

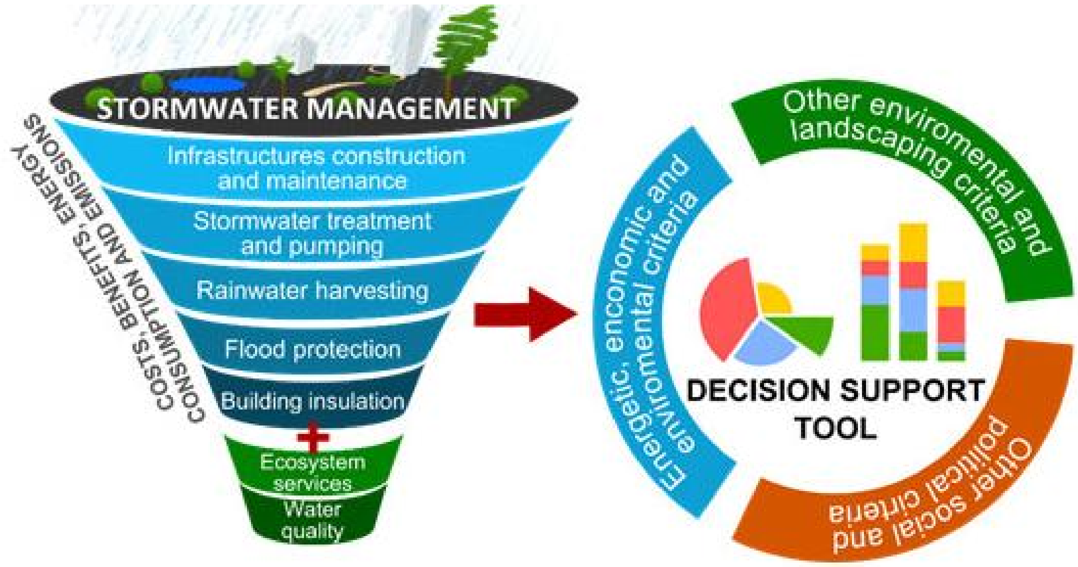


Figure 7-1: *Stormwater Management criteria using DST (from http://www.e2stormed.eu/)*

This software has been developed by the Polytechnic University of Valencia (Spain) with the assistance of the University of Abertay Dundee within the E²STORMED project. It is free and it can be downloaded from the E²STORMED official website. Would be the last step to realize, under a holistic view, what are the key benefits to implement this study under any Sustainable Drainage System model looking toward to the future.

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Appendix A. Economic Study

Below is shown to each case the breakdown of material required to make the project reality. The budget is approximate and should be check before of being approved.

A.1 Study Case 1

Gutters, Tubes and accessories:

PVC materials	Diameter (mm)	Long (m)	Price (€)
Gutter	150	75	337.5
Tube	110	5	30.6
Tube	125	10	90
Tube	150	5	35
Accessories	110-150		200
		Total:	**693.1**

Water Tank 3000L. Rectangular

It incorporates an antimicrobial additive that reduces the risk of contamination by microorganisms JIS standard Z 2801: 2010.

Technical characteristics:

- Material Polyethylene High Density (HDPE)
- Weight 114 Kilos.
- Measures 2,350 mm (length) x 880 mm (W) x 1,800 mm (H)
- Volume 3000 liters
- **Price: 673€**

Submersible pump SB 3-35M

Submersible pump 5 "diameter applications specially designed for domestic water supply.

Technical characteristics:

- Maximum flow: 6m3 / h.
- Maximum induction 4m.
- Max system pressure: 3.4 bar.
- Power: 1.00 hp.
- **Price: 608€**

Green Roof:

On the one hand to make the Green Roof is necessary:

Materials	Quantity	Price (€)
Drainage Layer	1118.7m^2	12€/m^2(12mmdepth) 13424
Substrate	1118.7m^2	30.8€/m^2(200mmdepth) 34456
Plants	500 / m^2	1650
	Total:	**49560**

On the other hand, to maintain of the green roof is necessary make the irrigation facility***:***

Material	Quantity	Price (€)
Tubes	300 m	180
Accessories	Several	50
Irrigation Scheduling with probes	1	240
	Total:	**470**

Total Price:

In short, the total budget, including work force is shown below:

Concept	Price (€)
Gutters	693
Water Tank (x3)	2019
Pump	608
Green Roof	49560
Irrigation	470
Workforce (4days/2people)	640
Total	**9386**

A.2 Study Case 2

Gutters, Tubes and accessories:

PVC materials	Diameter (mm)	Long (m)	Price (€)
Gutter	200	370	1665
Tube	200	120	4000
Tube	250	40	856
Accessories	200-250		650
		Total:	**7171**

Water Tank L. Buriable 10000 FV 10000 QR

Lightweight and easy to transport and install. Tightly sealed mouths man who allow access for inspection and maintenance. Imputrescible material without corrosion.

Technical characteristics:

- Material Polyethylene High Density (HDPE)
- Weight 320 Kgs.
- Measures 4,970 mm (length) x 1,850 mm (W) x 1,550 mm (H)
- Volume 10,000 liters
- Price 2.723,00 €

Submersible Pump SB 3-35M

Submersible pump 5 "diameter applications specially designed for domestic water supply.

Technical characteristics:

- Maximum flow: 6m3 / h.
- Maximum induction 4m.
- Max system pressure: 3.4 bar.
- Power: 1.00 hp.
- **Price: 608€**

<u>Total Price:</u>

In short, the total budget, including work force is shown below:

Concept	Price (€)
Gutters	7171
Water Tank (x2)	5446
Pump	608
Workforce (5days/2people)	800
Elevators Rent (3 days)	255
Total	**14280**

Important note: This budget is orientative, since the gutters are already installed and the pump would not necessary if the tank has a tap and the irrigation is in down elevation. So, the budget would be:

Concept	Price (€)
Tubes and fit accessories	2500
Water Tank (x2)	5446
Workforce (2days/2people)	320
Total	**8266**