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Rainwater Harvesting

Case Study: FCT/UNL Campus

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Resumo

Com uma crescente pressão sobre o meio ambiente, nomeadamente sobre os recursos hídricos, devido a forças externas como o aumento da população mundial e as alterações climáticas, a água é hoje um recurso escasso e altamente valioso. Com a necessidade de encontrar novas alternativas, o aproveitamento de águas pluviais deverá ser visto como uma importante estratégia para uma melhor gestão dos recursos hídricos, uma vez que constitui uma fonte gratuita de água potável.

Os sistemas de aproveitamento de águas pluviais são uma opção reconhecida para os edifícios urbanos reduzirem a sua dependência em relação à rede de abastecimento pública, já possuindo muitos exemplos de implementação a nível global.

O objectivo desta dissertação é o de produzir uma avaliação global sobre o aproveitamento de águas pluviais e o seu potencial de utilização em todo o mundo, bem como analisar os seus benefícios económicos e ambientais.

Um caso de estudo será apresentado, cujo principal objectivo será avaliar a viabilidade da implementação dum sistema de aproveitamento de águas pluviais para rega dos espaços verdes do campus da Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa.

Será fornecida uma caracterização detalhada do actual sistema de rega do campus, bem como do seu potencial para recolher e armazenar água da chuva. Através do balanço de água entre a oferta e a procura, vários cenários serão apresentados, com o objectivo de fornecer as informações necessárias que permitam aos decisores avaliar a melhor solução para a aplicação desejada. Para tal, toda a informação disponível foi analisada, a fim de determinar a viabilidade ambiental, técnica e económica do projecto.

Palavras-chave: Escassez de água, aproveitamento de águas pluviais, sistema de aproveitamento de águas pluviais, rega, reservatório, Método de Rippl.

Abstract

With increasing pressure on the environment, particularly on water resources, due to outside forces such as climate change and population growth, water is nowadays a scarce and a valuable resource. With the need to find new alternatives, rainwater harvesting should be seen as an important strategy for better management of water resources, once it constitutes a free source of potable water.

Rainwater harvesting systems, which already have a global implementation, are a recognised way for urban buildings to reduce their reliance on the public mains supply. Its applications are predominantly non-potable, namely toilet flushing and gardening.

The aim of this report is to produce a comprehensive assessment of rainwater harvesting and its potential use all over the world, as well as the potential economical and environmental benefits. It is provided a description of all the rainwater harvesting system components, as well as water quality requirements according to the water final purpose.

A case study is presented, which main object is to evaluate the feasibility of rainwater harvesting for gardening, applied to the University Campus of the Faculty of Sciences and Technology of Universidade Nova, Lisbon (FCT/UNL).

A detailed characterization of the existing irrigation system on campus is provided, as well as its potential ability to collect rainwater. According to the supply and demand balance, several scenarios are presented in order to provide the necessary information for the decision-makers to evaluate the best solution for the desired application. For such, all the available information was analyzed, in order to determine the environmental, technical and economical viability of the project.

Keywords: water scarcity, rainwater harvesting (RWH), rainwater harvesting systems (RHS), irrigation, reservoir, Rippl Method.

Symbols and Abbreviations

9MP – Ninth Malaysia Plan

ADWG – Australian Drinking Water Guidelines

ANQIP – National Association for Quality in Building Installation

ARCSA – The American Rainwater Catchment Systems Association

BS – British Standard

BT – Bell Tower Project

C – Runoff Coefficient

C_f – Filter Coefficient

cm – Centimeter

DB – Departmental Building

DL – Decreto Lei

DLC – Division of Logistics and Conservation

DR – Decreto Regulamentar

E. coli – Escherichia coli

EPA – Environmental Protection Agency

ET – Evapotranspiration

ETA – ANQUIP Technical Specification

EV – Evaporation

EWR – Environmental Water Requirement

FCT – UNL – Faculty of Sciences and Technology of New University of Lisbon

GHG – Green House Gas

GSB – Genome Science Laboratory Building

Gt – Gigaton

HB – House Bill

ha – hectare

IAPMO – International Association of Plumbing and Mechanical Officials

IPCC – Intergovernmental Panel on Climate Change

IWMI – International Water Management Institute

km^2 – Square kilometre

L – Litres

LNEC – National Laboratory of Civil Engineering

m^2 – Square Meter

m^3 – Cubic Meter

MDG – Millennium Development Goals

min – Minute

mm – Millimetre

NPW – Non-Potable Water

NSF – National Standards Foundation

ºC – Degrees Celsius

OECD – Organisation for Economic Co--operation and Development

OWASA – Orange Water and Sewer Authority

P1MC – Programme of One Million Cisterns

PAHs – Polycyclic Aromatic Hydrocarbons

PCV – Green Campus Project

PNUEA – National Program for Efficient Water Use

PVC – Polyvinyl Chloride

RHS – Rainwater Harvesting System

ROI – Return on Investment

RT – Technical Report

RWH – Rainwater Harvesting

SMAS – Municipal Services of Water and Sanitation

SNIRH – Water Resources National Information System

UEV – Green Spaces Unit

UK – United Kingdom

UKM – Universiti Kebangsaan Malaysia

UNC – University of North Carolina

UNEP – United Nations Environment Programme

US – United States

USD – U.S. Dollars

USEPA – United States Environmental Protection Agency

UV – Ultraviolet

VF1 – Volume Filtre 1

VOCs – Volatile Organic Compounds

WFD – Water Framework Directive

WHO – World Health Organization

WSI – Water Stress Index

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1. Introduction

In the late 20th and early 21st century, water emerged as one of the most relevant environmental and socio-economic themes in society. Formerly, water was seen as an inexhaustible good and accessible to all, without any economic value. However this situation changed dramatically, mainly due to outside forces such as climate change and population growth, making water a scarce and a valuable resource, economically and strategically.

There has always been a strong link between water resources and economic and social development. History has shown us how water has always contributed to development, requiring increasing amounts of water to meet all human and environmental needs. However, this balance has reached a breaking point in some places in the world, following a rise in strong environmental pressure and increasing conflict between consumers.

With the growing importance of the concept of sustainable development, water has become the epicentre of management strategies and world politics. New water sources must be found. Thus, among other actions, the collection and use of rainwater has gained increasing importance all over the world. It is a source of drinking water, which should be seen as an important strategy for better management of water resources and to minimize the problems related to its scarcity. This will reduce the consumption of freshwater, especially for non-potable uses, and also be a way to mitigate catastrophic natural events such as floods and droughts.

The use of rainwater was once widely applied by past civilizations, but as time went by, fell into disuse. Nevertheless, countries like Sweden, Germany, Brazil, Australia, the United States and some African countries like South Africa, have been focusing heavily on this practice, with large economic investments.

In Portugal, the achievements in the field of utilization of rainwater are practically non-existent, though not a totally obscure subject. At this point, Portugal is not particularly concerned about the scarcity of drinking water despite the fact that some regions, such as the Alentejo, already manifest acute water deficit. The collection and use of rainwater should be seen as an advantageous tool in terms of the environment and the economy.

Therefore, the aim of this report is to produce a comprehensive assessment of rainwater harvesting (RWH) and its potential use all over the world. A case study is presented, the main object of which is to evaluate the feasibility of use of rainwater for gardening, applied to the University Campus of the Faculty of Sciences and Technology of Universidad Nova, Lisbon (FCT-UNL).

1.1. Hydrologic Cycle

Water is essential to life, the functioning of ecosystems, economic growth and sustainable development. All this is influenced by its cycle and its variation in terms of quality and quantity, in both surface and subterranean aquatic systems, through the processes of precipitation, evaporation (EV) and evapotranspiration (ET).

Through the hydrological cycle, the oceans, continents and atmosphere are closely linked, since the same water circulates throughout each of these domains. However, of all the water on the planet, only a small percentage - 2.5% - is considered freshwater. For this reason, the terrestrial hydrological cycle is considered the keystone of the world's water resources as it is the basis of survival of the human race. As stated by the World Water Assessment Programme (2009), freshwater "is required for food production, industry, drinking water, inland water transport systems, waste dilution and healthy ecosystems".

The amount of water in the world is finite and therefore must be preserved. Nevertheless, its distribution is quite varied due to natural cycles of ice freezing and melting, to temporal variations in precipitation, the levels of ET and streamflow patterns.

As global temperature increased considerably over the 20th century, there is a general consensus among the climate science community that climate warming will intensify or accelerate the global hydrologic cycle, which could have major impacts on the world's water resources. This trend could be evidenced by the increasing rates of EV, ET, precipitation and streamflow in many areas. Associated changes in atmospheric water content, soil moisture, ocean salinity and glacier mass balance may also be implicated (Del Genio et al., 1991; Loaiciga et al., 1996; Trenberth, 1999; Held and Soden, 2000; Arnell and Liu, 2001 *in* World Water Assessment Programme, 2009).

Also important is that the acceleration of the water cycle could be associated with the more frequent occurrence of extreme events, such as droughts, floods and tropical storms. The consequences of these natural disasters are quite significant and can directly affect human health and welfare through catastrophic damage, or indirectly through adverse effects on ecosystems and crop productivity. These extreme hydrologic phenomena are a known threat to populations at risk, especially in developing countries, without the necessary means for adaptation and mitigation (Huntington, 2006).

While climate change will continue acting on the planet's water systems, other forces outside the water sector are currently a major source of concern. New and continuing human activities and processes of all types – demographic, economic and social – have become primary drivers of the pressures affecting our water resources.

The world population is growing fast, implying increased freshwater demand and consumption. According to the United Nations Population Fund Report (2007), by 2030, human population living in urban areas is expected to swell to almost 5 billion, about 1.7 billion more than in 2008, while the world's rural population is expected to decline by some 28 million. Furthermore, most of the urban growth will be in developing countries, consisting around 81 per cent of urban humanity (Figure 1).

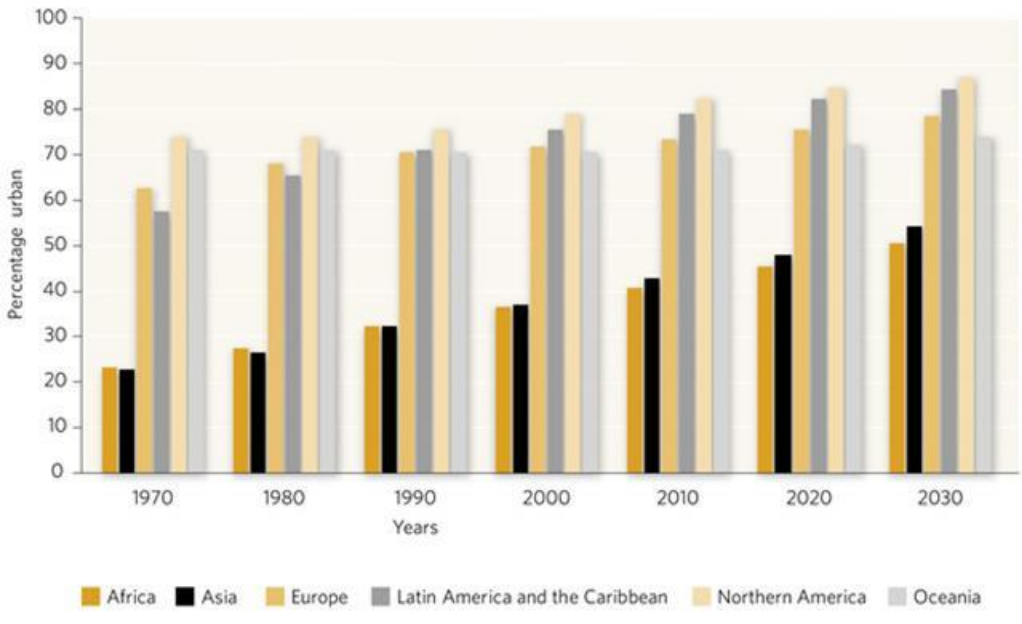

Figure 1 - Expected population living in urban areas, by 2030 (Source: UNFPA, 2007)

Figure 2 presents an expected population growth and decline by 2080. As stated, population will increase mainly throughout Africa, Southwest Asia and South America.

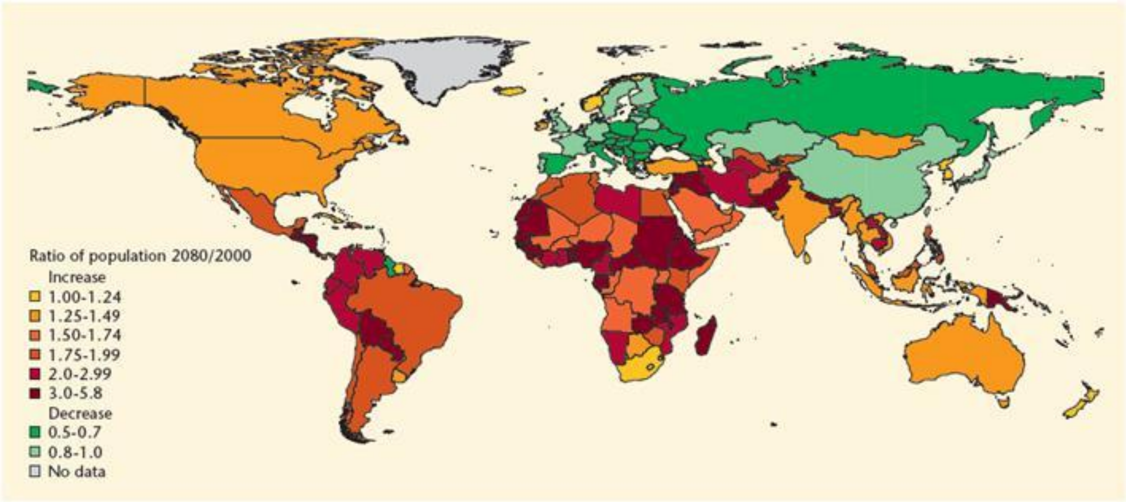

Figure 2 - Expected world's population growth and decline, between 2000 and 2080 (Source: Lutz, Sanderson and Scherbov, 2008 *in* World Water Assessment Programme, 2009).

This major urban expansion in developing countries has global implications, especially in regions where the current population does not have sustainable access to safe drinking water and adequate sanitation. Migration can be seen as the major factor of urbanization. People all over the world are seeking for better economic opportunities and better access to water and sanitation services. People are running away from war, political conflict and environmental crises. People are searching for refuge, poverty alleviation, political and environmental sustainability, health services and food, in order to survive.

Urbanization has unique social and environmental impacts, given that it is accompanied by the complete metamorphosis of natural land surfaces. With the increasing area of paved surfaces, the permeability of soil and infiltration decreases, and surface runoff accelerates, transporting all kind of pollutants and materials into superficial water systems, degrading water quality.

All these demographic processes combined with the rapid global rise in living standards – as incomes permit, people consume more – present the main threat to the sustainability of water resources. Water scarcity is a reality which has major impacts on people's well-being, at a global scale.

1.2. Water Scarcity and Global Crisis

"Water scarcity will be one of the major threats to humankind during this century" (Prinzs, 2000). According to the World Health Report 2007, "currently 1.1 billion people lack access to safe water and 2.6 billion people lack access to proper sanitation". The need to provide sanitation, both for drinking-water and hygiene, remains a huge challenge today in developing countries.

So, what is water scarcity? According to Rijsberman (2006) "when an individual does not have access to safe and affordable water to satisfy her or his needs for drinking, washing or their livelihoods we call that person water insecure. When a large number of people in an area are water insecure for a significant period of time, then we can call that area water scarce."

It is reasonable to state that there is no commonly accepted definition of water scarcity. To define an area as "water scarce" is necessary to take into account people's needs, and whether the needs of the environment are included in that definition, and what fraction of the resource is made available to satisfy these needs

For this author, it is evident and inexorable that while populations continue to spread, there will be more pressure and more demand over water resources which will culminate in an inevitable reduction of its availability. It is of crucial importance to understand that a major problem in many areas of the world is that water withdrawals from natural systems will exceed their ability to recharge, resulting in a progressive lowering of groundwater tables. It is a vicious cycle which has already managed to destroy several wetlands and will continue to cause irreparable damages in many others, unless brought into focus the urgent need for planned action to manage water resources effectively.

It is essential to evaluate and determine the availability of water, where and when, as it affects the perspective of general users and the judgement of policy makers, on the imperativeness to address water policies as a primary subject to focus on water crisis. Some water indicators are used to measure water well-being and to provide a very useful background to assess global water scarcity.

1.2.1. The Falkenmark Water Stress Indicator

This indicator is the most simple and easy-to-understand, as it relates water scarcity to water accessibility and human population. In other words, it associates water availability per capita per year, normally at a national scale. According to Falkenmark et al. (1989) *in* Rijsberman (2006), the attraction of such instrument is elementary: "if we know how much water is needed to satisfy a person's needs then the water availability per person can serve as a measure of scarcity." Based on the assessment of water needs for the environment and other sectors such as energy, industrial, agricultural and household, they recommended 2,000 cubic metres (m^3) of renewable water resources per capita per year as the lower limit necessary to accomplish water demands. Countries where supply is inferior to 1,000 m^3 are considered to experience water scarcity, and under 500 m^3, absolute scarcity. Between 1,000 m^3 and 2,000 m^3, countries are said to evidence water stress (Wallace, 2000).

Figure 3 represents future per capita water availability based on the Falkenmark indicator. The forecast is that around one in six people will have insufficient water to meet their primary needs and that 67% of the world's population in 2050 may suffer water stress (Wallace, 2000).

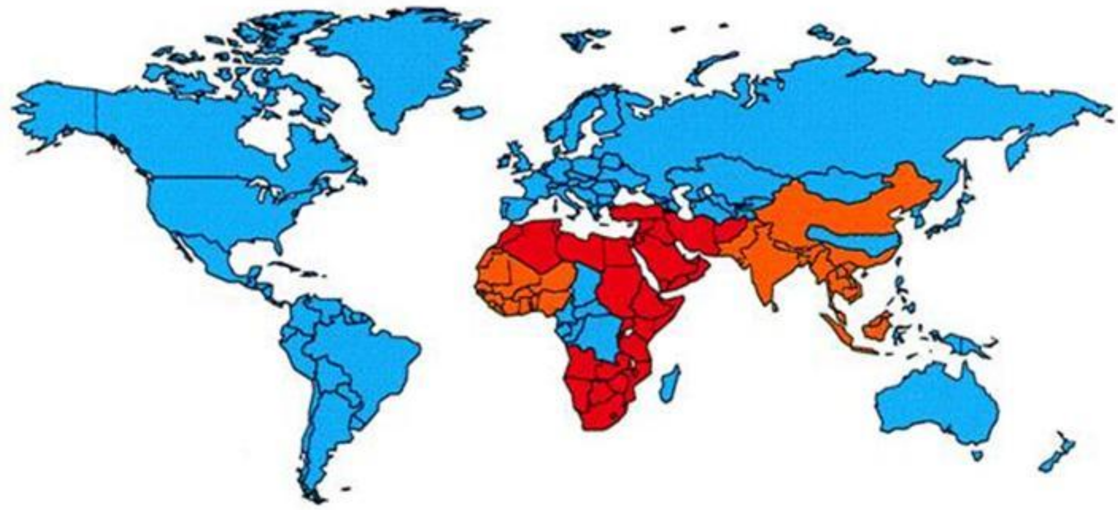

Figure 3 - Water scarcity in 2050 based on the Falkenmark indicator. Blue – more than 2,000 m^3 per person per year; Orange – between 1,000 and 2,000 m^3 per person per year; Red – less than 1,000 m^3 per person per year (Source: Fischer and Heilig, 1997 *in* Wallace, 2000).

1.2.2. Socio-Economical Scarcity Index

Others have aimed for a more precise evaluation of water demand, instead of considering fixed requirements per person, such as the basin factor, on a national scale. They correlated annual demand for water and annual renewable freshwater resources with human and environmental needs. In a more accurate approach Raskin et al. (1997) *in* Rijsberman (2006), replaced water demand for water withdrawals, presenting scarcity as "the total annual withdrawals as a percent of available water resources" - Water Stress Index (WSI). These water withdrawals can be interpreted as the quantity of water taken out of lakes, streams, rivers or groundwater aquifers to fulfil human necessities.

In other words, when the water drawn from groundwater and superficial systems is insufficient to assure all human and ecosystem needs, countries experience water scarcity. As an increasing number of river basins are insufficient to provide the water demanded, intense competition among all the potential users is inevitable (World Water Assessment Programme, 2009). The International Water Management Institute (IWMI) analysis of water scarcity assesses the quota of the renewable water resources attainable for human requirements as the primary water supply. It's evaluation of demands is based on ET and the remnant of water withdrawn is explainable as return flows (Figure 4) (Rijsberman, 2006).

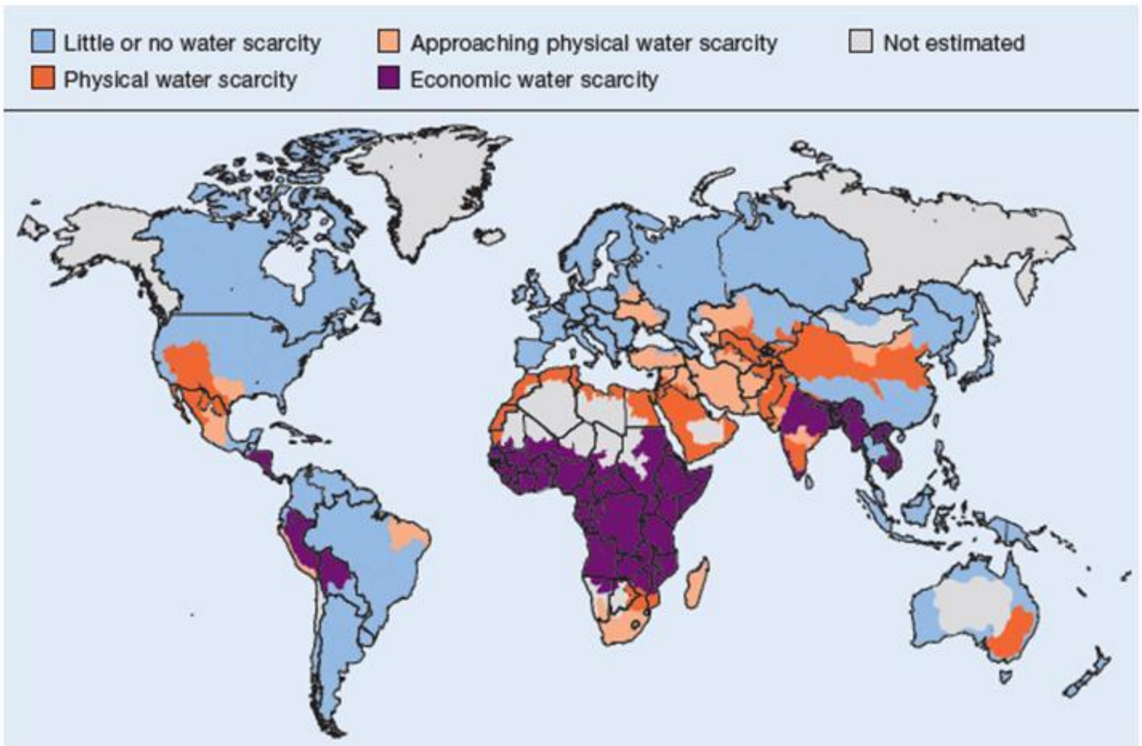

Figure 4 - IWMI water scarcity map (Source: based on Comprehensive Assessment of Water Management in Agriculture, 2007)

Economic scarcity occurs when countries have sufficient renewable resources, but would have to make very significant investment in water infrastructure to satisfy people demand for water. Much of Sub-Saharan Africa is characterized by economic scarcity. Countries that will not be able to meet both human demands and environmental flow needs are called physically water scarce. Arid regions are most often associated with physical water scarcity. Symptoms of physical water scarcity are severe environmental degradation, declining groundwater, and water allocations that favour some groups over others (Comprehensive Assessment of Water Management in Agriculture, 2007).

Available information however, hides the full reality of scarcity at local or basin level. For the biggest countries such as the United States (US) this is a very problematic issue, where average water use, according to US Department of Energy (2006) in World Water Assessment Programme (2009), accounts for only 25% of available resources at a national scale, but can reach 80% on a regional scale.

However, another approach of the earth's water stress identifies Nature as a stakeholder, since it supplies significant benefits to people and societies. It is an important step towards sustainability, since concerns over environmental issues often come in second place or when competition is critical. Despite some controversy, a voice for nature in sharing decisions for water withdrawal at the basin level was defined as the Environmental Water Requirement (EWR) (World Water Assessment Programme, 2009).

In Figure 5, Smakhtin et al. (2004) have attempted to present the distribution of WSI values on a global scale, taking into account an estimated EWR.

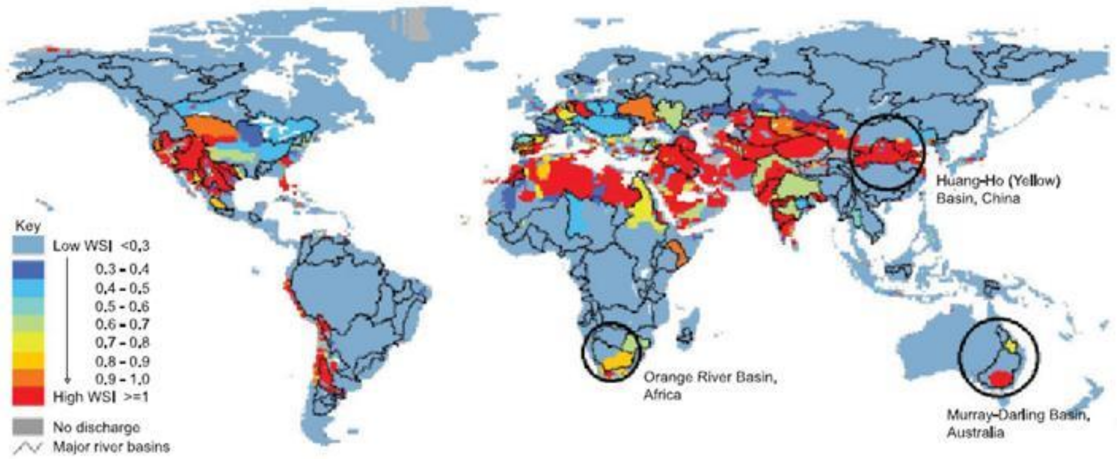

Figure 5 - A map of water stress indicator as human use of renewable water resources, which takes into account environmental water requirements. The yellow, orange and red bands designate the areas where water stress is more severe (Source: Smakhtin et al., 2004)

Figure 5 highlights important river basins (circles) where perspectives to meet EWR are at risk, particularly if water removals continue to increase, severely degrading downstream wetlands. Therefore, water use is reaching levels that seriously compromise development and life, especially for more vulnerable people who rely on natural ecosystems for their livelihoods. Examples include the world's largest shallow lake (Lake Chapala in Mexico) and some of the largest rivers (such as the Murray-Darling, Yellow and Orange) that are turning into smaller streams closer to their mouth, because flows are no longer sufficient to maintain the health of aquatic ecosystems (Smakhtin et al., 2004).

1.3. Water Scarcity in the World

The final verdict of many analyses about the global scarcity of water is that a considerable portion of the world population – around two-thirds – will be highly affected by water stress over the next decades (Rijsberman, 2006).

Some conclusions concerning water stress in some parts of the world, after analysing the maps presented above, are as follows.

1.3.1. Europe and other OECD Countries

In a general overview, there are no major concerns over water scarcity in Europe compared to other regions of the world. However, some countries have been experiencing growing water stress, mainly because water is still seen as an endless resource and a public commodity. According to Bixio et al. (2006), "Approximately half of the European countries, representing almost 70% of the population, are facing water stress issues today".

Since both people and water are unequally distributed on a global scale, not all water utilization puts the same pressure on its resources. Consistent with the WSI, when the proportion of water withdrawal to water availability is inferior to 10%, water stress is low. A ratio between 10 and 20% means that water stress is moderate. Between 20 and 40% indicates that a country is water scarce and that significant investments should be considered to provide adequate supplies. When the ratio is over 40% a country is considered to be extremely water scarce and both demand and supply need urgent management (Figure 6).

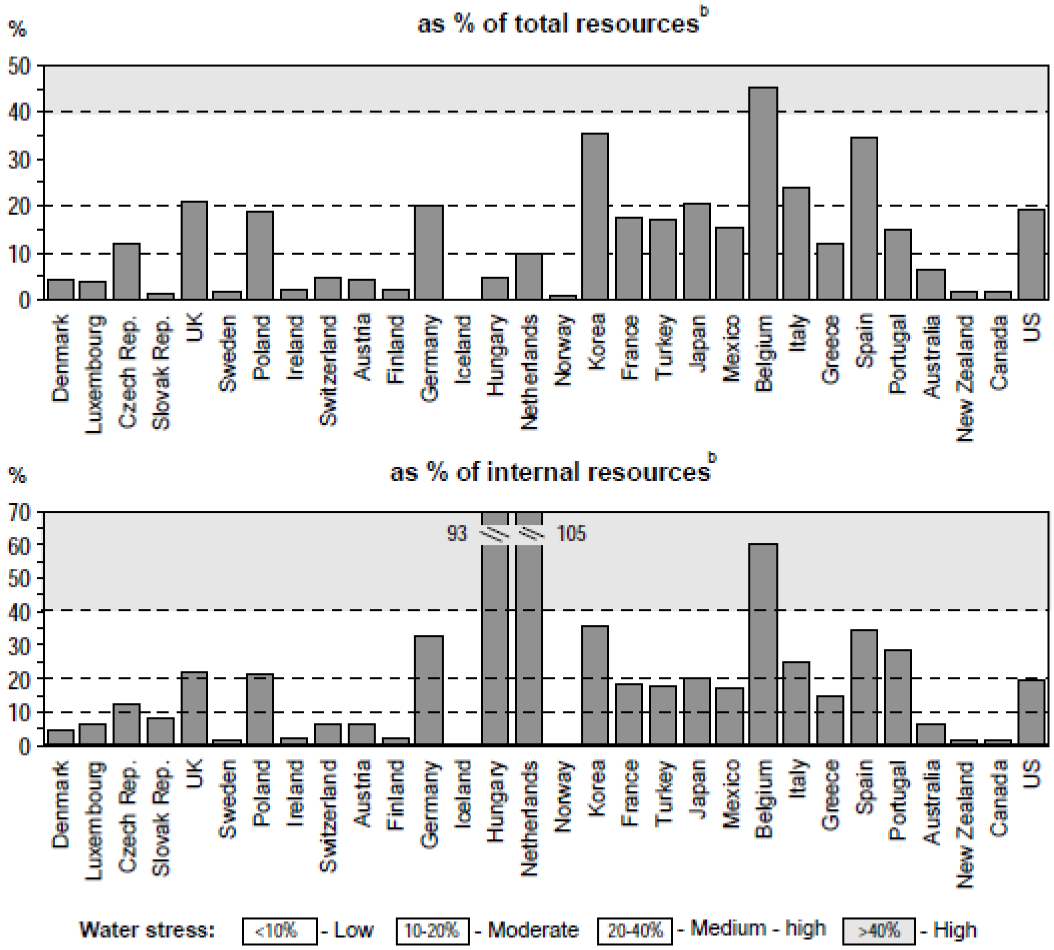

Figure 6 - Water stress in OECD countries based on gross freshwater abstractions (Source: OECD, 2005).

b) Internal resources = precipitation - ET;

Total resources = internal resources + transboundary inflows.

As it shown, seven OECD countries already withdraw more than 20% of their internal water resources, while Belgium, Hungary and the Netherlands face serious water problems.

1.3.2. Africa and Middle East

The most perceptive freshwater problems occur in the arid areas of the world and affect countries mostly in North Africa and in the Middle East. For most of them the Falkenmark indicator is already below the 1,000 m^3/capita/year threshold and for Egypt, the most populous country of this region according to Rijsberman (2006), "the Falkenmark indicator is likely to drop below the 500 m^3/capita/year within the next 25 years." This scenario is expected to worsen in the next decades and to spread out through large regions of Africa and large parts of South and Southeast Asia (Wallace, 2000).

West Africa is also a region that cries for attention, particularly the Sahelian countries. Desertification, erosion and deforestation are the main consequences of human-related activities in a region characterized by low, erratic and highly variable rainfall. Such blurred information is highly prejudicial for crop production, leading these zones to severe food production, starvation and malnutrition. The long dry periods induce people to migrate to overcrowded urban developments, leaving behind former fertile land. One of the Millennium Development Goals (MDG) is to help smallholder farmers ensuring successful interventions in rain-fed agriculture, with the objective to reduce poverty and hunger. Though successfully tested and, in some cases, already adopted, innovative ways to improve crop production such as RWH, have a great potential and should be always considered through integrated land and water management (Barry et al., 2008).

1.3.3. China and India

While the severe lack of freshwater resources is mainly related with the Middle East and Africa, important markets such as China and India are already facing economic restraint due to water scarcity.

The population of China is the largest, representing more than 22% of the world’s total. Nevertheless, this country possesses only 7% of earth's freshwater resources, being adversely distributed throughout the territory. South China holds nearly 81% of the water resources of the country, stopping only a third of total agricultural land and serving a population of around 700 million. On the other hand, the northern part, which only has 19% of usable water, represents two thirds of agricultural land and serves 40% of the population of the country. Currently, of the many challenges that China has, the problems associated with the quality and quantity of water is on top of their list of priorities (Smakhtin et al., 2004).

The Huang-Ho River (Yellow River) Basin is of major importance, with an area of almost 800,000 square kilometres (km^2), and serving more than 100 million people. As already demonstrated in Figure 5, this area is an example of an environmentally water scarce basin, reaching the critical point of total water exploitation (Smakhtin et al., 2004). In response to this crisis, china implemented a mega project to transfer water from the south (Yangze River) to the north (Yellow River), yet these efforts were not enough, since the topographic conditions that surround this river do not allow it. The land is characterized by great cliffs and high altitudes, which makes the construction of systems for transfer of water and irrigation networks absolutely impracticable. Therefore, the collection and use of rainwater emerge as a viable solution to lack of drinking water supply in areas badly affected by the hydrological stress. In the last two decades RWH, through the implementation of cistern storage, became the government's key water strategy in response to the critical situation of this area freshwater scarcity (Zhu et al., 2004).

India is the seventh largest country by geographical area and the second most populous country of the world. With its population exceeding one billion people, the demand for clean water increases exponentially. The intense exploration of the aquifers has led the country to go through complicated water stress, since they do not have the capacity to regenerate. Following this trend, within a few decades India will experience a severe shortage of water, especially in large urban areas like New Delhi (Sharma, 2007).

New measures have to be urgently taken to preserve water resources, both surface and underground, before it is too late. In this context, the use of rainwater in India is seen as an important weapon to reverse this trend. All over the country, especially in large cities, projects to collect rainwater from the roof-tops are being implemented. The water collected will be used for both domestic use and to recharge groundwater aquifers (Sharma, 2007).

2. Literature Review

2.1. Rainwater Management

The water issue has remained too low on the list of political priorities of world leaders and decision-makers, for too long. And this situation has to end. More and more people seek and require water, because their survival depends on it. And as water supplies are shrinking dramatically, the environment is deteriorating, people suffer and world crisis increases. Decisions have to be made and significant investment is needed to reverse this trend.

As the pressure on water resources intensifies, an efficient integrated management of water is essential for sustainable development, both economic and social, in order to meet multiple demands and purposes, poverty reduction and cares for equity.

With an aging water infrastructure, decreasing water quality and most of all with a growing population and intense urbanization, there is the urgent need to explore sustainable alternatives to our current water supply system. Among such possibilities, RWH is a topic with great potential and should not be ignored by government leaders. Despite some interest shown by certain societies, much can be done, since this issue can be seen as a great opportunity towards sustainable development by improving standards of living and protecting the environment (UNEP, 2009).

2.1.1. Rainwater Harvesting

In recent decades, rainfall has been considered a source of pollution from the moment it is formed in the atmosphere, continuing on the urban impervious surfaces – streets, roads, roofs and yards – where the stormwater run-off is mixed with all kinds of materials and pollutants accumulated during dry periods. A major objective of rainwater management is to assume stormwater as an important resource and not as a nuisance, implementing measures to protect the natural water cycle and ecological systems (Niemczynowicz, 1999).

Rainwater is seen by many as the ultimate source of free freshwater and therefore should be well utilized. Since most of it returns to the atmosphere through EV and ET, RWH has to be seen as an important strategy to address problems of water scarcity, and also to protect the quality of surface waters, reducing formation of surface run-off and downstream flooding occurrence. Collecting rainfall is a decentralised, environmental solution, which can be used for "toilet flushing, irrigation in urban small-scale urban agriculture or even for production of drinking water" (Niemczynowicz, 1999).

What is Rainwater Harvesting? RWH is a system which consists in numerous technologies used to collect water from rooftops and yards, and storing it in tanks or reservoirs for later uses, providing water for the purpose of meeting demand by humans and/or human activities. The RWH level varies from household level to large-scale water harvesting projects, and its technologies can be split into two types depending on source of water collected: *in situ* and *ex situ* techniques of RWH (UNEP, 2009).

In situ RWH aims to recharge soil water for crop and other vegetation growth, by enhancing rainfall infiltration and reduce surface runoff. This system has a relatively small RWH catchment and it is characterised by the soil being the storage medium for the water. This system can also be used to recharge shallow groundwater aquifers and/or to supply other water systems in the landscape, providing the availability of water for many purposes, including livestock and domestic supplies. *Ex situ* RWH distinguishes from the in situ practices, because the water is stored outside the collecting area. The catchment surface varies from natural soil to an artificial structure, such as roads, yards, pavements and rooftops. The water generated is usually stored in wells, dams, cisterns and tanks, and from there it can be applied for multiple purposes trough centralised or decentralised distribution systems: domestic and public uses, agriculture, irrigation, etc. (UNEP, 2009).

2.1.2. Benefits of Rainwater Harvesting

2.1.2.1. Rainwater Harvesting as a Strategic Tool for Adaptation to Climate Change

As mentioned before the global temperature is rising, the population multiplying, urbanization expanding and pressures on natural resources are reaching catastrophic levels.

One of the main consequences of climate change is the occurrence of natural disasters, including floods and droughts, characterized by the temporal variation of the precipitation phenomena, both in quantity and intensity. These events will negatively influence the amount of water / freshwater available, both for human-beings and natural ecosystems.

RWH should be seen as a key intervention in mitigation and adaptation to climate change, mainly as a way to meet the increasing water needs and demands.

Rainwater harvesting reducing CO_2 emissions

Using this technology, besides being cost effective, has the advantage of reducing Green House Gas (GHG) emissions, since its simple operating procedure requires less energy consumption when compared to the main water distribution systems. The latter are obviously more polluting, once the processes of capturing, storing and treatment of water are associated to the use of larger quantities of materials and higher energy consumption.

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) "the expanded use of rainwater harvesting and other "bottom-up" technologies have the potential of reducing emissions by around 6 Gig tons (GT) CO_2 equivalent/year in 2030". At the urban scale, infrastructures for collecting rainfall, such as green roofs or retention ponds, contribute to the cooling of cities affected by the urban heat island effect, through its ET. It's an important step towards reducing the CO_2 footprint and improving human well-being, by saving energy for cooling during the summer season (UNEP, 2009).

Rainwater harvesting as a strategic tool for drought mitigation

RWH helps communities, urban and rural, to adapt to water scarcity, both for potable and non potable purposes. Furthermore, it should be seen as a necessary strategy for the recharging of aquifers in areas where water levels are very low or its quality is much deteriorated. Thus, the exploitation of surface aquatic systems and the extraction of underground water will be lower, contributing to a better management of natural ecosystems.

Groundwater recharge can be induced through different structures, such as percolation tanks. These tanks show great promise in drought mitigation, especially in areas with impermeable surfaces but high percolation rates (UNEP, 2009).

2.1.2.2. Rainwater Harvesting in Rural Areas

In the rural context, many areas face concerning situations of abandonment and / or desertification, since intense agriculture and over-exploitation of aquifers and reservoirs are responsible for situations of heavy water scarcity. RWH is an important strategy for the rural people once its decentralized nature enables individuals and communities to manage their own water for their own purposes. Using harvested rainwater for the irrigation of higher value crops, such as in kitchen gardens, especially off-season has been beneficial for household food supplies and incomes.

The low cost of these technologies and its implied benefits, should be seen as an attractive investment option in rural areas.

Adaptation strategies to ecosystem management

In watershed management, RWH should be seen as a major instrument to preserve forests and other green areas, and to protect lands and water resources, by reducing their vulnerability to erosion and sediment load deposition. At the watershed basin, stormwater storing can contribute to water pollution control by collecting runoff from within a watershed area, storing it, and using it for other purposes. This way, there will be an increasing capacity for the ecosystems to provide sustainable water flows downstream, habitat for biodiversity and adequate livelihood support (UNEP, 2009).

Rainwater harvesting enhancing agricultural production

Collecting rainfall through *in situ* and *ex situ* RWH techniques has a direct benefit to the management of agro-eco systems. These interventions contribute to amplify both surface and shallow groundwater reserves, expanding the irrigated area and enabling an increased cropping intensity as well as cash crop production. This new management approach brings great opportunities for sustaining farm ecosystems and livestock benefits. In some cases, with an improved irrigation supply, farmers are able to grow a second crop during the winter season. This enhanced agricultural production, which provides work, income and food security, allied with a sustainable watershed management should be seen as an essential strategy to reverse the growing pressure of urbanization, by decreasing the tendency of migration and consequent desertification of the rural area (UNEP, 2009).

2.1.2.3. Rainwater Harvesting in Urban Areas

Cities are characterized by their extensive impermeable soil with hardly any natural infiltration. Its drainage systems were built to collect the urban flows in order to attenuate the peak flow, avoiding problems of flooding downstream. However, with increased variability and intensity of precipitation, coupled with solid waste pollution typical of cities, stormwater sinks are no longer effective in drainage of surface runoff and fail to provide flood protection. Adding stormwater collecting points within an urban catchment has the potential not only to provide protection against the risk of flooding, but also to allow the storage of freshwater, suitable for other requirements and to meet demand (Mitchell et al, 2007).

Economically, the primary benefit of RWH is its relevant savings on water bills, since rainwater falls for free. Moreover, incorporating it into an urban stormwater management plan will decrease the size of other rainwater facilities, helping to compensate the initial expense of a Rainwater Harvesting System (RHS).

In most urban areas, rooftop and surface runoff are linked to the drainage system that conveys the sewage to water treatment plants. These piping systems require the use of oversized pipes to handle the stormwater runoff, much more expensive. Once in those facilities, stormwater will be treated as waste water, implying a greater investment in the operations associated to the process.

But the most worrying situation occurs when witnessing heavy rains, as water treatment facilities are overwhelmed with stormwater. When this happens, in order to avoid further problems downstream, effluents are discharged directly into the receiving environment, contaminating the water with untreated sewage (Virginia Rainwater Harvesting Manual, 2009).

As it is obvious, treating rainwater as wastewater is totally unnecessary, requires large investments, lead to more pollution and ultimately wastes precious resources

That is why in many cities, especially in the United States of America (USA) and Canada, a downspout disconnect program has been implemented in recent years with great success (Virginia Rainwater Harvesting Manual, 2009).

Downspout disconnection represents an in situ technique where rooftop runoff is collected by eaves troughs installed along the edge of the roofline, where stormwater is conveyed to ground level by one or more downspouts. There, the water can be directly applied to land (lawns or gardens) or downspouts can connect directly into storm sewer system or into a combined storm and sanitary sewer system, depending on the local drainage system.

This program appears as a cost-effective alternative for reducing the volume of rainwater that requires public management, bringing a number of economic and environmental benefits to the municipality and to the homeowner (Downspout Disconnection, n.d.):

- in separate sewer areas, the redirected rainwater reduces volume of flows transported and carrying loads to watercourses;
- In mixed sewer areas, disconnection reduces the amount of combined flow requiring treatment, thus decreasing the threat of combined sewer overflows. The operation of centralized sewage treatment plants is improved by the higher concentration of sewage water, resulting in cleaner outflows to the receiving environment;
- Other environmental benefits can result in terms of groundwater recharge and availability of "recycled" rainwater.

2.1.3. Inconveniences of Rainwater Harvesting

The main inconvenience of RWH is associated to the limited supply and uncertainty of rainfall. Rainwater is not a reliable water source; therefore this is a less attractive issue to some governmental agencies tasked with providing water supplies in developing countries, especially those affected by prolonged droughts. Other numerous barriers to the acceptance of systems exist. The most relevant barriers and inconveniences to the uptake of RHS are (Mitchell et al., 2007, Roebuck, 2007, Kahinda et al., 2007, Farahbakhsh et al., 2009):

- Absence of legally binding water quality standards: unwillingness of any Government or regulatory body to take responsibility for setting and monitoring standards;
- Lack of information regarding RHS costs and maintenance requirements;
- Difficulty in achieving and maintaining reliable level of water quality;
- Lack of public awareness and acceptance;
- Current low cost of public mains water makes investment profit in water efficiency measures unattractive: water companies focus is on reducing consumer costs not

on creation of a sustainable water supply system; and, the cost of water is rarely a driver for the end-user but cost of installing a RHS may be seen as significant;

- Storing capacity limits the amount of harvested rainwater;
- Rainwater can be contaminated by all sorts of microbiological and chemical pollutants thus, if not properly treated before usage, may cause serious health risks;
- It is also acknowledged that harvesting excessive amounts of urban stormwater runoff could be detrimental to stream health;

2.2. Water Legislation

Currently, water laws don't deal with RWH as a source of good water for use in housing and for possible drinking purposes. However, in many countries, this procedure is being practised outside the legal framework without too much government involvement. This way, by creating facts on the many benefits that can be learned from the application of this practice, practitioners scattered all over the world hope that appropriate institutional and legal framework is established, comprising the use of rainwater.

With the support of institutions of higher importance at national and global scale, within and outside the water sector, this practice will be better promoted, with an assured future and can no longer be ignored.

As we shall see further ahead, some countries already have RWH as a strategy to take into account, and developed technical specifications or standards for implementation of systems for rainwater utilization.

2.2.1. Portuguese Legislation

It was only since the year 1995 that the concept of rainwater began to take shape in Portuguese legislation.

Decreto Lei (DL) Nº 207/94, of August 6th, came to update existing legislation on public systems and residential water distribution and sewerage, as well as approve the Decreto Regulamentar (DR) 23/95, of August 23rd, which defines for the first time the concept of rainwater. According to this DR, rainwater is defined as the water that "results from precipitation fallen directly on the spot or in adjacent watersheds and generally has smaller quantities of pollutants, especially of organic origin. Considered to be equivalent to stormwater from the watering of gardens and green areas, washing streets, sidewalks, public parks and parking lots, usually collected by gutters, sinks and drains" (Ministério das Obras Públicas, Transportes e Comunicações, 1995).

The most relevant DL regulating water in Portugal are:

DL nº 236/98, of August 1st, which sets standards, criteria and quality objectives in order to protect the aquatic environment and improve water quality in terms of its main uses. It defines the requirements of water use for the purposes of human consumption, aquaculture life support, bathing waters, irrigation and wastewater disposal (Ministério do Ambiente, 1998).

DL nº 306/2007, of August 27th, approves quality standards for water intended for human consumption, reviewing the DL nº 243/2001, of September 5th, which transposed into domestic law the Directive No. 98/83/EC, of the Council, November 3rd, related to the quality of water intended for human consumption (Ministério do Ambiente, 2007).

Today there is no legislation regulating the use of rainwater, proving very little progress in the last 15 years regarding this matter. Rainwater is still regarded by the Portuguese legislation as wastewater.

In 2001 the Programa Nacional para o Uso Eficiente da Água (PNUEA – National Program for Efficient Water Use) was prepared and approved by resolution of Council of Ministers No. 113/2005 of 30 June 2005, following the Water Framework Directive (WFD) - Council Directive 2000/60 EC of 23 October (Resolution of the Council of Ministers No. 113/2005). On December 29th, 2005, appears the Water Act or Law Nº 58/2005, which transposes into national law the Directive 2000/60/EC of the European Parliament and the Council, establishing the foundation and institutional framework for the sustainable management of water (Assembleia da República, 2005).

The PNUEA aims to promote efficient water use in Portugal, mainly at the level of urban areas, agriculture and industry, by proposing a set of strategic measures that will contribute not only to improve environmental conditions in aquatic resources, as well as to reduce the wastewater and energy consumption associated to its utilization. The measures which address the use of rainwater are measures 8 (Use or reuse of lower quality water), 38 (Use of rainwater in gardens and alike), 45 (Use of rainwater in lakes and lagoons) and 48 (Use of rainwater in sports fields, golf courses and other recreational spaces) (Baptista, et al., 2001).

In 2005 the Laboratório Nacional de Engenharia Civil (LNEC – Civil Engineering National Laboratory) prepared several Technical Reports for Support in Implementation of PNUEA, including the Relatório Técnico 9 (RT – Technical Report), which refers to the analysis of regulatory documents and regulatory framework, through which inconsistencies and disparities are identified in the implementation of the measures proposed by PNUEA. In accordance to RT9, the RD 23/95 "prohibits the use of non-drinking water in housing for purposes other than washing decks, irrigation and fire fighting (Article 86)" emerging as an obstacle to the possibility of using lower quality water in building networks, for toilet flushing for example (Oliveira, 2008).

Despite the relevance of this issue, there hasn't been an attempt to change the Portuguese legislation or to establish specific rules aimed at the collection and use of rainwater in building facilities. However, the Associação Nacional para a Qualidade nas Instalações Prediais (ANQIP – National Association for Quality in Building Installation) developed in 2008 two ANQIP Technical Specifications - ETA 0701 and ETA 0702 - which regard RHS in buildings. These technical recommendations consist of a set of guidelines, criteria, rules or procedures considered advisable, although not mandatory.

2.2.2. World Legislation

- **Spain**

Decreto 262/2007, December 20th, of Housing Department, approves new rules for Galician dwellings. All new residential buildings shall install a RHS for domestic reuse (Decreto 262/2007, 2008).

- **Australia**

Many cities throughout Australia are committed to certify that new housing is planned, designed and built in order to meet the latest water and energy efficiency standards, supported by national legislation

  - <u>Victoria</u>

5 Star Standard – Since 2005, new houses and apartments must be constructed to meet 5 Star energy efficiency rating for the building fabric and 5 Star water management efficiency for taps and fittings. Besides that, it also requires either a rainwater tank for toilet flushing, or a solar hot water system (International Water Harvesting and Related Financial Incentives, n.d.).

- <u>South Australia</u>

Since July 2006, new houses are required to have an additional water supply to supplement the main water distribution system. The additional water supply has to be plumbed into the house to a toilet, to a water heater or to all cold water outlets in the laundry, from a rainwater tank. “The same rules will apply to new extensions or alterations where the area of the extension or alteration is greater than 50 square metres (m^2) and includes a toilet, water heater or laundry cold water outlet” (Rainwater Tanks, 2009)**.**

- <u>New South Wales</u>

BASIX (Building Sustainability Index) – sets energy and water reduction targets for house and buildings. This index may contribute to a 40% reduction in mains water utilization in new dwellings, by including an alternative water supply, such as a rainwater tank, for outdoor water use and toilet flushing and/or laundry (International Water Harvesting and Related Financial Incentives, n.d.).

- <u>Gold Coast</u>

“The construction of a 3,000 litres (L) rainwater tank has been made mandatory in the Pimpama Coomera Master Plan area of the Gold Coast. This is for all homes and business centres connected to the Class A+ recycled Water system. The tank should be plumbed to their cold-water washing machine and outdoors faucets” (International Water Harvesting and Related Financial Incentives, n.d.).

- **Brazil**

Lei Estadual 4.393/2004 – regulates about the "business planners and construction companies are to provide the mandatory necessary devices to capture rainwater for all the residential and commercial housing” (Lei Estadual nº 4.393, 2004). The same law dictates “the installation of a device for rainwater collection in residential developments with more than 50 families and in commercial developments with more than 50 m^2 of built area in the State of Rio.”

Projecto de Lei No. 317/2006 – “requires the installation of devices to capture rainwater in residential and commercial properties built in the state of Espírito Santo” (Pojecto de Lei N° 317/2006, 2006). According to the same source, the same Draft states that design and construction companies, as well as public agencies, which conceive architectural projects, are “obliged to plan for the installation of RWH apparatus in residential projects or commercial enterprises with more than 50 m^2 of built area in the State of the Espírito Santo.”

- **United States of America**

The American Rainwater Catchment Systems Association (ARCSA) has been alerting Americans to the problems related to water scarcity, promoting the importance of RWH through numerous conferences and workshops performed all over the country. This association, together with the International Association of Plumbing and Mechanical Officials (IAPMO), developed a standards guide which contains specifications for each system component and example diagrams, and it’s an excellent tool for those interested in designing and installing rainwater catchment systems (HarvestH2o, 2010).

RWH is exploding in almost all states, cities and localities in the United States of America (USA). Below is a list of the states that have given more relevance and spent greater effort on trying to approve Bills or Standards towards legalization of RWH.

➢ <u>Illinois</u>

SB2549 Status – redresses the Illinois Plumbing License Law. Provides that “if a unit of local government regulates RHS, then the reclaimed water systems must meet specific requirements” (HarvestH2o, 2010).

The Illinois Department of Public Health shall publish a “minimum code of standards for RWH collection systems and RWH distribution systems by March 1, 2011” (PLUMBING-RAINWATER SYSTEMS, 2010). According to the same source, this law “requires rainwater harvesting collection systems and rainwater harvesting distribution systems to be (A) used only for non-potable uses and (B) constructed in accordance with the Illinois Plumbing Code.”

➢ <u>Ohio</u>

The state of Ohio has the most widespread regulations on RWH in the country, with codes on “cistern size and material, manhole openings, outlet drains, overflow pipes, fittings, couplings, and even roof washers. Ohio’s rules also address disinfection of private water systems” (HarvestH2o, 2010).

➢ Texas

House Bill (HB) 645 – approved by the 78th Legislature in 2003, "prevents home-owners associations from banning outdoor water-conserving measures such as composting, water-efficient landscapes, drip irrigation, and RWH installations. The legislation allows home-owners associations to require screening or shielding to obscure view of the tanks" (HarvestH2o, 2010).

HB 4299 – "requires rainwater collection on all state buildings and recommends water agencies counties promote RWH. Also authorizes financial institutions to issues loans for developments using rainwater as a sole source. Approved by the House and died in the Senate" (HarvestH2o, 2010).

HB 2430 of May 2005 – establishes "rainwater harvesting evaluation committee to recommend minimum water quality guidelines and standards for potable and non-potable indoor uses of rainwater. The committee will also recommend treatment methods for indoor uses of rainwater, methods by which RHS could be used in conjunction with existing municipal water systems, and ways in which that the state can further promote rainwater harvesting" (TWDB, 2005).

➢ Washington

Law RCW 36.89.080 of 2003 – mandates the reduction in stormwater fees of at least 10% for any commercial facilities that installed RHS (HarvestH2o, 2010).

- **United Kingdom**

British Standard (BS) 8515 – gives recommendations on the design, installation, alteration, testing and maintenance of RHS supplying non-potable water for remodelling or new UK houses, giving the public confidence that their RHS is of the best quality. This standard only covers for systems supplying water for domestic water uses that do not require potable water quality such as laundry, toilet flushing and garden watering (BSI Group, 2009).

- **Germany**

DIN 1989 – Planning, installation, operation and maintenance of RHS.

"This standard applies to systems utilizing rainwater in households and commercial and industrial companies, as well as in public organizations, in which it is used for flushing toilets, for cooling purposes, for washing and cleaning systems and for watering green areas.” (V 8 - Rainwater Harvesting Systems, n.d.).

This standard is in the vanguard on rainwater utilization being considered as the most complete and reliable on this subject. Therefore, it should be an example to follow by every country that aims to adopt RWH as a key strategy towards water management sustainability. The German Standard provides technical reliability and ensures designs are high-quality and safe (Virginia Rainwater Harvesting Manual, 2009)

2.3. Potential Uses of Rainwater

As mentioned earlier, one of the benefits of using rainwater is savings on water bills. Rainwater falls for free and it's available for everyone who wants to capture it from their home or building roofs and yards.

Most water used in homes and industries does not need high quality water – e.g., toilet flushing and gardening. As we can see in Figure 7, many of the activities typical of every household do not require potable water (Harmer Kessel, 2009).

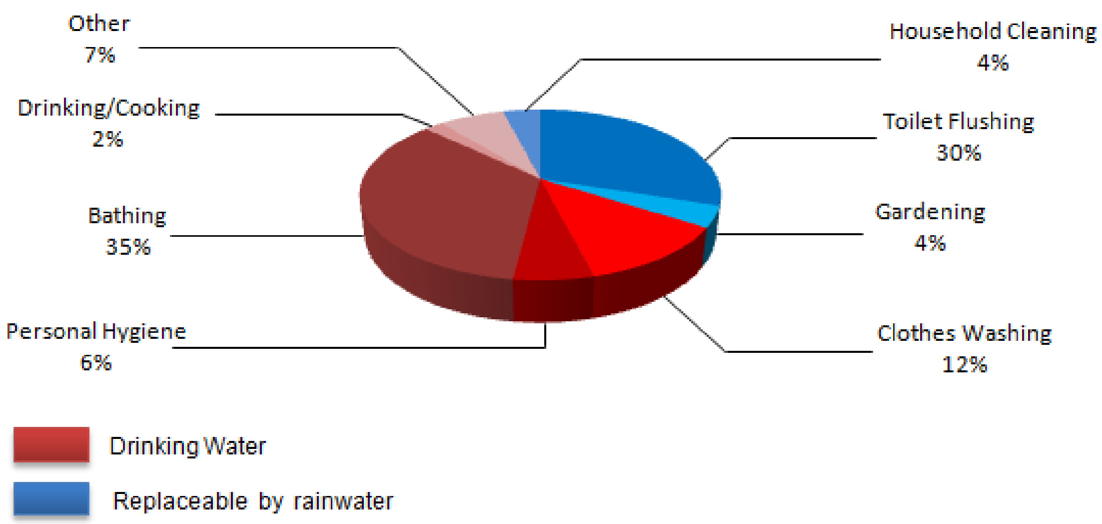

Figure 7 - Distribution of water consumption in a common dwelling (Source: Harmer Kessel, 2009).

Figure 8 indicates the average water use in office buildings (Roebuck, 2007).

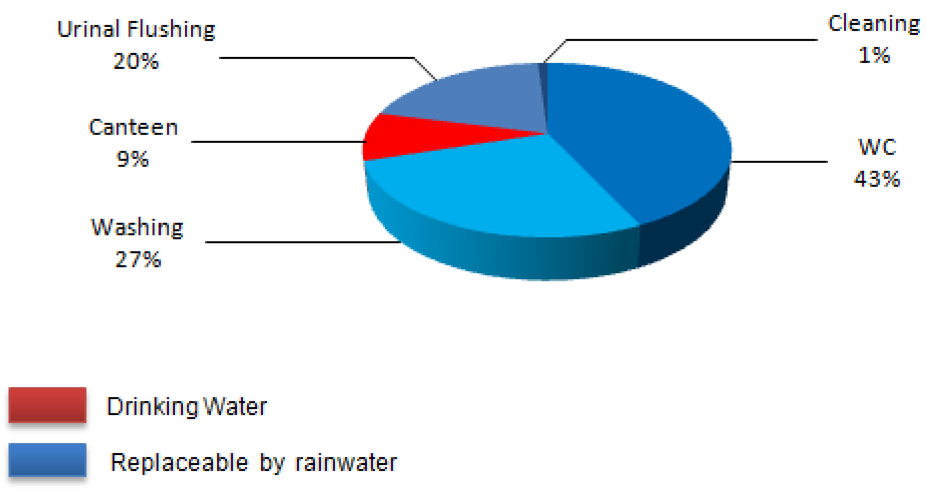

Figure 8 - Average water use in office buildings (Source: Leggett *et al,* 2001a in Roebuck, 2007).

The same water we drink is used to wash cars, irrigate lawns, to wash clothes and toilet flushing. Consumption suitable to be replaced by rainwater is nearly 50% of the total average water consumption spent in a dwelling, in contrast to the 2% of water used for cooking and drinking, the activities that really need higher quality water. Of course these values vary from case to case, but never stray too far from this reality.

Although mainly aimed at non-potable demands, harvested rainwater can be used for potable purposes (drinking and food production) if properly treated according to WHO Standards. However, since it is a process that requires more care and higher treatment costs, it is a less common solution.

In short, the several uses of rainwater include:

- Toilet flushing
- Laundry / clothes washing
- Landscape irrigation / water gardening
- Household cleaning
- Vehicle washing
- Building washing
- Cooling towers
- Fire fighting
- Industrial processing
- If properly treated, potable purposes include:
    - Drinking water

- Bathing
- Cooking
- Dish washing

For all the problems associated with water scarcity and the continuing increase of its demand, the concept of RWH has been acknowledged by many countries, cities, societies and individuals, all over the world. With the growing interest and adequate investment, the development of new technology was inevitable, and therefore examples of simple high-tech RHS can be found through all the 5 continents, especially in countries like Australia, Brazil, Germany and Japan.

Some success stories are presented below, which could serve as a starting engine for other countries to adopt this strategy, with the aim of using alternative water sources and reduce global water crisis.

2.3.1. Case Studies – World Success Stories

- **Berlin, Germany**

  ➢ Daimler-Chrysler Complex at the Potsdamer Platz

Between 1996 and 1998 was constructed one of the largest building site in Europe, under very strict stormwater management conditions, introducing RHS in its buildings architecture in order to save city water, to create a better microclimate and to control urban flooding (UNEP, 2002).

To comply with these goals, some techniques were adapted to the building structures (Centgraf & Schmidt, 2005):

- Extensive and intensive green roofs

- Collection of roof-runoff

- An artificial lake for rainwater retention and EV

About 23 m^3 of rainwater is collected from the rooftops of the 19 buildings which comprise the complex, equivalent to a total catchment area of 32,000 m^2. The water is stored in a 3,500 m^3 underground cistern and from there it is fed into the system of canals built on the south side of the building complex (Sustainable Cities™, 2008). The water is then used for refilling the artificial lake, for toilet flushing and irrigation of green areas including intensively greened roofs (UNEP, 2002).

- Belss-Luedecke-Strasse

Another important project is the Belss-Luedecke-Strasse building estate. Rainwater from all roof areas along with the runoff from streets, parking spaces and pathways, is collected and discharged into a separate public rainwater sewer and conveyed into a reservoir with a capacity of 160 m^3. The water is treated in several stages and used for toilet flushing as well as for garden watering.

This system is designed to flush out the initial flow into the sanitary sewer for proper treatment in a sewage plant, ensuring the removal of the majority of the pollutants of the initial rainfall. It is estimated that the savings of potable water through the use of this system are of about 2,430 m^3 per year, thus preserving the groundwater reservoirs of Berlin (UNEP, 2002).

- Sony-Center

This building complex is a symbol of contemporary Berlin, where the 400 m^2 glass-roof covering the shopping centre is the landmark of its modernization. One of the concerns of this development architecture was the integration of a rainwater utilization system. The water collected on the roof is drained into the storage tanks located in the basement, with a capacity ranging from 100 to 200 m^3. Among the various reservoirs, the system has a total capacity of 900 m^3 (König, 2001).

The harvested rainwater is used for the irrigation of outdoor recreational facilities and for the toilets and urinals in the Office Tower (building A), from the 1st to the 14th floor. Still to mention that there is a reserve tank in case of fire (König, 2001).

Figure 9 - Aerial image of the Sony Centre glass-roof (Travel Lynx, 2010).

- **Brazil**

In Brazil, many projects have been developed focusing on rainwater utilization. From the year 2000, the Cosch Company began to spread this technology and is responsible for most of the Brazilian reference projects, mainly in Rio de Janeiro, São Paulo and Curitiba (Cosch, 2007).

Some of these success stories are:

➢ Coca-Cola Brazil

Coca-Cola Brazil, formed by Coca-Cola headquarters in Rio de Janeiro and 17 groups of manufacturers, prioritizes the efficient and rational use of water once it is its main raw material. To this end, Coca-Cola joined the Clean Water Program that seeks to reduce consumption, prevent waste, promote reuse and search for alternative sources of water (Coca-Cola Brasil, 2006).

Currently, this system uses 2.08 L of water for each L of beverage produced, holding one of the best rates of this industry around the world. Twelve years ago, this rate was around 5 L (Coca-Cola Brasil, 2009). A major factor which led to the reduction of water consumption is related to the search for new sources of water. In fact, Coca-Cola Brazil stopped using water from the public supply and set out to capture its own water, mainly rainwater. Since 2005, the implemented RHS (RHS) already operates successfully in the headquarters, where rainwater is used for feeding the cooling towers (Coca-Cola Brasil, 2006).

Besides its headquarters, there are already nine manufacturers who use rainwater collected from their harvesting systems as the main raw input, which represents 2.3% of the average consumption of these factories, reaching the mark of 12% in some cases. Today, the ability to capture rainwater in all Coca-Cola factories, including its headquarters, is 89 million L of water per year (Saúde & Lazer, 2009).

- Projects in the 2007 Pan American (Cosentino, 2009)

These projects include the João Havelange Stadium, the Water Park, the Multisport Arena and Velodrome. Its RHS were design in a way that from the moment the rain falls on the roof, the system operates by collecting and storing it, providing quality water for non-potable purposes, such as, toilet flushing, irrigation, fire fighting reserve and floor washing.

The João Havelange Stadium has a catchment area of 13,000 m^2 and its total storage capacity is an average of 953,000 L of rainwater per month.

The Water Park has a catchment area of 6,000 m^2 and its total storage capacity is 460,000 L of average rainwater per month.

The Multisport Arena has a catchment area of 14,750 m^2 and its total storage capacity is 1,148 m^3 of average rainwater per month, distributed by four 140 m^3 reservoirs.

The Velodrome has a catchment area of 3,000 m^2 and its total storage capacity is 233 m^3 of average rainwater per month, distributed by two 70 m^3 reservoirs.

- Programa Um Milhão de Cisternas (P1MC – Programme of One Million Cisterns)

This program developed by the Articulação do Semi-Árido Brasileiro (ASA Network – Articulation of the Semi-Arid of Brazil) started in 2003, which the primary objective is to provide clean water for cooking and drinking for 1 million homes, equivalent to about 5 million people. This job will be achieved through *in situ* construction of 1 million cisterns, whose unit capacity is to store around 16 billion L (16 million m^3) of rainwater. Through this program, besides providing drought security, each family is independent and has the freedom to make the management of its own water resources. By March

2010 about 287,500 tanks have been built and are already being explored by many municipalities of the semi-arid, benefiting more than 1 million people (P1MC, n.d.).

Figure 10 - Brazilian family and their rainwater cistern (Source: CECOR, 2008).

- **Tokyo, Japan**

In Tokyo and other Japanese cities, more and more municipalities and organizations have given utmost importance to rainwater utilization since the mid 80's. Thus, instead of channelling it into sewers and then to the ocean, RWH in Japan aims to secure water sources for emergency responses, to prevent urban flooding, to restore water's natural cycle and to find alternative water for non-drinking purposes (König, 2001).

➢ <u>Sumida City, Tokyo</u>

Sumida ward is considered to be one of the leaders in rainwater utilization at the local government level and there are several examples of such sustainable approach.

➢ <u>Ryogoku Kokugikan Sumo-wrestling Arena</u>

This Sumo Wrestling Stadium, built in 1985, is very well known for its substantial rainwater utilization system. From the 8,400 m^2 building rooftop, stormwater is captured and drained into a 1,000 m^3 underground storage tank. The collected water represents a considerable proportion of the water used for toilet flushing and air conditioning (UNEP, 2002).

- Rojisons

"Rojison" represents a simple rainwater utilization facility available at the community level. Consists in a system where rainwater is collected from the roofs of private houses and stored in several underground tanks, with capacities of 3 tons to 10 tons each. The tanks are accessible for general public and local residents can pump up the water by hand, using it for watering gardens, drinking water in case of emergencies and for fire-fighting (Samaddar & Okada, 2007).

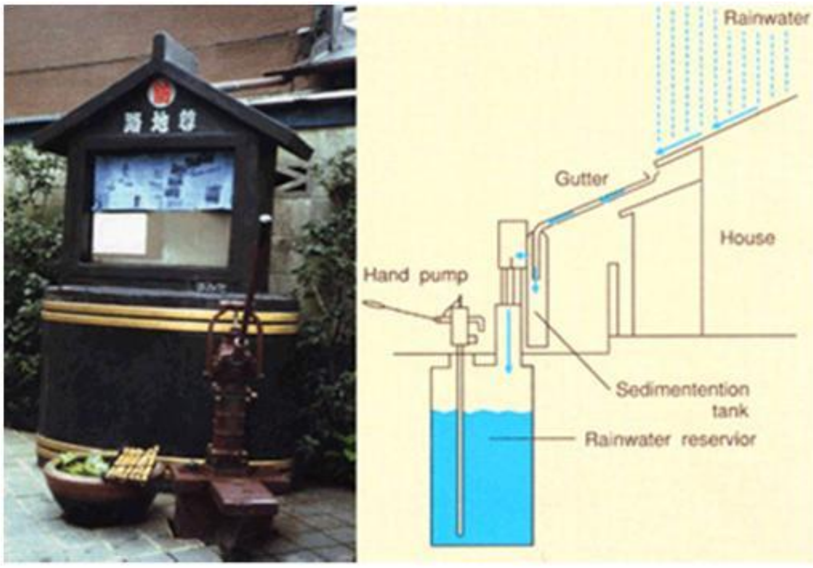

Figure 11 - Typical Japanese "Rojison" mechanism (Source: International Technology - Urban Case Studies)

According to Samaddar (2007), about 180 tanks have already been installed in Sumida City, with a total storage capacity of 10,000 m^3 of rainwater. Furthermore, Sumida ward accounts for more than 19 "Rojison" used by its communities. Since 1985, all newly constructed buildings are required to install rainwater utilization facilities.

2.3.2. Case Studies – Implementations in Universities

- **Universiti Kebangsaan Malaysia**

In March 2006 the Ninth Malaysia Plan (9MP) was announced to the country. This plan consists of the allocation of the national budget between the years 2006 and 2010 to all economic sectors, in order to overcome Asian financial crisis towards economic and environmental sustainability.

Under this initiative, the Universiti Kebangsaan Malaysia (UKM) began the construction of a new building in the Faculty of Science and Technology consisting of two blocks, namely the Administration edifice and the Laboratory edifice. It's in this new complex, financed by the 9MP in about 750 million MYR (180 million €), that will be installed the pilot project of RHS.

Initially, this system was implemented only for the Administration Building, since it is the first one to be constructed. Its rooftop was considered to be the most suitable catchment area and from there, the rainwater is conveyed through the gutters, into the downpipes which are linked to the filtration tank. The filtration tank is where the water collected will be filtered before channelled to the storage tank. The filtration method consists of three phases: natural sand filter, stone and charcoal filter and finally, bio-filter.

The storage tank is a solid concrete structure, built underground, with a capacity to store 50 m^3 of water before pumping it to a delivery tank situated on the top of the building. This tank is connected to the public water distribution system, which will provide water in case of low rainwater supply. The plumbing system is separated from the public water supply, to keep harvested rainwater from mixing with treated city water.

The main goal of this project is to provide the maximum water for toilet flushing and building washing. According to the data available in this paper, the amount of water demand only for toilet flushing in the Administration Block can be covered by the harvested rainwater in the month with the lowest average rainfall (January).

At first, the water collected will be applied for toilet flushing and building washing, but eventually could be used for other activities such as washing vehicles and watering plants and gardens.

The implementation of this project in the UKM will bring many economic and social benefits. It will provide water for non-potable uses reducing the consumption of drinking water thus helping to reduce the dependence on the public system, and therefore on water bills. Socially, it will be an important step to attract and involve students and practitioners who are interested in this subject, contributing for future research (Rashid & Darus, 2009).

- **University of North Carolina – The Bell Tower Project**

The University of North Carolina (UNC) at the town of Chapel Hill is the oldest public university in the USA and one of the more aware that we live an era of crisis, always looking to create innovative solutions to a complex array of issues using a holistic, sustainable approach

In the year 2000, an investment was made in the university campus of around 2 billion U.S. Dollars (USD) (1.5 billion €) for various program improvements, including the construction of the Bell Tower Project (BT), one of the greatest buildings ever completed on campus. This project involved an investment of 231.5 million USD (170 million €) and consists of a multi-purpose complex whose main feature is its innovative water grid, which is being incorporated into the design as part of a pilot project for testing and optimization.

The construction of this complex aims, in addition to the educational services offered, to accomplish the fulfilment of several key strategies including reducing water consumption of the public network, and storm water management, by maintaining or improving water quality, peak discharge attenuation and total volume reduction.

It is located immediately upstream of the confluence of two small streams of 10 and is 25 hectares in size. The existing buildings of the BT occupy much of the perimeter of the 10 hectare sub-watershed and a 16,350 m^2 asphalt parking lot is situated in the centre of the watershed. The Genome Science Laboratory Building (GSB) and the parking deck, which are the major structures of this development, will be connected by a new central park, a large green area that replaced the existing parking lot.

Below this park lies the stormwater management facilities, composed by a “1,365 m^3 concrete stormwater detention structure and a 1,325 m^3 stone-filled cistern for storage and reuse of harvested roof water.” All new and existing stormwater surface pipe and drainage systems are connected to the underground concrete detention system.

The water that falls on building rooftops will be captured and reused as a water supply source for irrigation and toilet flushing, promoting the concept of non-potable water (NPW) system. This system also incorporates an automatic reclaimed water makeup system to provide a reliable secondary source of water, when the city experiences severe droughts. The entire stormwater management facility has the ability to treat approximately 2,690 m^3 of stormwater.

According to this article, upon completion of this project, the NPW systems will reduce UNC's demand on Orange Water and Sewer Authority (OWASA) potable water "by an average of 3,785 m^3 per day, or about 10% of the average daily demand of the entire OWASA system. This volume reduction is expected to increase to 5,678 m^3 per day by the year 2028" (Efland et al., 2008).

- **Universities in the United Kingdom**

Several universities in the UK, such as, University of York, Sheffield Hallam University and University of Southampton, are implementing energy and water efficiency concepts in some of the existing campus buildings and its new developments are a practical example of sustainable construction.

The new National Science Learning Centre located at the University of York cost around £11 million (13 million €), but includes many beneficial features, among them, a geothermal cooling/heating system which saves £11,000 (13,000 €) annually compared to conventional alternatives, extensive use of natural lighting and ventilation and utilization of rainwater for WC and urinal flush systems (People & Planet, 2006).

The University of Southampton's new Administration and Student Services Building increases the capacity of an older building by linking through a spectacular three-storey glass atrium. In association with its main features is RHS to flush W.C. (HEEPI&SUST, 2008).

2.3.3. Case Studies in Portugal

The new SETH engineering headquarters, located in Oeiras, Lisbon, implemented innovative solutions on the building design in favour of greater environmental responsibility. One of the applied technologies was the installation of a RHS. The water is collected from roofs and balconies of the building and conveyed to a reservoir with 30 m^3 capacity. From there, the water is used for sanitary facilities, garage washing and gardening (SETH Engineering, 2009).

- **Natura Towers**

The Natura Towers are a new development of two office buildings in Telheiras, Lisbon, designed to maximize their energy performance and minimize its environmental impact through a proper selection of ecological and self-sustaining solutions. One measure refers to RWH, from the building rooftops. The water is stored in underground reservoirs and from there is used for irrigation of green spaces (MSF TUR.IM, 2009).

- **Herdade da Boavista e Sampaio**

This project is an eco friendly tourist village, sited in the municipality of Alcácer do Sal, Alentejo, designed to enhance the closest contact with nature in a sustainable manner. The development, in addition to the reuse of graywater, has incorporated a RHS which collects water from the house roofs. The stored water is mainly used for irrigation of the adjacent green areas (Amazing Projects, 2010 and Pedro, 2010).

- **Mar Mediterrâneo building**

The Mar Mediterrâneo building, SONAECOM headquarters in Lisbon, distinguishes for its high quality aesthetics and sustainable construction. It is characterized by its rationalization and efficiency of energy consumption, especially with regard to water consumption. The building has the particularity of having a rainwater reuse system adapted to its toilet flushing system (Bouygues Imobiliária, 2007).

- **Aerodrome Control Tower of Castelo Branco**

This project was developed aiming at the use of rainwater for toilets and urinals discharging, for all WC located on floors 1 and 0. The collection is made from the tower rooftop, with an approximate area of 120 m^2, where water is diverted into a reservoir, with a capacity of 7 m^3, located on the 4th floor. Before entering the reservoir, the water flows through a filter in order to remove all types of debris such as tree leaves. The “polluted” water will be forwarded to the property sewer collector, while the clean water will be stored in the reservoir.

During the dry periods, the public water supply will feed the reservoir through a monitored valve which will be triggered as soon as the water level reaches the minimum quota of 30 cm from the bottom of the reservoir (Bertolo, 2006).

2.4. Water Quality Aspects Related to Rainwater and its Potential Uses

In the past, rainwater was considered to be pure, soft and free of chemical and microbiological contaminants. So clean, that it could be used and consumed without any treatment. However, with the intensification of the industrial revolution as the main cause, this is no longer true.

With increasing pollution, stormwater collected in many places, especially in megacities, may contain a variety of chemical and organic impurities. From the moment it falls, as it dissolves carbon dioxide and nitrogen – acid rain – through the catchment surface (rooftops, ponds, gutters), to the storage site, there is a potential for chemical, physical and microbiological contamination (UNEP, 2002).

Nowadays, in general, rainwater does not meet the quality standards imposed by WHO (The Schumacher Centre for Technology & Development, 2008). Yet, that doesn't mean that the water is inadequate for use. The problem is that there is no specific internationally recognized standards regulation for the use of rainwater for non potable purposes. If one day that happens, it will promote the use of rainwater sources and avoid potential health risks due to misuse. Obviously, the type of treatment to be applied to the harvested water varies with the purpose for which it'll be used. Although rainwater can be collected in various ways, this paper will focus only on the collection of rainwater from roof catchment systems and therefore, the quality problems of ground-surface rainwater runoffs will not be covered through this chapter.

A rooftop RHS is essentially composed of a catchment surface (roof), a conveyance system (gutters or pipes) and a storage structure (a cistern or a tank). During this process there is a potential for chemical, physical and microbiological contamination, in all three stages. Despite roofs being higher than the ground, it doesn't mean they are free from dirt, dust, faeces from birds and small animals and other debris, such as leaves and twigs. Thus, falling rainwater not only dissolves air pollutants, as when it falls on the roof, but it also dissolves contaminants from the roof material, collects dirt and then flows into storage. Changes may also occur during storage, depending on its location, water depth and the material used (Meera & Ahammed, 2006).

In short, there are several factors that influence the water quality of roof runoff (Lye, 2009):

- Roof material – chemical characteristics, roughness, surface coating and age;
- Construction methods of the roof – size, exposure, inclination;
- Local weather and environmental conditions – season, antecedent dry periods;
- Precipitation events – intensity, wind, duration;
- Chemical properties of pollutants – vapour pressure, solubility in water;
- Location of the catchment surface – proximity to pollution sources: industrial areas, agricultural areas, heavy traffic;

Despite the significant water conservation and stormwater management potential for RWH, there are still many uncertainties about the impact of this practice to human beings, hence it is necessary to make a thorough assessment of its quality and its potential jeopardy to human health. The most common hazards in harvested rainwater from rooftops are microbiological hazards and physico-chemical hazards.

2.4.1. Physico-Chemical Hazards

The physico-chemical contamination of rainwater is an issue which greatly affects this practice, varying in space and time.

The sources of physical-chemical hazards of RWH can be divided in two categories (enHealth Council, 2004):

1 – Off-site sources: hazards whose origin is far from the point of collection, beyond the control of the owner/resident. That includes industrial emissions, agricultural pollution, traffic emissions, bushfires, etc.

2 – On-site sources: hazards that arise from the conception of the system, controllable by the owner/resident. That includes materials and characteristics of the catchment surface, roof materials, gutters, tank material, etc.

- **Industrial emissions**

The biggest urban and industrial areas are likely to be more air polluted. Thus, there is a greater probability of rainwater becoming contaminated as it falls in these surroundings, by airborne pollutants such as particulate matter and heavy metals (TWDB, 2005). In these localities, rainwater collection for human consumption has attracted most concern since long-term contamination by heavy metals is known to cause numerous biological disorders (Lye, 2009). Several surveys reported that rainwater collected in domestic tanks in Port Pirie have shown concentrations of lead exceeding drinking water guidelines, the source of which is thought to be a very large smelter. Therefore, residents of Port Pire were recommended not to use rainwater collected in domestic tanks for drinking or food preparation (enHealth Council, 2004).

Trace organic compounds, such as Volatile Organic Compounds (VOCs) and Polycyclic Aromatic Hydrocarbons (PAHs), are commonly found in roof runoff. These chemical are of great concern because of their potential hazards to public health, being considered the largest class of suspected carcinogens prevalent in urban atmospheric deposition (Meera & Ahammed, 2006). Several studies report that the highest levels of PAHs in urban runoff are usually found in the vicinity of industrial areas or intense urban traffic. Moreover, some of them alert for the fact that roof characteristics also seem to affect the level of trace organics in roof runoff (Zobrist et al., 2000; Moilleron et al., 2002; Polkowska et al., 2002).

- **Agricultural pollution**

In agricultural areas, the main source of pollution may be the use of chemicals, such as pesticides, in intensive farming. In fact, according to Lye (2009), the use of fertilizers and pesticides in agriculture “is a leading pollution source of rainwater in rural areas of many countries.” Thus the potential contamination of rainwater and catchment surfaces (roofs) by nitrates due to fertilizer residue in the atmosphere, and pesticide residues deposition from crop dusting is of great public concern (TWDB, 2005).

Despite all the potential risks, surveys of rainwater quality in rural areas presented in EnHealth Council (2004), reported that “pesticides are rarely detected and, where they are, concentrations are well below health-related guideline values”. Nevertheless, periodic assessments of contamination of harvested rainwater by pesticides are necessary, to avoid possible health problems.

- **Bushfires and Particulate matter**

Bushfires, if not induced, tend to be most common and severe during warm and dry seasons. This event generates large amounts of ash, fine particulates and other debris, susceptible of settling on roof catchment surfaces or to be incorporated in rainwater as it falls through the atmosphere. Such material is likely to be washed into storage tanks, either when a rain event occurs or during roof cleaning. Even though the presence of particulate matter in stormwater doesn't represent a major health concern, it may affect the taste, turbidity and colour of harvested rainwater (enHealth Council, 2004).

- **Roof Material**

The type of roof material and its periodic cleaning will highly affect the quality of rooftop RWH.

According to numerous studies (EnHealth Council, 2004; Meera & Ahammed, 2006; Hamdan, 2009; Despins et al., 2009) nearly all water quality parameters – turbidity, Total Organic Carbon, hardness, colour, pH, organic matter, concentration of heavy metals, etc – were considered to vary significantly based on the type of rooftop material.

Roofs can be fabricated from a diversity of materials such as concrete, bitumen, asbestos/fibrocement, metal, terracotta and clay tiles, polycarbonate or fibreglass sheeting (EnHealth Council, 2004; Hamdan, 2009).

Differences in roofing material affect turbidity, hardness and colour of harvested rainwater. Wide variations are seen in the concentration of most constituents such as major ions, nutrients, pesticides and heavy metals. According to Zobrist et al. (2000), in a typical rain event, runoff from a tile roof presented high concentrations of most constituents in the first minutes or first tenths mm of runoff depth, while runoff from a gravel roof exhibited a different behaviour, as there was a significant retention of rainwater in the gravel layer.

Studies by Wallinder et al. (2000), Chang et al. (2004) and TWDB (2005), suggested that variations depended not only on roof material, but also on characteristics of precipitation, orientation and slope of roof, air quality of the region, weather patterns, etc. Dust derived from calcium rich-soils is susceptible to settle in rooftops, consisting in a source of calcium and magnesium in the form of carbonates. Also, acidic ions like nitrates and sulphates are considered to be transported by deposition.

Another important parameter for this subject is the pH value of the harvested rainwater. In theory, pH of rainwater varies between 4.5 and 6.5 but usually increases slightly as soon as it falls on the roof and during tank storage. This chemical phenomenon is of great relevance, once it is a key factor in chemical precipitation of pollutants in stormwater runoff. As it runs on certain types of roofs, like fibrous cement, rainwater tends to become more alkaline which is a favourable condition for precipitation of heavy metals compounds (Zobrist et al., 2000; Hamdan, 2009).

Heavy metals are of singular importance in RWH "due to their toxicity, ubiquitousness, and the fact that metals cannot be chemically transformed or destroyed", by simple treatment processes (Davis et al., 2001). Several attempts have been made over the years to determine the influence of atmospheric deposition, especially in the vicinity of industrial areas, and roofing materials on heavy metal contamination of rooftop runoff. Roofs can act as a source of heavy metals through leaching and disintegration of its building materials over the years. Among the many possible types of materials, metals surfaces in direct contact with falling rainwater, besides being subjected to atmospheric corrosion, will dominate the runoff pollution pattern, especially for lead, zinc and copper (Zobrist et al., 2000; Davis et al., 2001; Chang et al., 2004; Eletta & Oyeyipo, 2008).

The presence of lead in harvested rainwater is the most common since lead can stem from several types of roofs, including polyester, slate, galvanized iron and asphalt shingle roof. Lead fittings have also been suggested as potential sources of contamination of harvested rainwater, mainly in poorly maintained roofs and gutters (Zobrist et al., 2000; Wallinder et al., 2000; Metre & Mahler, 2003). Therefore lead fittings are not recommended.

Water quality should be monitored for heavy metals in order to avoid major hazards to human health, especially if the harvested rainwater is to be used for drinking purposes or food preparation.

- **Tank Material**

All details about rainwater storage have a major influence on overall water quality. The design of tanks, the materials used and its location are the most influential issues in obtaining water with good or poor quality.

Tank design solutions include techniques to minimize re-suspension of sediments, such as the installation of a wave absorber mechanism at the tank water inlet in order to reduce water turbulence, and a specialized service for storage tank maintenance. Most storage reservoirs should be equipped with manholes to allow access for cleaning (Lye, 2009).

A study by Han & Mun (2008) revealed that the quality of stored water delivered to the end users will not only determine its final use but will also affect its acceptance by the general public, as a suitable alternative of potable water. They suggested that higher efficiency in particle removal can be obtained by having a considerable distance between inlet and outlet. It is also recommended that tanks should be designed to maintain a minimum of 3 m water depth and to withdraw water from the near-surface by using a floating suction device.

Rainwater reservoirs can be designed from several suitable materials including plastic, concrete, fibreglass and galvanized steel (enHealth Council, 2004). Studies by Zhu et al. (2004) and Despins et al. (2009) reported the effect of storage material on some quality parameters such as taste, turbidity, colour and pH, being this variable the most sensitive to the type of material. Rainwater stored in concrete tanks tends to be more basic, and this could be attributed to the presumable leaching of calcium carbonate from the cistern walls. Rainwater stored in non-concrete tanks is likely to be slightly acidic; however it is unlikely to have a direct health impact on humans. New rainwater cisterns may also provide specific tastes and odours to the harvested water. Concrete reservoirs can release excess lime, inflicting a bitter taste to water. Galvanized tanks can impart a metallic taste when first filled, due to leaching of excess zinc (Despins et al., 2009).

Summarizing, many studies from different parts of the world on the physico-chemical characteristics of roof-harvested rainwater, report that, in general, physico-chemical quality meets the drinking-water quality guidelines with the notable exception being pH.

2.4.2. Microbiological Hazards

Stormwater harvesting from rooftops is subject to contain a wide variety of microorganisms from various sources. Although many are considered safe and not likely to cause illness, their presence indicates that disease-causing organisms (pathogens) could be in the stored rainwater. Therefore, water quality and safety will be ensured by the minimization or exclusion of their presence (enHealth Council, 2004).

The most common indicators of faecal contamination generally used for assessing the microbial quality of water are *Escherichia coli* (E. coli) and *faecal coliforms* (or Thermotolerant coliforms). However, an increasing number of microorganisms are being added to the current US Environmental Protection Agency (USEPA) microbiological guidelines for water that is going to be ingested in some manner by the consumer. Some pathogenic and opportunistic organisms, such as *Salmonella spp.*, *Pseudomonas aeruginosa*, *Legionella spp*., *Campylobacter* spp. and *Cryptosporidium* (protozoan pathogens) are often present in harvested rainwater. These organisms are likely to cause possible health problems to its consumers and therefore none of them is allowed (zero CFU per 100 ml) in high quality drinking water sources (Lye, 2002). Thus serious doubts were raised about whether traditional indicators will be sufficient to accurately assess the state of water safety.

Microbial quality/contamination of harvested rainwater from roofs depends on several factors (EnHealth Council, 2004 and Meera & Ahammed, 2006):

- faecal material (droppings) deposited by birds, lizards, rats and other climbing animals;
- dead animals and insects, either in the roof or gutters, or in the tank itself – can lead to direct faecal contamination and has a certain impact on the water taste and odour;
- soil and leaf litter accumulated in gutters, especially if kept damp for long periods due to poor drainage;
- type of roof – microbial quality of water collected from metallic roofs is usually better than that from other types of roofs;
- Periods between precipitation events – contamination increases with longer dry periods between rainfall episodes due to greater deposition occurrence on roofs.
- Weather patterns and environmental conditions: wind speed/direction, temperature and rainfall intensity – can significantly influence the bacterial load of roof run-off.

Also quite relevant are the issues relative to storage tanks. The majority are installed above ground. Yet, underground tanks will not cease to exist. These require higher constructive considerations, since if they aren't fully sealed and protected against run-off, microorganisms in the soil associated with human and animal faeces may also contaminate stored rainwater (enHealth Council, 2004). Additionally, rainwater tanks serve as an excellent site for mosquito breeding. Besides the discomfort and nuisance they cause, certain types of mosquitoes can be vectors of viruses and diseases, such as malaria and the dengue virus, especially in 3rd world countries located in tropical and subtropical areas, where water scarcity is a capital problem. To avoid or minimize this situation, it is recommended that all tanks should have devices to prevent mosquito proliferation (enHealth Council, 2004).

There are many surveys about the influence of the storage period and location of rainwater cisterns on the microbiological quality of water. It is considered that relatively clean water entering the tank will generally improve in quality if allowed to sit inside for some time. However, it is possible that certain bacterial strains are likely to proliferate during storage and that levels remained constant during long term storage. It is assumed that these contradictory results are linked to the availability of nutrients and environmental conditions, suitable for bacterial proliferation in storage cisterns. Therefore, physical location of the tanks is of utmost importance (Meera & Ahammed, 2006). They should be sited in a shady, dark spot to prevent algae growth and keep water cool (The Schumacher Centre for Technology & Development, 2008).

Numerous studies from different parts of the world (Lye, 2002; EnHealth Council, 2004; Meera & Ahammed, 2006; Sazakli et al., 2007) reported that the microbiological quality of rainwater is often suspect and does not meet microbial drinking-water quality standards. Consumption of untreated stormwater is likely to cause some health related problems, yet more studies are necessary to assess the real microbial risk of rainwater to human beings.

Despite these revealed conclusions, Meera & Ahammed (2006) emphasised that “collected rainwater still represents the best option in many situations in terms of microbiological quality”, sometimes even better than that of other sources of drinking water such as shallow groundwater.

2.4.3. Water Quality Standards for Irrigation

As stated by Lye (2009), chemical water quality standards, chemical analyses and chemical detection limits are very similar worldwide, almost reaching for universal agreement. In stark contrast are the levels of microbiological contamination of water, whose standards vary greatly throughout the world from relatively simple to relatively complex, corroborating a lack of general compliance.

The quality requirements should be different whether the water is for potable or non-potable purposes. Within this category, recommended standards will depend on whether the water comes into contact situations or not with the human being, or even if it is for ecological applications. For example, it is assumed that the water quality standards required for bathing will be different than those for toilet flushing or garden irrigation (Lye, 2009).

In Portugal it seems there is no research on the characterization of the quality of rainwater. Since there is no legislation governing the use of rainwater for irrigation, this technique must be governed by DL nº 236/98. In Annex , the maximum recommended concentrations (MRC) as well as the maximum acceptable concentrations (MAC) of water quality for irrigation are established (Ministério do Ambiente, 1998).

This DL establishes the parameters limiting the quality of water for irrigation, without distinguishing agricultural irrigation from recreational or landscaping irrigation.

2.4.3.1. Rainwater Quality Parameters

As stated before, quality requirements for non-potable applications vary if the water is likely to get in contact or not with humans. Nevertheless, people everywhere are exposed to all kinds of bacteria during everyday activities at home, at work and between both. Thus, minimal exposure to slightly contaminated harvested rainwater shouldn't be that significant.

Many studies and reports throughout the years support this theory. According to Konig (2001), "in well designed and operated systems only coarse filtration prior to entry into the storage tank is required and that the risk to human health from non-potable applications is minimal". Leggett et al (2001b) reports that when harvested rainwater is to be used for toilet flushing or irrigation, disinfection techniques are not necessary and should not be applied. Shaffer et al (2004) asserts that when rainwater is intended for WC flushing, irrigation and other non-potable uses, coarse filtration and tank settlement provide satisfactory treatment (Roebuck, 2007).

Based on the testimonials presented above, it was decided that rainwater quality parameters would not be considered in the thesis. Assuming that contamination from the catchment surface is low and that the system is well designed and operated, there will be no major consequences if the water gets in contact situations with human beings.

2.5. Recommendations on the design, installation and maintenance of a Rainwater Harvesting System

Water supply and water quality associated with rooftop harvesting depends on implementing a system maintenance program. Simple and sensible management procedures should be considered in order to minimize health and aesthetic hazards for the collected rainwater. Some preventive measures associated with design, installation and maintenance of RHS are presented below (enHealth Council, 2004; TWDB, 2005; May & Prado, 2006; Lye, 2009):

- Proper design/sizing of the RHS components;
- Use of most appropriate materials in construction, according to local characteristics;
- Coating of roof surfaces, especially of metal materials, to minimize contamination by leaching;
- Protect all inlets, overflows and other openings with insect proof mesh
- Regular cleaning of the catchment surface: removal of atmospheric depositions, dust, leaves and animal faeces;
- Regular cleaning of gutters and first-flush devices;
- Monitoring tank levels;
- Avoid exposure of the storage tank to sunlight to inhibit algae growth;
- The rainwater tank should be connected to an independent backup water supply network in order to meet daily non-potable consumption, in case of low rainwater supplies;
- Proper treatment/disinfection materials and procedures, according to the water final use;
- Periodic water quality testing;
- Periodic reparation and maintenance of the RHS;
- Rainwater pipes should be distinguishable from potable water pipes, through the application of different colours. Moreover, warning signs should be placed next to taps and hoses, where rainwater is being utilized;

2.5.1. ANQUIP Hydric Certification

As mentioned in section 2.2.1, ANQIP developed two Technical Specifications - ETA 0701 and ETA 0702 - regarding the certification of RHS in Portugal. ETA 0701 establishes technical criteria for the implementation of RHS for non-potable purposes. When installing a RHS, all the essential components and additional accessories should be considered, in order to assure the proper functioning. The main criteria relevant for the implementation of RHS for irrigation of recreational gardens and parks, according to this report, are presented bellow (ANQIP, 2008):

- The rainwater piping should be dimensioned similarly to the dimensioning of the potable network. It is recommended that the rainwater piping and all the related accessories should be properly identified, using colored tape or colored pipes, different from the potable piping system.
- It is recommended that all washing or irrigation taps should be provided with a detachable handle (security key) to prevent improper use.
- Rainwater use for irrigation does not require any physico-chemical or bacteriological complementary treatment.
- It is advisable to evaluate the quality of the stored at least every six months, mainly due to pH control.

Table 1 - Estimated Annual Consumption for Green Areas Irrigation

	Green Areas		
	Lawn**	**Garden****	**Golf Course*****
Annual Consumption* for 6 months: (April-September)	450 to 800 l/m^2	60 to 400 l/ m^2	200 to 450 l/ m^2

* Mean Values
** Depending on the variety of grass, soil type and country region.
*** Varying according to different playing zones; varying according to soil type and country region;

For technical reasons and regarding public health, facilities certification under the ANQIP Technical Specification ETA-0702 is highly recommended. This certification requires the preliminary assessment of the project by ANQIP as well as a continuous analysis of the project development.

2.6. Components of a Rooftop Rainwater Harvesting System

RHS is the direct collection of rainwater from purpose-built catchments, usually building rooftops. The systems can be categorized as small, medium and large scale generally based on the size of catchment area.

A RHS consists of six main elements (TWDB, 2005; Che-Ani et al., 2009):

(1) The catchment surface;
(2) A conveyance system – gutters and downspouts;
(3) Filtration system and first flush diverters;
(4) The storage facility;

(5) A delivery system – gravity fed or pumped to the end use;
(6) Treatment techniques

2.6.1. The Catchment Surface

The rooftop of a building or a house is the most common catchment area as they are already built and able to collect large volumes of rainwater. The quantity and quality of the harvested rainwater from a catchment surface is a function of the rain intensity, type of roof material, roof surface area and the surrounding environment (TWDB, 2005; The Schumacher Centre for Technology & Development, 2008).

There are several types of materials that can be used, yet roofs should be ideally built of chemically inert materials such as plastic, aluminium or fibreglass. Nevertheless, other materials are also considered suitable including slates, clay/concrete tiles and galvanised corrugated iron. It is also recommended that if paint is used, it should be non-toxic – no lead-based paints (Khoury-Nolde, n.d.).

- **Metal roofs**

The amount of rainwater collected not only varies with the size, but also with the texture of the roof: the smoother the better. Metal roofs in general have a smooth surface and a high runoff coefficient, where losses are negligible. Some cautions however should be taken into account regarding some materials. Copper roofs and roofs with lead components such as flashings and paints, are not recommended, especially if the harvested rainwater is to be used for potable purposes (TWDB, 2005; Virginia Rainwater Harvesting Manual, 2009).

A largely commercialized roofing material for RWH in Australia and also in the USA, is 55 % aluminium/45 % zinc allocated sheet steel named Galvalume® (TWDB, 2005).

- **Asphalt shingle**

Asphalt roofs are usually identified as an inappropriate catchment surface for potable systems due to leaching of toxins, such as lead and mercury (Metre & Mahler, 2003; TWDB, 2005). However, the composition of a specific asphalt roof vary widely from each location, and therefore, these surfaces can be used to collect water for irrigation. These roofs have an approximated runoff coefficient of 90% (Downey, 2009).

- **Clay/concrete tiles**

Clay and concrete tiles are suitable for potable or non-potable systems, and are easily available materials. Since both are semi-porous, the system's efficiency will decrease due to water loss by absorption or poor flow, which is around a 10 percent deficit. These porous materials are also susceptible to create an ideal habitat for algae and other microorganism's development. To prevent bacterial growth and reduce water loss, tiles should be painted or coated with a special sealant (TWDB, 2005).

- **Slate**

According to the TWDB (2005) "slate's smoothness makes it ideal for a catchment surface for potable use, assuming no toxic sealant is used". However, cost considerations are a barrier to its use.

- **Gravel**

These roofing materials are rare, and the water harvested is usually suitable only for irrigation due to leaching of compounds.

2.6.1.1. Roof Runoff

Not all the rain falling on a roof surface will be collected and conveyed to the storage system. Some water runoff will be lost mainly due to processes such as depression storage, and EV. Other factors that also contribute to water losses include the rainfall depth and intensity, the type of roof material and the roof slope (Roebuck, 2007). The "effective runoff" represents the amount of water that can be collected from a roof surface, whilst the "runoff losses" represent the water that cannot be collected. The most commonly used approach for estimating the effective runoff volume is the application of a dimensionless runoff coefficient which represents the observed losses from the catchment compared with an idealised catchment from which no losses occur (Fewkes, 2006).

- **Runoff Coefficient**

According to Fewkes (2006) the runoff coefficient represents the proportion of rainwater collected from an actual roof compared with an idealised roof from which no losses occur. The effective runoff volume is calculated by multiplying the volume of rain falling on the roof by the runoff coefficient.

Table 2 provides some examples of coefficients for a variety of different roof types. These data are based on specialized bibliography and on the long-term experience of these subject experts (Roebuck, 2007; Downey, 2009; Tomaz, 2009).

Table 2 - Runoff coefficients for different roof types (Source: Adapted from Roebuck, 2007).

		Range of Coefficients		
Reference	**Roof Type**	**High**	**Average**	**Low**
Dharmabalan (1989)	Roof tiles	0.9		0.8
	Corrugated sheets	0.9		0.7
	Plastic sheets	0.8		0.7
Fewkes & Warm (2000)	Pitched roof, slates	1		0.75
	Flat roof, impervious membrane	0.5		0
	Green roof, flat	0.5		0
Legget et al. (2001)	Pitched roof tiles	0.9		0.75
Liaw & Tsai (2004)	Iron and Cement roofs		0.82	
Tomaz (2009)	Glazed tiles	0.95		0.9
	Asbestos cement	0.9		0.8
	PVC	0.95		0.9
Downey (2009)	Asphalt		0.9	
	Metal		0.95	
	Concrete		0.9	
	Tar and Gravel	0.85		0.8

Note: coefficient of 0 = 0% runoff, coefficient of 1 = 100% runoff

- **Filter Coefficient**

The filter coefficient is given by the ratio between the total volume of rainwater that reaches the filter and the total volume of filtered rainwater that hits the tank. Therefore, the losses during the filtration process reflect the volume of water that is usually discharged to the wastewater or rainwater sewage systems. A typical and accepted value for the filter coefficient is 0.9, which means that 90% of rainfall is collected (Ashley & Roebuck, n.d.); Balmoral Tanks, 2008).

2.6.2. Conveyance System

A conveyance system, consisting of gutters and downspouts, is required to transfer the rainwater from the roof catchment area to the storage system.

Gutters are usually installed along the building just below the roof and capture the water as it falls from the roof, conveying it to the downspouts. It is very important that the gutters are installed with the appropriate slope towards the downspout, in order to avoid water accumulation in a specific section which can lead to algae growth and mosquito breeding. Still & Thomas (2002) recommend a dual-slope gutter (with a slope in the region of 0.5% for 2/3 of its length, 1.0% for the remaining 1/3 of its length) and that the inside edge of the gutter should be 20 mm inside the roof edge, regardless the roof shape. Their findings support that roof area is the primary determinant of gutter size. They also suggest a trapezoidal or semi-circular gutter shape (Figure 12) for optimal interception and conveyance. Semi-circular or trapezoidal shapes are recommended because they are able to drain a larger roof area, hence contributing to a more efficient drainage system. The down pipes usually present an inferior cross section, and are connected to the guttering system through drop outlet which generally consists in a 45-degree "elbow" that allows the downspout pipe to snug to the side of the house or building (TWDB, 2005).

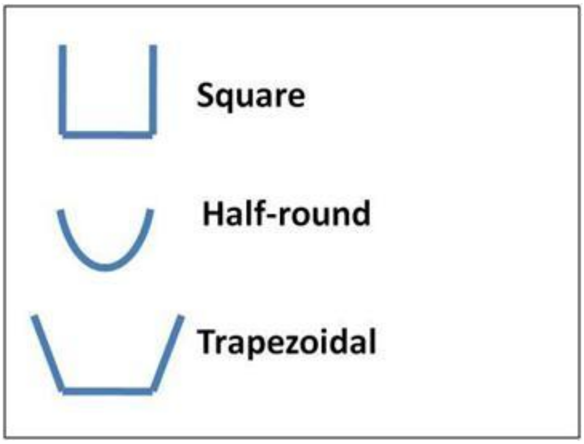

Figure 12 - Common gutter shapes (Source: Virginia Rainwater Harvesting Manual, 2009).

The gutter system should be regularly inspected and cleaned, in order to minimize water contamination and to ensure that water moves freely through the conveyance system. According to the Virginia Rainwater Harvesting Manual (2009) "installing covered gutters or adding guards to existing gutters is ideal to prevent debris build-up and clogging" (Figure 13). Mesh screens are mostly used in locations with tree overhang.

Figure 13 - Gutter guard (Source: GutterSupply Company)

Materials suitable for the pipework are polyvinyl chloride (PVC), galvanized steel and the more expensive seamless aluminium. Once again, it is recommended that lead flashings shouldn't be used, in order to avoid water contamination (TWDB, 2005).

2.6.3. Pre-Tank Filtration and First-Flush Diversion

- **Pre-tank filters**

The inclusion of filter screens in a RHS is another protective mechanism of water quality by keeping debris out of the storage system. Nowadays, an advanced filter does not restrict the diameter of the gutter, being usually installed in the downspouts. It can also be connected along the gutter system (Virginia Rainwater Harvesting Manual, 2009).

Pre-tank filter design is very relevant since, if leaves are allowed to accumulate on the screen or mesh, water quality will be impaired. If organic debris enters the storage cistern, a succession of events will certainly occur, culminating in the reduction of oxygen levels and consequent bacterial growth. According to the Virginia Rainwater Harvesting Manual (2009), the best filter device should be self-cleaning and self-drying between rainfall events to prevent biofilm growth, which would block the pores. The best material is considered to be stainless steel, since it can stand up to all weather conditions, maintain shape and does not rust, therefore reducing contamination likelihood.

The German company 3P Technik is today in the front line of filter manufacturing and other innovative developments for RWH. Among several alternatives, the volume filter VF1 (Figure 14) with or without telescopic extension, has been widely commercialized throughout Germany and also other countries (Dierkes, 2009).

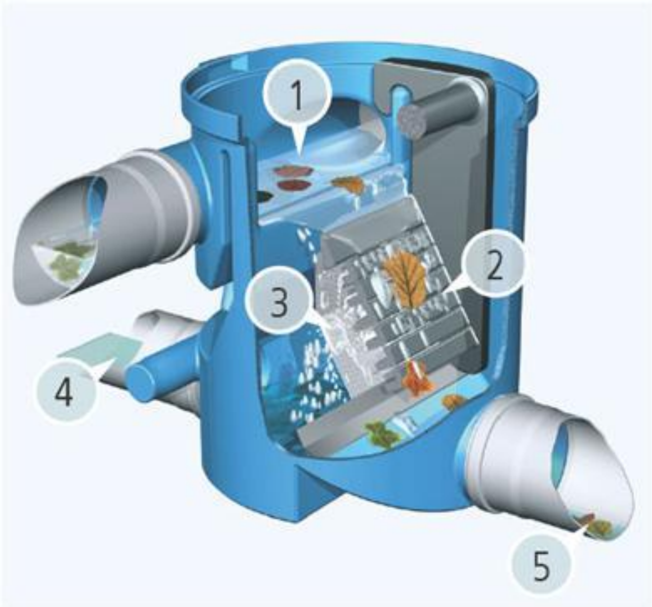

Figure 14 - VF1 filter (Source: 3P Technik)

The water coming from the downspout(s) enters the filter and is equally distributed across the cascade filtration (1). The larger residues (leaves) are led across the primary filter cascades directly to the sewer (2). The cleaner water then flows through a secondary filter sieve, with pores of 0.65 millimetres (mm) (3). The cleaned water then flows into the next system component, eventually a first-flush diverter or the storage tank (4), and the filtered dirt flows to the sewer (5) (3P Technik, n.d.).

An important feature related to the secondary filter's mesh structure is that dirt is continuously cleaned away into the sewer due to the steep inclination of the filter cartridge. Thus, VF1 filter requires very low maintenance and needs to be cleaned only 1 to 2 times per year. This filter type has a connection capacity for roof areas up to 350 m^2, according to DIN 1986 (3P Technik, n.d.).

- **First-Flush Devices**

A rooftop collects and accumulates dirt, dust, animal faeces, dead animals, airborne residues and other debris, especially during dry periods. When it rains, water will slowly capture all the sediment present in the roof, all of which are undesirable elements to have in a water harvesting system.

The first flush phenomenon is the initial surface runoff of a rainstorm which is likely to contain all kinds of microbial and physico-chemical pollutants. First flush diversion of initial runoff is a simple precautionary measure which will prevent highly contaminated water from entering the storage tank, improving significantly the quality of collected rainwater. The flushed water, depending on its quality, can be routed to a planted area or be used for other purposes such as cleaning, washing, etc. (TWDB, 2005; Mosley, 2005).

In the first minutes of a rain event the contaminant concentrations in roof runoff are expected to be extremely high, decreasing later on towards a constant level. However, not enough is known in order to identify exactly what constitutes a “first flush”. There are many variables that influence the determination of how much rain needs to be diverted to ensure clean and safe water. For example, the geographical parameters, the intensity of a rain event, the effects of weather patterns (dry period length between rain events), the properties of the catchment surfaces and the nature of the contaminants themselves, have great influence on the volume of rainwater to be discharged (TWDB, 2005; Meera & Ahammed, 2006).

Opinions vary on the amount of first flush water that needs to be diverted. Yaziz et al. (1989) for both types of roof catchments sited near the University of Agriculture campus in Serdang, reported that bypassing a volume of 5 L (0.5 mm), would be sufficient to prevent microbiological contamination by faecal coliforms. However, the presence of heavy metals, such as zinc and lead and, high levels of total coliforms and plate counts, suggests that caution is needed in selecting a suitable first-flush volume before rainwater harvesting. Kus et al. (2010) based on the analysis of roof runoff from an urban residential roof located in the Sydney metropolitan area, concluded that water with most water quality parameters compliant with the Australian Drinking Water Guidelines (ADWG) standards was generally obtainable by diverting the first 2 mm of rainfall. However, lead and turbidity did not comply, requiring diversion of approximately the first 5 mm of rainfall to meet ADWG standards. According to the TWDB (2005) the recommended volume ranges from 4 to 8 L (0.4 to 0.8 mm) of first-flush diversion for each 9 m^2 of collection area.

There are different types of first flush devices available worldwide. The most common and simple systems are (TWDB, 2005; Mosley, 2005):

(1) Down pipe first flush diverter: a PVC standpipe fills with the initial water runoff during a rainfall event. When the pipe becomes full, cleaner water will flow into

the main collecting pipework connected to the storage tank (Figure 15 and Figure 16). The first flush standpipe is drained continuously via a pinhole or by a tap left slightly open. Besides that, the same pipe usually has a cleanout fitting at the bottom, which must be emptied and cleaned after each rainfall event.

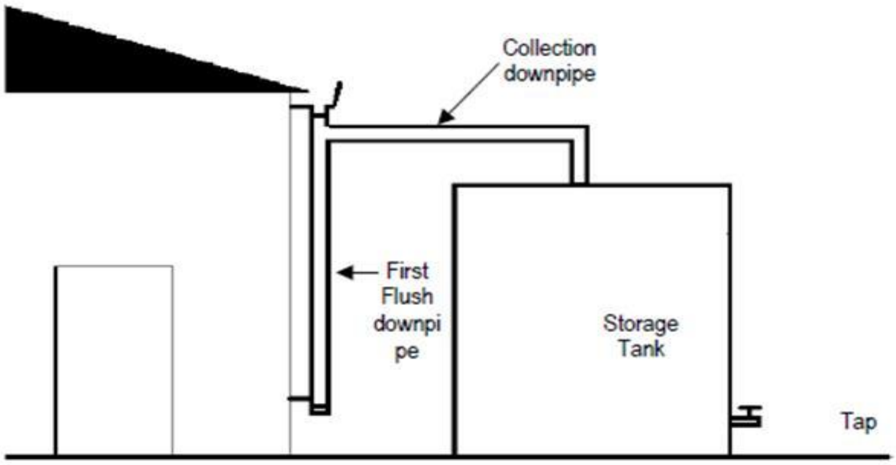

Figure 15 - Simple scheme of a dwelling's down pipe first flush diverter (Source: Mosley, 2005).

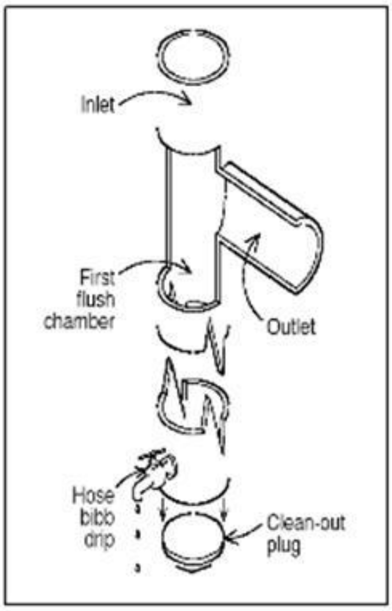

Figure 16 - Standpipe first flush diverter (Source: TWDB, 2005).

(2) Standpipe with ball valve: the ball valve type consists of a floating ball that floats up, as the chamber fills, and seals off the top of the diverter pipe (Figure 17) trapping first-flush water and routing the clean water to the tank.

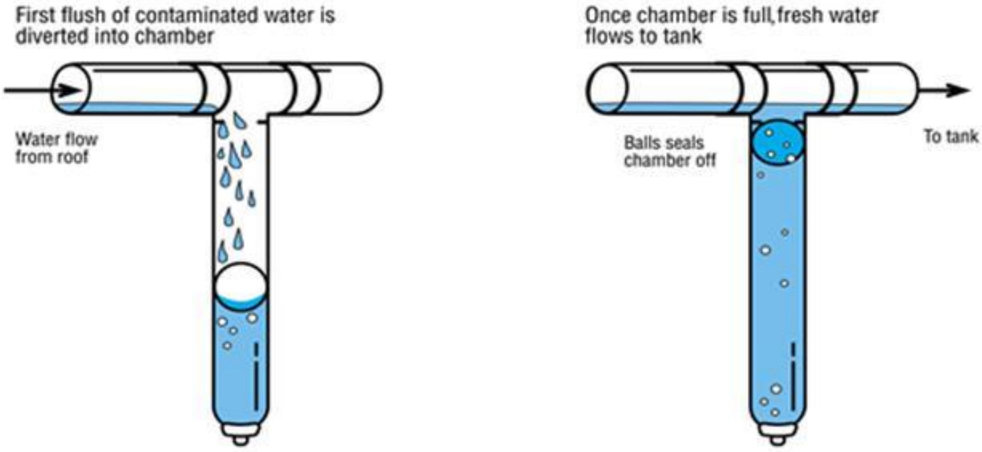

Figure 17 - Standpipe first flush diverter, with ball valve (Source: Rain Harvesting).

In Figure 18 the external appearance of a first flush system is presented. As it seen, the first flush chamber is routed directly to a flower garden.

Figure 18 - External appearance of a first flush diverter system (Source: Bailey Tanks, 2010).

2.6.4. Storage Tanks

The storage facility is considered to represent the biggest capital investment of a RHS (TWDB, 2005; The Schumacher Centre for Technology & Development, 2008; Virginia Rainwater Harvesting Manual, 2009). Therefore the tank must be carefully thought and designed, to provide optimal storage capacity according to the site location, while being economically feasible.

Some key considerations should be taken into account in every tank design (Khoury-Nolde, n.d.; TWDB, 2005; Virginia Rainwater Harvesting Manual, 2009):

- Storage tanks must be opaque, especially if located above ground, to prevent algae growth.
- Tanks must be covered to prevent environmental contamination and mosquito breeding.
- All tanks must include an adequate extraction system, a screened vent pipe, a calm rainwater inlet and an overflow device.
- The tanks should be placed in a site with appropriate support and foundations, since water has a considerable weight.
- Tanks must have an accessible manhole for cleaning and maintenance purposes.

According to the Virginia Rainwater Harvesting Manual (2009), tank selection is based on three main criteria: size, location and material. Size selection will affect tank location, and both together will determine the choice of tank materials.

2.6.4.1. Tank Sizing

The sizing of a storage tank is determined by correlating several variables (EnHealth Council, 2004; TWDB, 2005; The Schumacher Centre for Technology & Development, 2008; Virginia Rainwater Harvesting Manual, 2009):

- area of the catchment surface;
- local precipitation and weather patterns;
- volume of water needed (demand);
- maximum amount of rainwater collected (supply);
- availability of a backup water supply;
- availability of space on the site;
- budget;

There are a number of different methods used for tank sizing. These methods vary in complexity and sophistication and can be seen from two perspectives: the demand side approach or the supply side approach. Each of these approaches varies from manufacturer to manufacturer, country to country, region to region.

➢ Demand Side Approach

According to the Schumacher Centre for Technology & Development (2008), this simple method consists of the calculation of the largest storage requirement based on the building occupancy and consumption rates. As an example, the following typical data was used:

- ✓ Consumption per capita per day, C = 20 L
- ✓ Number of people per household, n = 6
- ✓ Longest average dry period = 25 days
- ✓ Daily consumption = C x n = 120 L
- ✓ Storage requirement, Total daily demand = 120 x 25 = 3,000 L

Which means that the tank volume required for this example would be 3 m^3. This method assumes sufficient rainfall and catchment area, and therefore should only be applied in areas where this is the situation. It is the simplest method available for rough estimates of tank size.

➢ Supply Side Approach

According to EnHealth Council (2004) the maximum volume of rainwater that can be collected can be calculated using the formula:

$$\text{Runoff } (m^3) = A \times (\text{rainfall} - B) \times \text{roof area}$$

Where:

- ❖ "A" is the efficiency of collection. Values between 0.8–0.85 (that is, 80–85% efficiency) have been used.
- ❖ "B" is the loss associated with absorption of surfaces and first flush diversion
- ❖ "Rainfall" should be expressed in m and 'roof area' in m^2.

The Schumacher Centre for Technology & Development (2008) method is quite similar to the previous, but instead of applying a collection efficiency value, it uses a runoff coefficient which depends on roof material and slope. The volume of collected rainwater is calculated through the formula:

$$\text{Total Rainwater } (m^3) = \text{roof area} \times \text{rainfall} \times \text{runoff coefficient}$$

Where:

- “Rainfall” is expressed in m and “roof area” in m^2.
- “Runoff coefficient” values vary widely, according to the roofing material. It may also take into consideration losses due to percolation, EV, etc.

  - <u>Average Rainfall</u>

In areas where rainfall has a non-uniform distribution, more care is needed in the design of the storage tank. During certain periods of the year, when there is a deficit of rainwater, either the tank is big enough to collect all the water during rainfall events needed to meet demand during dry seasons, or the tank shall be connected to a public water supply system. In general, the average rainfall (daily and monthly) value is used to estimate the total volume of collected rainwater (enHealth Council, 2004). However, according to the Virginia Rainwater Harvesting Manual (2009), “using monthly averages of rainfall can lead to significant errors in tank sizing”. This ideology is based on the following principle: imagine 2 cities where each receives 100 mm of rain per month. If city A has only one heavy rain event per month, the tank must have the size to collect all 100 mm at the same time. If city B has many small rain events distributed throughout the month, only a small storage tank will be needed.

In Portugal, the most accurate source of daily rainfall data can be obtained from the Sistema Nacional de Informação de Recursos Hídricos (SNIRH – Water Resources National Information System) from Water Institute.

2.6.4.2. Tank Location

Tank location is dependent on its size, aesthetics, space available, climate and soil conditions. They can be installed below ground, partly underground or above ground, preferably located close to supply and demand points to reduce the distance of pipework as well as pump requirements. In compliance with the Virginia Rainwater Harvesting Manual (2009), although there is no governmental law or rule, for storage volumes exceeding 40 m^3 or if multiple downspouts or roof drains are being used, the most viable option is underground storage. A below-ground storage vessel is unobtrusive, protected from direct sunlight and the water is kept cooler. Figure 19 shows a typical example of an underground storage tank. However, some inconveniences arise such as the increase in installation and construction costs, especially if the soil is hard and rocky, or if the site's groundwater level is high. Also, to avoid water contamination it is recommended that the tanks should be located at least 15 m away from potential sources of pollution such as animal stables or septic tank systems (TWDB, 2005). Needless to say that underground tanks are of much more difficult maintenance.

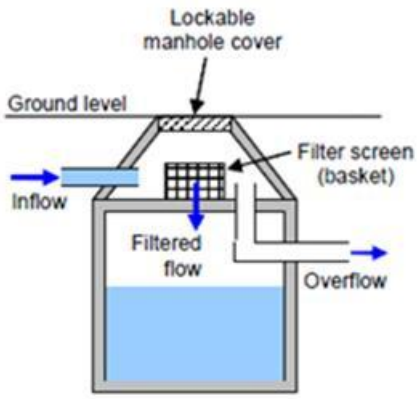

Figure 19 - Complete underground storage tank (Source: Roebuck, 2007 in König, 2001).

2.6.4.3. Tank Materials

- **Metal**

Galvanised steel is an attractive, widely used material for construction of rainwater tanks. These tanks are lightweight, easy to relocate and available in variety of sizes, from 570 L to 9,460 L (TWDB, 2005). Metal tanks, from the outset, are not resistant to corrosion and are likely to leach some metals which may cause water contamination, making it unsuitable for potable purposes. To avoid such nuisance, metal tanks should be lined with rust-resistant coatings such as Zincalume® or Aquaplate® (enHealth Council, 2004) or with a food-grade liner, usually polyethylene or PVC (TWDB, 2005).

These types of tanks can only be installed above ground (Virginia Rainwater Harvesting Manual, 2009). New metal tanks should always be flushed before use, due to the probable leaching of contaminants which may affect water quality. Other precautions should be considered when Aquaplate® coatings are applied (enHealth Council, 2004).

Tanks must be covered at all times, because the coating is not resistant to prolonged exposure to sunlight;

When cleaning or installing the tank, the coating must not be damaged. If so, it should be immediately repaired or replaced.

- **Concrete**

Concrete tanks are either poured in place or prefabricated, and may be installed above ground or below ground. They are strong and very durable, and likely to keep water cool in hotter climates. A big advantage over other tank materials is that concrete neutralizes the acidity of harvested rainwater, providing at the same time a desirable flavour imparted to the water from the calcium in the concrete, dissolved by the slightly acidic rainwater (TWDB, 2005).

Concrete tanks are expensive to build and difficult to maintain. They are likely to crack and leak, especially if constructed below ground in clay soil (Virginia Rainwater Harvesting Manual, 2009). To avoid these problems a structural engineer should be involved during installation of a poured-in-place concrete cistern, to determine accurately the size and spacing of reinforcing steel to match the structural loads of the tank.

- **Polyethylene and Polypropylene**

Commercially available plastic tanks are increasing in a wide variety of sizes and low prices. They are durable, lightweight, easy to install and easy to relocate if necessary. They are usually placed above ground nonetheless, specially reinforced tanks, in order to tolerate soil expansion and contraction, can be installed underground (TWDB, 2005).

Plastic tanks should be constructed with opaque plastic to inhibit algae growth. The tanks should also be coated or painted with materials of food-grade standard, to prevent ultraviolet (UV) degradation (Virginia Rainwater Harvesting Manual, 2009).

- **Fibreglass**

Fibreglass tanks are also available in a wide variety of sizes, however, for capacities under 379 L, the tanks are considered expensive so polypropylene cisterns are recommended. They are manufactured with a food-grade coating on their interior surface and should also be opaque, to prevent algae proliferation. These types of tanks are highly durable, lightweight and require low maintenance. One of its main features is that the fittings are an integral part of the tank, eliminating the potential problem of leaking (TWDB, 2005).

2.6.4.4. Tank Installation

Rainwater tanks must be properly installed to prevent damage and to minimise risk of contamination. Below-ground tanks must be accurately sealed, especially in the access points, to avoid infiltrations from underground water or surface run-off. Above-ground tanks should be installed on a stable, level soil or pad and underground tanks must be designed to support the weight of the soil above (Virginia Rainwater Harvesting Manual, 2009).

All tanks should have a few accessories that will enhance their performance and the quality of water supplied: a screened vent pipe, to expel air as rainwater enters the tank and draw air in as rainwater is pumped out of the tank; a rainwater inlet; an overflow device; and a backup water supply.

- **Rainwater Inlet to the Tank**

Calming rainwater inlets in the pipeline access to the reservoir is a very important mechanism to maintain quality of the stored water. This device will direct the entering water upwards to prevent the stirring up of the sediment layer that usually settles on the bottom of the tank (Figure 20). The gadget also supplies the lower part of the tank with oxygen, preventing the occurrence of an anaerobic process in stagnant water.

Figure 20 - Calmed inlet for rainwater storage tanks (Source: 3P Technik).

The sediment layer at the bottom of a rainwater tank is often known as biofilm. Biofilms are layers of bacteria bind by chains of polymer matrices, usually carbohydrates, which offer protection for their development based on symbiotic relationships, enabling their survival in hostile environments. Coombes et al. (2006) proposed that the formation of biofilms contribute to improving water quality on a storage system. Their observations reveal that typical soil and environmental bacteria such as *Bacillus Spp.* are likely to form biofilms in rainwater tanks. They conclude that the processes of formation of biofilms remove bacteria and heavy metals from the tank water.

To protect the biofilm and ensure high water quality, cleaning the rainwater storage tank should be avoided at all times, as long as the other components of the RHS are functioning properly. Any disturbance of the system could be harmful to the bacteria. This is particularly worrying if the backup water supply has to be activated, since the treatment chemicals present in the water are likely to kill the biofilm layer. The backup water should instead bypass the tank through solenoid valves and appropriate backflow prevention (Virginia Rainwater Harvesting Manual, 2009).

- **Overflow Device**

The storage tanks should have an overflow device adapted to the inlet pipe to prevent water backup in the downspouts and to promote the best possible water quality. Even with proper pre-tank filtration and first-flush devices, small debris, such as pollen, are likely to enter the tank. These particles are expected to float at water surface, since they are lighter than water (Virginia Rainwater Harvesting Manual, 2009).

As illustrated in Figure 21, as the tank water level rises, the floating debris will be skimmed off by the siphon inlet into the sewer or to an infiltration soak away (3P Technik, n.d.). The surplus runoff with the debris should be directed to a pervious area (garden) or to a storm drainage system.

Figure 21 - Overflow siphon with skimming effect on tank water surface from chamfered inlet slots

(Source: 3P Technik).

As the tank water level rises, the water flows over the skimmer siphon inlet into the sewer or to an infiltration soakaway. Any floating materials are skimmed off via the chamfered slots. The surplus water with the pollen is led out of the rainwater tank (outlet 110 mm).

- **Backup Water Supply**

As a preventive measure, a RHS should always have an independent connection to the municipal water supplies. Since rain is an irregular event, there's always the possibility of rainwater shortage. Therefore, the storage tanks can be partially filled with potable water, as a backup for the system water needs.

These systems are required to incorporate in its design a backflow device inside the potable water pipe connected to the tank, in order to prevent contamination of the public water supply by the harvested rainwater. It is also recommended that the municipal water inlet should be installed above the highest possible rainwater level, to ensure cross contamination does not occur (Virginia Rainwater Harvesting Manual, 2009).

This system is activated by several means. The most applied is based on floating switches and activation valves. If the stored rainwater reaches a certain level too low, a floating switch will be activated shutting off the RWH pump and activating a valve which enables water to flow from the backup source. Another conjecture is based on a pressure differential system. According to this concept, the RHS operates at a higher pressure than the backup source. When the water level in the tank becomes low, the rainwater pump cuts off. Therefore, the higher pressure water no longer retains lower pressure water from the backup source allowing it to flow to the final purpose of the RHS. Figure 22 illustrates how a pressure differential backup water supply system could be constructed (Virginia Rainwater Harvesting Manual, 2009).

In these configurations is also important to assure that the piping systems can be distinguished through different colours. It is known that the colour purple is often used to designate non-potable water piping, particularly wastewater. However, Portuguese technical specifications do not establish a mandatory colour to designate rainwater piping. Therefore it should be of the responsibility of the system designer to properly identify rainwater piping systems.

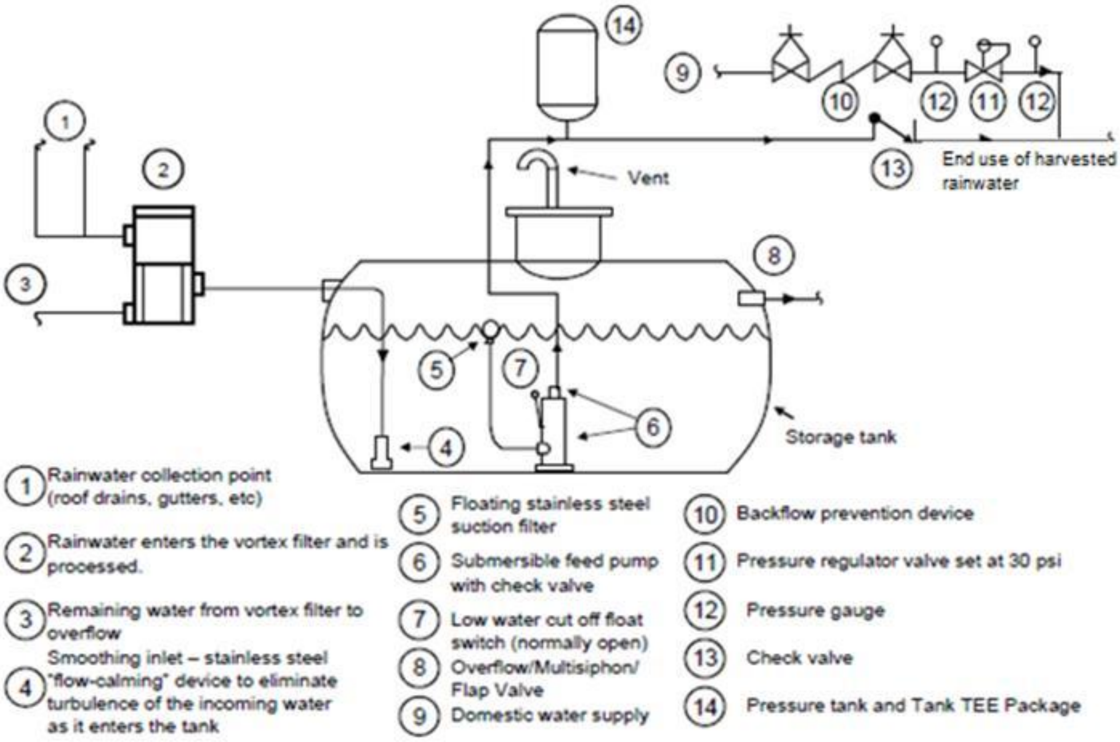

Figure 22 - Below ground tank with submersible pump and pressure difference municipal backup with check valve (Source: adapted from RMS)

2.6.5. Pressure Tanks and Pumps

Pump systems and pressure tanks are responsible for the distribution of water, from the storage tank to the end use, with the required pressures and necessary amounts. This can be accomplished by the use of some applications: a submersible pump, a booster/jet pumps or a combination of pumps, according to the requirements of each project (Virginia Rainwater Harvesting Manual, 2009).

- **Submersible Pumps**

These pumps lodge in the bottom of the tank, where they are supposed to draw water from. However, as mentioned before, a layer of sediments and bacteria usually settle to the bottom of the tank and the surface of the water is often charged with a film of grease and floating debris. Therefore, in order to aspirate the cleanest water of the rainwater tank, the submersible pump is fitted with a floating pump intake with a hose (Figure 23) (Virginia Rainwater Harvesting Manual, 2009). The floating ball will protect the pump from sucking up sediment, increasing the safety of every rainwater installation.

Figure 23 - Submersible Pump with floating pump intake (Source: 3P Technik).

- **Booster/Jet Pumps**

These pumps operate by lifting the water out of the tank and pushing it to the desired location. Once they are external, they are louder than submersible pumps and should also be protected from the weather (Virginia Rainwater Harvesting Manual, 2009).

- **Pump Combinations – Pump/Pressure Tank**

Pump combinations are generally necessary when the distance from the cistern to the end use is significant. One typical combination is the pump-and-pressure tank arrangement Pump combinations are generally necessary when the distance from the cistern to the end use is significant. One typical combination is the pump-and-pressure tank arrangement (TWDB, 2005). The pump system will draw the water, pressurize it and store it in a pressure tank until needed. It is very important to include a check valve and a pressure switch in this configuration, especially if more than one pump is being used. A one way check valve between the tank and the pump prevents pressurized water from being returned to the tank. The pressure switch regulates operation of the pressure tank. If two or more pumps are being used, the pressure switch will determine which pump will run to meet the demand, drawing more water into the pressure tank. The pressure tank maintains pressure throughout the system and its size is essential to ensure that the system operates efficiently and effectively. In compliance with the TWDB (2005), the pressure tank has a typical capacity of 150 L.

- **On-demand Pump**

This configuration combines in the same unit, a pump, a motor, a controller, a check valve and a pressure tank. The on-demand pumps are designed to activate in response to a demand, eliminating the need, cost, and space of a pressure tank. These systems can be specifically designed to be used with rainwater and, in addition, may incorporate a 5-micron fibre filter, a 3-micron activated charcoal filter and an UV lamp, for the necessary treatment purposes (Figure 24) (TWDB, 2005).

Figure 24 - Typical on-demand system for rainwater, incorporated with an integrated treatment device (Source: TWDB, 2005).

- **Floating Filters**

This device is similar to the floating pump intake, usually attached to the Submersible pumps. The main difference is that the water is being filtered as it is drawn from the storage tank. The filter is usually designed using an adequate pore size to prevent clogging (Virginia Rainwater Harvesting Manual, 2009). The floating ball will certify that the suction basket of the floating pump intake is always situated approximately 15 to 20 cm below the water surface (Figure 25) (3P Technik, n.d.).

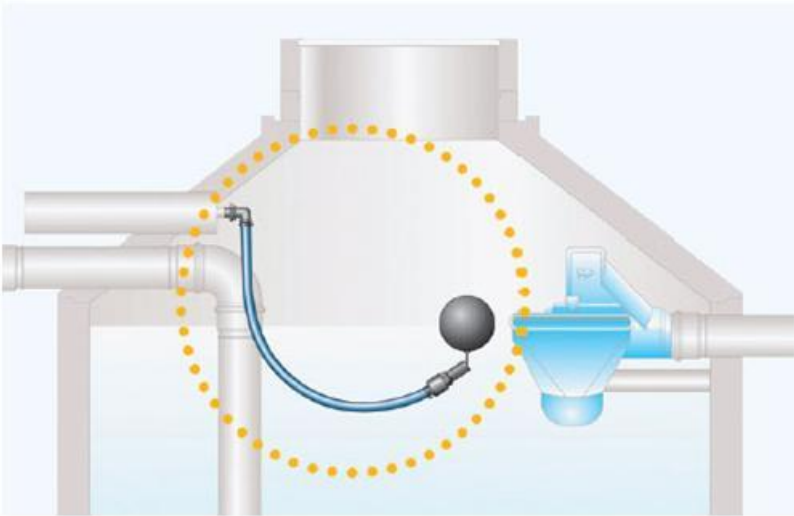

Figure 25 - Floating filter with pump intake (Source: 3P Technik).

2.6.6. Water Treatment

Water quality is highly dependent on the appropriate design and maintenance strategies of the RHS. These strategies range from the elementary practice such as the regular cleaning of the catchment surfaces and storage tanks, to more elaborate methods of treatment such as chlorination and UV light disinfection.

If the water is to be used for drinking purposes or cooking, it requires the necessary treatment methods available for the individual country, to secure the fully potable standards. However, if the water is for non-potable uses it is expected that the quality requirements will be lower than those for human consumption, and therefore treatment recommendations will be less stringent. But one certainty exists: suspended solids and bacterial microorganisms will be present in harvested rainwater and therefore, some form of treatment of the harvested rainwater is necessary, and the level of treatment will be in accordance to its final use. Table 3 provides an example of minimum water quality guidelines and suggested treatment methods for collected rainwater.

Table 3 - Minimum Water Quality Guidelines and Treatment Options for Harvested Rainwater (Source: Kloss, 2008)

Use	Minimum Water Quality Guidelines	Suggested Treatment Options
Potable indoor uses	Total coliforms – 0 Fecal coliforms – 0 Protozoan cysts – 0 Viruses – 0 Turbidity < 1 NTU	1 - Pre-filtration – first flush diverter 2 - Cartridge filtration – 3 micron sediment filter followed by 3 micron activated carbon filter 3 - Disinfection – chlorine residual of 0.2 ppm or UV disinfection
Non-potable indoor uses	Total coliforms < 500 cfu per 100 mL Fecal coliforms < 100 cfu per 100 mL	1 - Pre-filtration – first flush diverter 2 - Cartridge filtration – 5 micron sediment filter 3 - Disinfection – chlorination with household bleach or UV disinfection
Outdoor uses	N/A	Pre-filtration – first flush diverter

2.6.6.1. Filtration

- **Sediment Filtration**

Sediment filtration removes small particles and associated contaminants that haven't settled in the bottom of the tank. This preventive measure will increase the effectiveness of disinfection. According to the Environmental Protection Agency (EPA) guidelines, for non-potable indoor uses, sediment filters should be 5 micron or finer. For potable indoor uses, sediment filters should be 3 micron or smaller (Kloss, 2008).

- **Carbon Filtration**

Filtration by activated carbon is very effective at removal of organic compounds, such as pesticides and some hydrocarbons. Therefore, this technique is highly recommended in treating water for potable uses. It also improves aesthetic quality of water (i.e. odour and taste). An activated carbon filter of 3 micron or smaller should be placed after the sediment filter (Kloss, 2008).

2.6.6.2. Disinfection

- **Chlorination**

Chlorination is a simple and economic method, once it is the most frequent process used to disinfect public drinking water. The most usual forms of chlorine are liquid sodium hypochlorite (common bleach) and solid calcium hypochlorite (TWDB, 2005).

Table 4 presents chlorine contact times correlating water temperature with its pH value, consistent with TWDB (2005). As shown, chlorine dosing is less effective as pH levels increase.

Table 4 - Contact Time with Chlorine (Source: TWDB, 2005)

Water pH	**Water Temperature**		
	10 ºC or warmer	7 ºC	4 ºC or colder
		Contact time (min)	
6.0	3	4	5
6.5	4	5	6
7.0	8	10	12
7.5	12	15	18
8.0	16	20	24

As a security measure, it is recommended that chlorine should be carefully diluted in a plastic bucket already filled with water, before adding it to the storage cistern. If possible, the mixture should be spread evenly across the surface to maximize the blending. A period between 1 to 24 hours is suggested before using the water (enHealth Council, 2004; Mosley, 2005).

As stated by the enHealth Council (2004), “to achieve effective disinfection, it is necessary to add sufficient chlorine to provide a free chlorine residual of at least 0.5 mg/L after a contact time of 30 minutes”. This can be accomplished by measuring the chlorine residual through a swimming pool test kit. Yet, these values of chlorine contact time and concentrations vary according to tank volume and to type of bleach – each one has a different level of active ingredient (enHealth Council, 2004; Mosley, 2005).

This practice, however, is not considered appropriate in most cases and should only be applied in specific occasions as a remedial action. Besides giving an unpleasant smell and taste to water, its effectiveness is of short duration and will only act on the water stored at the time of dosing. Another drawback is that chlorine residuals react with decaying organic matter in water to form trihalomethanes, considered to be a very dangerous and carcinogenic by-product. Chlorine is effective against harmful bacteria and many viruses, but is limited in neutralizing *Giardia* or *Cryptosporidium*. To eliminate these microbial pathogens, it is necessary to implement a mechanism of micro-filtration (enHealth Council, 2004; TWDB, 2005).

- **UV Light**

UV radiation has always been a very common disinfection process in wastewater treatment plants, and nowadays is also widely used in potable water treatment. It is a very effective operation in exterminating or sterilizing all bacteria, virus, and cysts present in water, by exposure to UV light, providing a continuous assurance of water quality. Besides its powerful disinfecting ability, this practice has the advantage of not involving addition of chemicals and doesn't leave behind any disinfection by-products (enHealth Council, 2004; TWDB, 2005).

In the specific case of applying this method for harvested rainwater treatment, it is imperative that the water must go first through sediment filtration, once pathogens can be shadowed from the UV light by suspended particles in the water (TWDB, 2005). The UV light system may be installed in pipework delivering water from the storage cistern to a dwelling or to specific taps used to supply water for drinking and cooking purposes (enHealth Council, 2004).

The UV light setup requires relatively low maintenance. Nevertheless UV lamps have a limited effective life and need to be replaced after a period of nine to 12 months. It is also recommended the installation of a system incorporating a sensor which indicates when the device is or is not operational (enHealth Council, 2004).

- **Ozone**

Ozone acts as a powerful oxidizing agent to reduce colour, to eliminate foul odours, and to reduce total organic carbon in water. An ozone generator forces ozone into storage tanks through rings or a diffuser stone, where it will quickly react due to its strong instability (TWDB, 2005). For disinfection purposes, ozone is generally less effective at destruction of viruses but still highly effective in killing bacteria or protozoa (such as *Giardia*). Unlike chlorine, ozone does not leave a disinfectant residual in the treated water (Virginia Rainwater Harvesting Manual, 2009).

- **Reverse Osmosis**

Reverse osmosis works by forcing water under high pressure through a semi-permeable membrane, from an area of higher concentration of contaminants, to an area of lesser concentration of contaminants. This mechanism does not destroy or deactivate bacteria or viruses; it removes them by using a membrane with a pore size smaller than 0.0001 micron (Virginia Rainwater Harvesting Manual, 2009). This is however not a recommended method for rainwater treatment, once a considerable amount of water is lost during the process.

2.6.6.3. pH Treatment

As stated before (section 2.4), the pH of rainwater tends to be slightly acidic, which can cause some nuisances in the use of harvested rainwater. However, most problems related with pH can be easily corrected with low-cost, low-maintenance, but highly effective solutions.

Harvested rainwater pH should be always tested before use. Home testing kits are available at low prices or samples can be taken to state-certified laboratories. In accordance with the EPA and the National Standards Foundation (NSF) recommendations, water pH should be above 6.5, especially when dealing with metal plumbing systems. If the pH value is inferior to 6.5, treatment solutions should be considered.

Frequently used techniques are based on the addition of neutralizing agents, such as pieces of limestone rock, to the storing tank. Other common neutralizing agents and their dose per 4 m^3 of water are as follows (Virginia Rainwater Harvesting Manual, 2009):

- Limestone: 60 grams;
- Quicklime: 30 grams;
- Hydrated lime: 30 grams;
- Soda ash: 30 grams;
- Caustic soda: 45 grams;

Another recommended solution to address this problem is to use a storing system made of concrete. The addition of limestone to concrete reservoirs will help neutralize the acid with no maintenance required (Younos, T.M. Et al., 1998 *in* Virginia Rainwater Harvesting Manual, 2009).

3. Case Study: Rainwater Harvesting for FCT/UNL Campus Irrigation

3.1. Goals

The main goal of this case study is to assess the feasibility of collecting and using rainwater for irrigation of green areas in the FCT-UNL campus. Primarily there will be an overview of the university campus, as well as a thorough characterization of the existing irrigation system in operation. By gathering all the necessary information, a characterization of supply and demand will be carried out, as well as the existing limitations on the effective capture of rainwater. According to the constraints encountered, various scenarios of water balance will be presented in order to find the best solution for the desired application. For such, an optimal sizing of the reservoir must be achieved, as well as the complete analysis of all the available information, in order to assess the environmental, technical and economical components of this project and thus, determine its viability.

3.2. Methodology

The followed methodology in preparing this case study was based primarily on gathering information on six key variables: Rainfall Data, Determination of Irrigation Water Consumption, Water Demand, Determination of Green Areas with Active and Inactive Irrigation, Determination of the Roof Areas and Roofing Material.

3.2.1. Rainfall Data

The rainfall information must be collected from the closest weather station to the site under consideration and with the longest data extension possible, in order to reflect local climatic variations. To promote the system simulation process for probabilistic study, the longer the record length, the more reliable the results will be.

For this case study the data are initially collected from the Meteorological Station of Monte da Caparica. The reporting period is 25 years (series of daily precipitation), from which weekly series of precipitation data will be used to compute the balance of rainwater inflow volumes and the consumption of irrigation water (total of 1301 weeks). In spite of the fact that daily rainfall series would produce results of greater reliability it would require a very extensive data set, while using weekly precipitation series, the data set will be less extensive but still very significant and with the desired reliability, appropriate for display of long-term trend.

Despite being the closest station to the FCT, there are several gaps in available data between 1985 and 2009. Thus, these breaches were filled primarily with data from the Meteorological Station of Alcochete, since it is the second closest to the study area, and also with data from a rain sensor of the FCT, in existence since 2002, and with the data from Meteorological Station of Vila Nogueira de Azeitão.

All data from the meteorological stations were collected through the website of the SNIRH.

3.2.2. Determination of Irrigation Water Consumption

Since there are no meters for water consumed in irrigation, the determination of annual expenditures was made empirically through a field survey, which identifies all the existing irrigation equipment operating in the various sectors of the FCT Campus. Once all the equipment was identified, the water flow of each unit was determined as well as its weekly operating period. For this to be achieved, the collaboration of the gardening team of FCT was crucial. In section 3.3.2 a detailed characterization of the existing irrigation system on campus is provided.

3.2.3. Water Demand

Water demand determines the amount of water needed for irrigation and consequently the storage requirements. The water demand over the year is not constant; therefore it is necessary to assess the monthly distribution rate of water requisites for green spaces irrigation.

3.2.4. Determination of Green Areas with Active and Inactive Irrigation

The identification of all green areas that exist in the campus was made by direct measurement of the same, from the existing drawings in AutoCAD format (Annex II) provided by the Rectory of the UNL and by the heads of the Projecto Campus Verde (PCV – Green Campus Project). However, since the available documents date back to 2004, some green areas had not yet been considered to integrate the mentioned drawings. Therefore, the missing areas were measured using the measuring tool provided by Google Maps.

3.2.5. Determination of the Roof Areas

The determination of roof areas of the several buildings included in the FCT Campus was performed through AutoCAD drawings (Annex III), using the measurement tool provided by this software. The drawings in question were provided by the heads of the PCV.

3.2.6. Roofing Material

This variable is very important since it will influence the rainwater runoff and thus, the amount of water that can be potentially collected and conveyed to the storage tank. This information was gathered through a direct field survey, with support from the Security Office on FCT Campus.

3.2.7. Determination of Reservoir Capacity

3.2.6.1. Rippl Method

The most commonly used method for tank dimensioning in rainwater harvesting, is the Rippl Method. It consists on the calculation of a storage volume required to ensure a regular flow during the most critical period of drought observed. It usually considers monthly series of precipitation data, with the most possible extension. In this particular case, weekly series of precipitation data will be applied (Annecchini, 2005; Tomaz, 2009).

For this method, the affluence inflow is deducted from the water demand flow, for the same time period. The maximum positive accumulated difference corresponds to the volume of the reservoir (Pereira et al., 2010). By this method, the tank usually presents an oversized volume, since it is dimensioned to meet demand during the most critical dry periods.

To accomplish the rainwater tank dimensioning by the Rippl Method, an Excel spreadsheet was used, which was based on collecting all the necessary data (Figure 26).

	A	B	C	D	E	F	G
1	C1	C2	C3	C4	C5	C6	C7
2	Week	Precipitation (m)	Catchment Area (m2)	Total Water Inflow (supply) (m3)	Total Water Demand (m3)	Demand - Supply (m3)	Acumulated Storage (m3)
3	1						
4	2						
5	3						
6	4						
7	5						
8	...						
9	1301						

Figure 26 - Data required for rainwater tank dimensioning by the Rippl method.

- Column 1 – Reporting period time in weeks (1301 weeks).
- Column 2 – Weekly precipitation data.
- Column 3 – Total catchment area (roofs area).
- Column 4 – Total water inflow collected by the system. It is obtained multiplying C2 by C3 and by the runoff coefficient related to each roof surface (see section 2.6.1.1).
- Column 5 – Weekly water demand for irrigation, which varies according to the month.
- Column 6 – Difference between water demand and water inflow.
- Column 7 – Accumulated sum of the values obtained in C6. The maximum positive accumulated difference corresponds to the volume of the reservoir.

3.3. FCT-UNL Presentation

3.3.1. General Description of the University Campus

The FCT University Campus, created in 1977, is located in Monte da Caparica, Almada, and is one of nine units of the UNL. Currently with an area of 30 ha, with capacity for expansion up to 60 ha, the FCT is attended by about 7500 students, of whom about 1,400 are graduate students (master's and doctorates) (Faculdade de Ciências e Tecnologia - Universidade Nova de Lisboa, 2010).

The urbanization plan of the campus has three poles of development: the university centre run by the rectory of FCT and UNL, the area of university residences managed by the UNL Social Services and the Almada - Setúbal Science and Technology Park (Madan Park) (Calado & Fouto, 2000).

Currently, through its 14 departmental sectors, 18 research centres and its 8 support services, in addition to the teaching and research activities, FCT-UNL provides assistance to public and private entities in their areas of expertise. Figure 27 shows a picture of the FCT campus locating all buildings.

Figure 27 - Aerial view of the FCT University campus (Adapted from: www.fct.unl.pt).

3.3.1.1. Rainwater Drainage

The sewerage and domestic water drainage systems were built in phases, as the campus was expanding. The first phase consisted on the implementation of networks of Buildings I, II, former sports complex, canteen and Hangars I, II, III and IV. Then the networks of Buildings III, IV, VI and Departmental Building (DB), Environmental Excellence Centre and the Grand Auditorium were the next to be built. Over the past ten years the campus has grown to the south sector with the construction of Buildings VII, VIII, IX and X, with the New Library being the last structure to be elevated.

The water drainage system of the FCT is presented in Annex IV. According to Faustino (2008) two collectors of concrete, a 600 mm and a 700 mm (in the south zone), for rainwater, depart from the campus of Monte da Caparica. However, this map is quite outdated concerning to the final layout of the collectors, to some connections between branches and to some piping diameters. This is mainly due to the construction of new buildings in the southern part of the university, which altered the topography and infrastructure of the campus (Faustino, 2008).

The buildings VII, VIII, IX and X and the DB were designed to drain rainwater directly from their roofs into existing storm sewers located below ground. Thus, once the infrastructure is already installed, it will be of outmost importance to identify the precise location of the connection points of these buildings' storm sewers to the main stormwater collector, since it is precisely in those points that the harvested rainwater from each roof must be intercepted, in order to be conveyed to the storing system, yet to be built.

As stated by Faustino, in 2005 a complete survey was conducted of the water supply network of the campus. Annex V is referred to the mentioned survey, where the existence of two connection points to the municipal supply can be verified. Point A is located on the north ring road between the Grand Auditorium and the New Library buildings and point B is located in front of the main entrance gate of the campus.

An exhaustive survey was held of the domestic wastewater and rainwater networks from the entire campus in late 2007 under the coordination of the Divisão de Logística e Conservação (DLC – Division of Logistics and Conservation). However, this information is still being compiled and it's not yet available for consulting.

3.3.2. Characterization of the FCT Irrigation System

Primarily, this case study was designed with the purpose of rainwater harvesting for toilet flushing, since this domain represents a large share of consumption of potable water in housing and offices. However, a project of this dimension involves a high initial investment, determined by the need to build a dual network of mains water supply – one for potable water and the other for rainwater. It only becomes economically interesting in projects build from scratch and, therefore, it was decided to go with other perspective.

The scenario under study will be rainwater harvesting for irrigation of the campus green areas, with the aim of presenting viable solutions to reduce consumption of potable water from the mains water supply.

Annex II shows the map of the green areas on campus. This map has been amended in accordance with existing green sectors of the Campus. Through this map, both active and inactive watering areas were estimated, as shown in Table 5.

Table 5 - Active and inactive irrigation areas of FCT.

	Area (m^2)	Area(ha)
Active Irrigation Sectors	11 210	1.1
Inactive Irrigation Sectors	11 760	1.2
Total	22 970	2.3

Recently, an exhaustive survey was conducted of all the campus irrigation sectors and the equipment associated with each sector – about 37. Through this field survey it was possible to identify all the equipment in automatic and manual operation, as well as the zones with active and inactive watering. Only then, since there is no water meters associated with irrigation, was it possible to estimate the weekly flow rate of water consumed in this process. In Table 6, all the equipments operating on campus, as well as all the associated features, are presented:

Table 6 - Operating Watering Equipments in FCT Campus.

Equipment	Brand	Series	Nº	Watering Frequency (min/week)	Flow Rate (m^3/min)	Total Water Flow (m^3/week)
Sprinkler	**Rainbird**	T-bird (T-22)	2	140	0.005	1.4
		T-bird (T-30)	10	140	0.005	7.0
		T-bird (T-30)	3	180	0.005	2.7
		T-bird (T-40)	13	140	0.007	12.1
		5000 +	41	140	0.012	67.0
		5000 +	38	180	0.012	79.8
		5000 +	21	210	0.012	51.5
		Maxipaw	5	140	0.008	5.8
		Maxipaw	4	180	0.008	6.0
	Toro	Super 800	20	140	0.013	37.3
		Super 800	2	180	0.013	4.8
	Hunter	PGP	15	140	0.012	24.5
		PGP	3	180	0.012	6.3
		PGP	15	210	0.012	26.8
Sprayer	**Rainbird**	18 Van	15	140	0.007	4.7
		18 Van	16	180	0.007	19.2
		18 Van	7	210	0.007	9.8
	Toro	Tvan	27	140	0.006	22.1
		Tvan	1	180	0.006	1.1
Dripper	**Rainbird**	Rain Bug (5 heads)	55	210	6.7E-05	3.9
Total						**403.7**

The flow rate of each device was taken from available irrigation catalogs representative of the associated brand (Hunter Industries Incorporated, 2010; Rain Bird Corporation, 2010; The Toro Company, 2010). With the assistance of Engineer Paixão, head of the Unidade de Espaços Verdes (UEV – Green Spaces Unit), it was possible to accurately determine the specific flow rate of each series.

3.3.2.1. Water Demand

Analyzing Table 6, the weekly consumption of irrigation water is expected to be around **403.7 m^3**, regardless the month or season of the year. Considering that the irrigation system on campus is usually programmed week by week and that many sectors are manually programmed, it was decided that this value corresponds to the water consumption per week during 8 months of the year – from March till October. Taking into account the estimated area with active irrigation – **1.1 ha** – it is conclusive that the annual water expenditure is expected to be **1.25 m^3/m^2 per year,** equivalent to **13 750 m3 per year**.

Taking into account Table 1, complemented with information provided by several entities specialized on this subject, the reference value of water consumption for irrigation of small gardens and parks is between **0.1 and 0.8 m^3/m^2 per year**. Comparing the reference value with the actual expenditure it is considered that there is a considerable inefficiency in water consumption, currently carried out by the FCT green area watering system. Besides the economic inefficiency, one cannot ignore the involved environmental component, when using significant amounts of drinking water unnecessarily. Thus, new values must be considered for sizing the entire RHS.

Considering that the inactive sectors can resume activity in the future or assuming that new green areas may arise in the coming years, it is admitted, for sizing purposes, that the considered irrigation area is equivalent to both active and inactive sectors **– 2.3 ha**. Therefore, according to the assumption presented above, the volume of water spent per year is expected to be around **28 750 m^3** per year.

Table 7 presents the numbers for the actual average weekly flow of water consumed for irrigation in FCT and the hypothetical consumption if all the FCT green sectors were being irrigated.

Table 7 - Average weekly flow of water consumed for irrigation in FCT

Irrigated Area = 1,1 ha	**Irrigated Area = 2,3 ha**
Average weekly flow of water consumed for irrigation in FCT = **403,7 m^3**	Average weekly flow of water consumed for irrigation in FCT = **827,1 m^3**
Annual water expenditure for irrigation (8 months) = **1,25 m^3/m^2.year**	
Average annual flow of water consumed for irrigation in FCT = **13 750 m^3**	Average annual flow of water consumed for irrigation in FCT = **28 750 m^3**
Current Scenario	**Hypothetical Scenario**

Table 8 presents the water needs for irrigation as well as the mean weekly flow rate for each month, to be considered for sizing the RHS, which is based on typical values for irrigation at the central and coastal part of Portugal.

Table 8 - Water demand for irrigation.

		Area=2.3ha	Area=1.1ha	Area=2.3ha	Area=1.1ha
Month	**Irrigation (mm/month)**	**Irrigation (m^3/month)**	**Irrigation (m^3/month)**	**Flow rate (m^3/week)**	**Flow rate (m^3/week)**
January	0	0	0	0	0
February	0	0	0	0	0
March	22	505	247	116	57
April	57.1	1312	640	302	147
May	84	1930	942	444	217
June	107.1	2 459	1 200	566	276
July	123.6	2 839	1 386	653	319
August	111.2	2 554	1 247	588	287
September	78.4	1 801	879	414	202
October	24.4	561	274	129	63
November	0	0	0	0	0
December	0	0	0	0	0
Total	**608**	**13 962**	**6 814**		

Figure 28 represents the percentage distribution of water demand for irrigation per month, according to water requirements for irrigation represented in column 2 of Table 8. As expected, water needs for the rainiest months is null, while for the hotter and driest months water demand has the higher values.

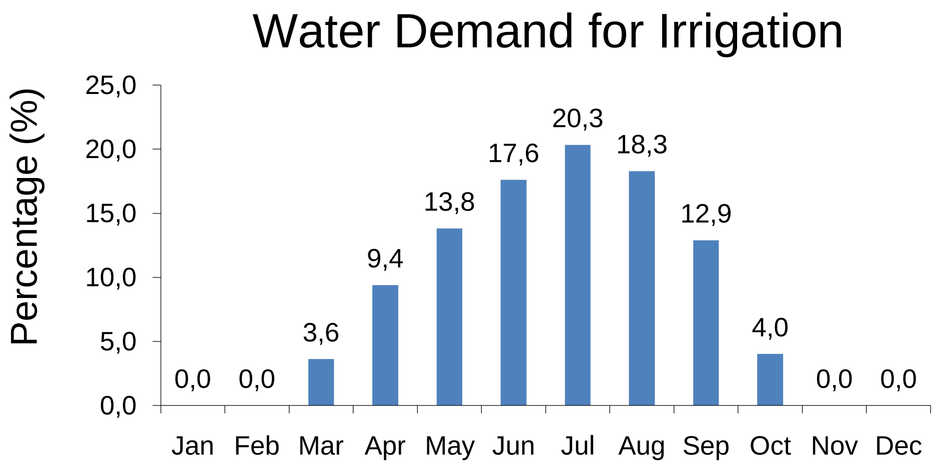

Figure 28 - Percentage distribution of water demand for irrigation of green areas.

3.3.3. Supply Management

For this case study, the considered catchment surfaces are the roofs of several buildings located in the FCT Campus. Figure 29, Figure 30, Figure 31 and Figure 32 illustrate the roof materials of those buildings.

Figure 29 - Building I roof, consisting of tile cement. Building II roof is identical.

Figure 30 - Building X roof, covered with gravel. Buildings VII, VIII and IX roofs are identical.

Figure 31 - View of the DB roof. As seen, the surface material is cement.

Figure 32 - Aerial view of Buildings III, IV and V. All three are tar screen coated.

Table 9 characterizes all the contemplated roofs, as well as the respective affluences. As illustrated above, all the roofing materials were identified in order to determine the runoff coefficient to be considered for each situation. The affluence values were determined taking into account the precipitation data for the reporting period of 25 years.

Table 9 - Characteristics of all the roofs contemplated in the case study.

Roof	Area (m^2)	Material	Runoff Coefficient	Average Affluences (m^3/year)
Building I	2 870	Cement Tile	0.82	1 470
Building II	2 713	Cement Tile	0.82	1 390
Building III, IV, V	2 790	Tar Screen	0.9	1 568
DB	4 881	Cement	0.82	2 500
Building VII	3 334	Gravel	0.8	1 666
Building VIII	1 793	Gravel	0.8	896
Building IX	1 768	Gravel	0.8	883
Building X	1 365	Gravel	0.8	682
Total	**21 514**			**11 056**

Analyzing all data collected and all the available information, the next step was to compare water supply with water demand, in order to produce several or the most viable solution for the implementation of a RHS on the FCT university campus. With this goal, several scenarios of water balance were examined.

3.4. Water balance

Five possible scenarios were studied to determine which one best suits the application of the concept according to the objectives and requirements of the RHS.

3.4.1. Null Hypothesis

A null hypothesis is the basic assumption that will operate as a starting point to develop other scenarios. This would be the most viable solution in terms of logistics and infrastructures existing on campus, since the catchment surfaces that fall under this hypothesis are the roofs of buildings VII, VIII, IX, X and DB (see section 3.3.1.1). The irrigation area considered for this hypothesis is equivalent to the active and inactive watering sectors of the campus, namely 2.3 ha. Figure 33 represents all the irrigation sectors (green) of the FCT campus.

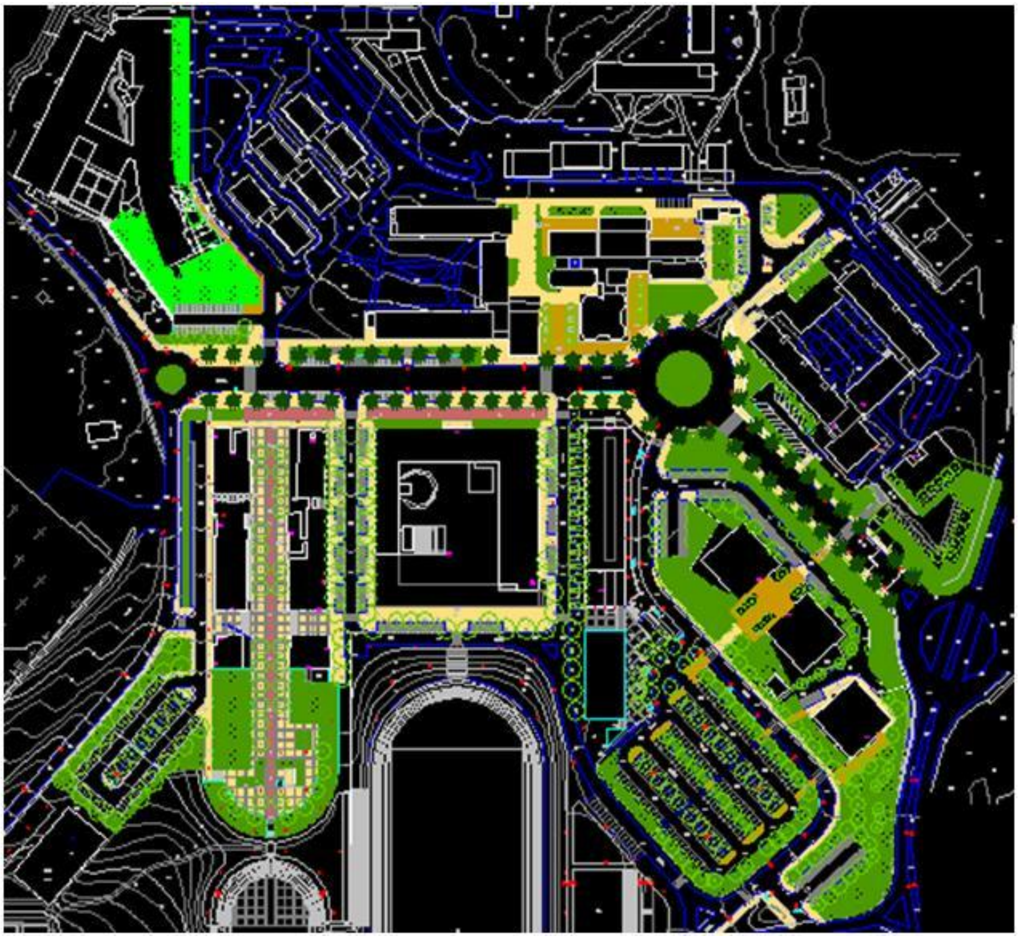

Figure 33 - Green sectors of the FCT Campus.

Table 10 presents the figures of total water runoff for each building per year, as well as the value of total irrigation water consumption per year, considering average annual values.

Table 10 - Average annual volume of affluences by building and total irrigation water consumption.

Affluence – DB (m^3)	2 500
Affluence – Building VII (m^3)	1 666
Affluence – Building VIII (m^3)	896
Affluence – Building IX (m^3)	883
Affluence – Building X (m^3)	683
Total Affluence (m^3)	6 628
Irrigation Water Consumption (m^3)	13 962

As seen by the analysis of Table 10, the volume of average water consumption is well above the volume of average inflow, which means that supply of rainwater will not be sufficient to meet all demand. According to the calculations for this scenario the RHS would require a **193 054 m^3** reservoir. Technically, for these conditions, it's not rational to dimension a RHS where the average inflow is lower than the average outflow. Not only would the reservoir be of monumental dimensions, as it would be an unaffordable investment.

The reliability and efficiency of RHS are linked directly to a proper sizing of the storage tank, requiring an optimum combination between the storage volume and the volume of demand to be met, resulting in higher reliability with lower possible expenditure.

Table 11 introduces an estimate of the total volume of water consumed for irrigation per year in FCT Campus, as well as the corresponding economic value, for the null hypothesis.

Table 11 - Estimated annual volume of irrigation water and respective economic value, for the considered irrigation area of 2.3 ha.

Average weekly flow of water consumed for irrigation in FCT (m^3)	827.1
Average annual flow of water consumed for irrigation (m^3)	28 750
Cost of 1 m^3 of water charged by SMAS (€)	1.44
Amount spent per year in irrigation water (€)	41 343

Note: The average annual flow of water consumed for irrigation is regarding to the current volume of water consumed per week for the considered time period of 8 months, as mentioned in section 3.3.2.1.

In Annex VI is provided a recent water bill paid to Serviços Municipalizados de Água e Saneamento (SMAS – Municipal Services of Water and Sanitation) of Almada by the FCT. Through this document, it can be observed the value paid for 1 m^3 of mains water supply, as well as all the fees charged for 1 m^3 of water consumption. Table 12 presents an assessment of the economic value on the fees charged for water consumption by the SMAS, which in this case corresponds to the average annual flow of water consumed for irrigation – 28 750 m^3.

Table 12 - Assessment of the economic value associated to the fees charged for water consumption by the SMAS.

Tax	Unit Value (€)	Value (€year)
Drainage Utilization Fee[i]	1.44	16 537
Treatment Utilization Fee	0.3	8 613
Solid Waste Fee	0.21	6 029
Water Resources Fee	0.0264	758
VAT of 6%		1 723
Amount spent per year related to the charging fees (€)		33 661

[1] The drainage utilization fee corresponds to 40% of the total water consumed for irrigation, namely 40% of 28 750 m^3 per year.

By examining Table 11 and Table 12, the economic amount saved in water by the FCT would be of **75 004 € per year**. Although being a substantial value, taking into account the size of the reservoir, the expected Return on Investment Period (ROI) will make a project of this size unfeasible.

Concluding, for the given reasons and figures presented, this hypothesis is completely impractical. Thus, new scenarios were developed with better economic and constructive solutions, which may enable the application of this concept in the future.

3.4.2. 1st Scenario

The 1st scenario conceived is similar in almost everything to the null hypothesis, except this will include the affluences of buildings I and II. Figure 34 represents the blueprint of the FCT buildings, where all the catchment surfaces are properly identified.

Figure 34 - Blueprint of all the FCT buildings and the considered catchment surfaces.

Table 13 displays the figures of total water runoff for each building, as well as the value of total water consumption for the period under review, considering average annual values.

Table 13 - Average annual volume of affluences by building and total irrigation water consumption, for the 1st scenario.

Affluence – Building I (m^3)	1 470
Affluence – Building II (m^3)	1 390
Affluence – DB (m^3)	2 500
Affluence – Building VII (m^3)	1 666
Affluence – Building VIII (m^3)	896
Affluence – Building IX (m^3)	883
Affluence – Building X (m^3)	683
Total Affluence (m^3)	9 487
Irrigation Water Consumption (m^3)	13 962

Analyzing Table 13, the value of average inflow is still below the average consumption, which means that supply is not yet sufficient to meet all water demand. According to the calculations for this scenario, to ensure annual watering for irrigation of the campus, the RHS would require a **124 949 m^3** reservoir. Technically, for these conditions, it's not rational to dimension a RHS where the average inflow is lower than the average outflow. For the given reasons, the storage volume is still totally impractical, both constructive and economically.

The economic savings related to water consumption regarding this scenario are the same presented in Table 10 and Table 11, since the considered irrigated area is also 2.3 ha.

Concluding, for the given reasons and figures presented, this hypothesis is still completely impractical. Thus, new scenarios were developed with better economic and constructive solutions, which may enable the application of this concept in the future.

3.4.3. 2nd Scenario

The catchment surfaces considered for this scenario include the buildings VII, VIII, IX, X and the DB's roofs, same as the null hypothesis. The main assumption of this scenario lies in the area susceptible to be watered. The irrigation area considered for the sizing of the RHS corresponds to the current active irrigation sectors (see Section 3.3.2.) – 1.1 ha (Figure 35). Thus, based on the values presented in Table 8, all calculations of water supply and demand were redone, in order to come up with a new storage volume.

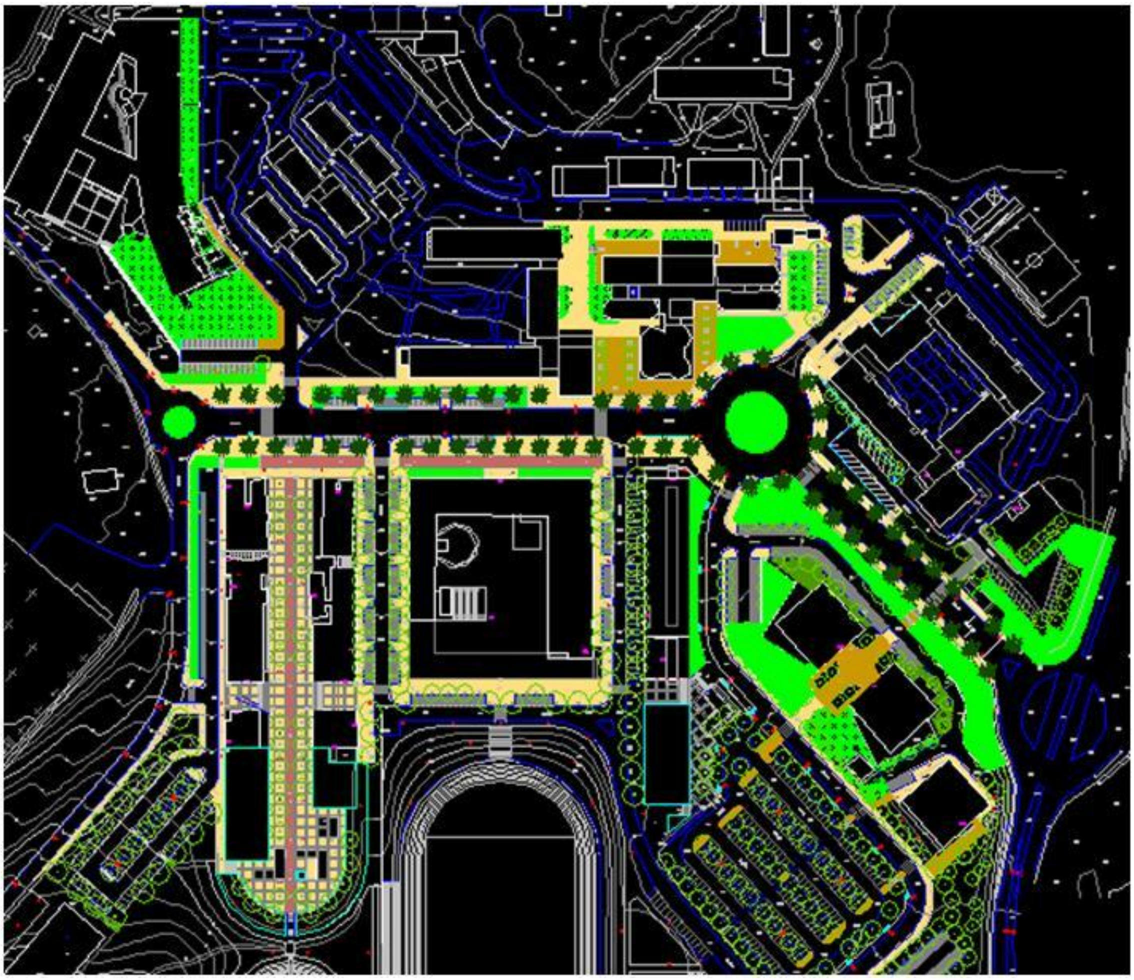

Figure 35 - Blueprint of the campus green areas with active irrigation.

Comparing Figure 33 - Green sectors of the FCT Campus. with Figure 35, it is noticeable the differences between the 2 plants. Table 14 presents the figures of total water runoff for each building, as well as the value of total water consumption for the period under review, considering average annual values.

Table 14 - Average annual volume of affluences by building and total irrigation water consumption, for the 2nd scenario.

Affluence – DB (m^3)	2 500
Affluence – Building VII (m^3)	1 666
Affluence – Building VIII (m^3)	896
Affluence – Building IX (m^3)	883
Affluence – Building X (m^3)	683
Total Affluence (m^3)	6 628
Irrigation Water Consumption (m^3)	6 814

Analyzing Table 14, the values of average inflow and average consumption are quite similar. However, water supply is not yet sufficient to meet all water demand. According to the calculations for this scenario the RHS would require a **13 408 m^3** reservoir to ensure annual watering of the campus. This volume is still quite significant. However, there is a substantial difference between this and the previous scenarios regarding to the project feasibility. However, once again, technically, it's not rational to dimension a RHS where the average inflow is lower than the average outflow. Not to mention that this solution was designed only to consider the current active irrigation area of 1.1 ha. Considering that the inactive sectors may resume activity in the future, or assuming that new green zones may arise in the coming years, the system designed for this scenario is unable to meet their water requirements.

Table 15 introduces an estimate of the total volume of water consumed for irrigation per year in FCT Campus, as well as the corresponding economic value, for the 2nd scenario.

Table 15 - Estimated annual volume of irrigation water and respective economic value, for the considered irrigation area of 1.1 ha.

Average weekly flow of water consumed for irrigation in FCT (m^3)	403.7
Average annual flow of water consumed for irrigation (m^3)	13 750
Cost of 1 m^3 of water charged by SMAS (€)	1.44
Amount spent per year in irrigation water (€)	20 177

Note: The average annual flow of water consumed for irrigation is regarding to the current volume of water consumed per week for the considered time period of 8 months, as mentioned in section 3.3.2.1.

Table 16 presents an assessment of the economic value on the fees charged for water consumption by the SMAS, which in this case corresponds to the average annual flow of water consumed for irrigation – 13 750 m^3.

Table 16 - Assessment of the economic value associated to the fees charged for water consumption by the SMAS.

Tax	Unit Value (€)	Value (€year)
Drainage Utilization Fee[ii]	1.44	8 071
Treatment Utilization Fee	0.3	4 204
Solid Waste Fee	0.21	2 943
Water Resources Fee	0.0264	370
VAT of 6%		841
Amount spent per year related to the charging fees (€)		16 428

[1] The drainage utilization fee corresponds to 40% of the total water consumed for irrigation, namely 40% of 13 750 m^3 per year.

By examining Table 15 and Table 16, the economic amount saved in water by the FCT would be of **36 605 € per year**. Although being a substantial value, taking into account the size of the reservoir, the expected Return on Investment Period (ROI) will make a project of this size unfeasible.

Concluding, for the given reasons and figures presented, this hypothesis is still irrational. Thus, new scenarios were developed with better economic and constructive solutions, which may enable the application of this concept in the future.

3.4.4. 3rd Scenario

The 3rd scenario is similar to the 2nd scenario except that also includes the affluences of buildings I and II (see Figure 34). Thus, based on the values presented in Table 8, all calculations of water supply and demand were redone, in order to come up with a new storage volume.

Table 17 displays the figures of total water runoff for each building, as well as the value of total water consumption for the period under review, considering average annual values.

Table 17 - Average annual volume of affluences by building and total irrigation water consumption, for the 3rd scenario.

Affluence – Building I (m^3)	1 470
Affluence – Building II (m^3)	1 390
Affluence – DB (m^3)	2 500
Affluence – Building VII (m^3)	1 666
Affluence – Building VIII (m^3)	896
Affluence – Building IX (m^3)	883
Affluence – Building X (m^3)	683
Total Affluence (m^3)	9 487
Irrigation Water Consumption (m^3)	6 814

As seen in Table 17, the value of average consumption is below the average rainwater inflow, which means that supply is sufficient to cover water demand. The economic savings related to water consumption regarding this scenario are the same for the previous scenario, demonstrated in Table 15 and Table 16.

According to the calculations for this scenario the RHS would require a **4 161 m³** reservoir. The reservoir volume is quite acceptable in size, making the system in terms of construction, a feasible project and the most interesting of all scenarios previously evaluated. However, as the 2nd scenario, this solution was designed only to consider the current active irrigation area of 1.1 ha. Considering that the inactive sectors may resume activity in the future or, assuming that new green zones may arise in the coming years, the system designed for this scenario is unable to meet their potential water requirements.

3.4.5. 4th Scenario

For this 4th and final solution proposed, the considered catchment surfaces include the roofs of buildings I, II, III, IV, V, VI, VII, VIII, IX and X, and the DB roof. The irrigation area considered is equivalent to the campus active and inactive watering sectors, namely 2.3 ha (see Figure 33). According to the mentioned assumptions, Table 18 shows the figures of total water runoff for each building, as well as the value of total water consumption for the period under review, considering average annual values.

Table 18 - Average annual volume of affluences by building and total irrigation water consumption, for the 4th scenario.

Affluence – Building I (m^3)	1 470
Affluence – Building II (m^3)	1 390
Affluence – Building III, IV and V (m^3)	1 568
Affluence – DB (m^3)	2 500
Affluence – Building VII (m^3)	1 666
Affluence – Building VIII (m^3)	896
Affluence – Building IX (m^3)	883
Affluence – Building X (m^3)	683
Total Affluence (m^3)	11 056
Irrigation Water Consumption (m^3)	13 962

As seen by the analysis of Table 18, the volume of average water consumption is above the volume of average inflow, which means that supply will be insufficient to meet all water demand. According to the calculations for this scenario, to ensure the annual watering of the campus, the RHS would require an **87 595 m³** reservoir. Despite the difference between supply and demand is not as acute as the one presented in the null hypothesis, this scenario is still unfeasible, since it is technically irrational to dimension a RHS where the average inflow is lower than the average outflow.

The economic savings related to water consumption regarding this scenario are the same for the null hypothesis and for the 1st scenario, demonstrated in Table 11 and Table 12.

Despite the monumental dimensions of this reservoir, as well as the unaffordable investment, this scenario provides the best numbers regarding the volume of harvested rainwater and considers the total area of the campus green sectors. Therefore, it was decided to consider this scenario as a starting point to develop several new solutions for different system efficiencies, according to the assumption that the average inflow must cover the average outflow, in order to assure the system feasibility. A detailed analysis of all these scenarios is presented below in section 3.5. Table 19 summarizes the main characteristics associated to each of the presented solutions presented above.

Table 19 - Summary of the characteristics associated to each scenario.

	Null Hypothesis	**1st Scenario**	**2nd Scenario**	**3rd Scenario**	**4th Scenario**
Catchment Surface	DB; Buildings VII, VIII, IX, X	DB; Buildings I, II, VII, VIII, IX, X	DB; Buildings VII, VIII, IX, X	DB; Buildings I, II, VII, VIII, IX, X	DB; Buildings I, II, III, IV, V, VII, VIII, IX, X
Total Catchment Area (m^2)	13 141	18 724	13 141	18 724	21 514
Irrigation Area (ha)	2.3	2.3	1.1	1.1	2.3
Water Savings (€/year)	75 004	75 004	36 605	36 605	75 004
Tank Volume (m^3)	193 054	124 949	13 408	4 161	87 595

As it can be seen, the difference of the tank size is quite significant between similar circumstances where the only change is the area to be watered.

3.5. Determination of the Optimum Tank Size

As mentioned, since the RHS evaluated for all scenarios are completely unfeasible, except for the 3rd scenario, new alternatives were developed for different system efficiencies, based on results obtained with 4th scenario. For the same assumptions, the 4th scenario provided as the cornerstone to present several solutions for future potential investors and/or decision makers, according to the desired purpose. Table 20 presents new scenarios according to the irrigation efficiency.

Table 20 - Characteristics of proposed RHS for different percentage of irrigated area.

RHS Efficiency (%)	Tank Volume (m^3)	Irrigated Area (m^2)	Water Savings (m^3/year)	Water Savings (€/year)
90%	52 505	20 672	25 840	67 503
80%	17 416	18 375	22 969	60 003
75%	8 182	17 226	21 533	56 253
70%	6 867	16 078	20 097	52 503
60%	5 290	13 781	17 226	45 002
50%	3 880	11 484	14 355	37 502
40%	2 469	9 187	11 484	30 001
30%	1 058	6 891	8 613	22 501
20%	36	4 594	5 742	15 001
10%	13	2 297	2 871	7 500

As seen, the characteristics of each system, with the exception of the storage volume, do not show a marked variation from case to case. However, for the tank size, there is a remarkable difference when the percentage of irrigated drops from 90% to 80% and from 80% to 75%. Figure 36 presents the evolution of each tank size according to the percentage of irrigated area.

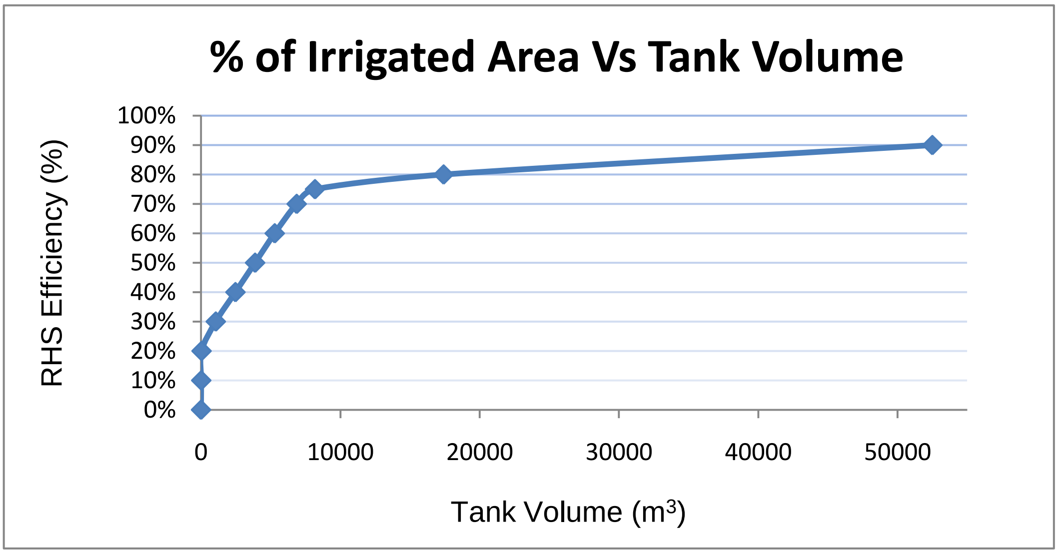

Figure 36 - Tank volume according to the percentage of irrigated area.

Figure 36 corroborates the difference between the RHS designed to irrigate 80% and 90% of area from the other studied solutions. It is expected that the economic viability of such systems will be reduced or even null, being the reservoir the most expensive component of a RHS. Therefore, the exponential increase of the tank size does not compensate an increase of 5 to 10% of irrigated area. Decision making should be based in choosing a tank size that is appropriate in terms of costs, resources and construction methods; even if it means that the tanks have to be limited to lower capacities than would otherwise be justified by roof areas or likely needs of consumers. This way optimization of tank size will be achieved, according to water demand and water supply, with a lower Return on Investment (ROI) period.

To assist in decision making, it is necessary to complement the presented scenarios with a preliminary economic assessment for each RHS.

3.5.1. Economic Analysis of the Rainwater Harvesting Systems

The installation of a RHS presumes the existence of a preliminary economic analysis, to provide a more rational judgment by the decision-maker.

The total cost of a RHS must take into account all expenditures associated to the systems installation and operation (water supply systems and electrical and electromechanical equipment), and construction costs. Though, in order to simplify the calculations, only the construction costs associated to the water reservoir were considered, since it is the most expensive component of a RHS, varying significantly with its size.

As stated previously in section 2.6.4.3., there are several tanks available in the market for RWH, made from many different materials. However, for this particular case study, the most viable option is the construction *in situ* of reinforced concrete reservoirs or the design of an artificial pond.

After consulting with certain companies that provide this service, it was conclusive that most of them only provide tanks for small projects, mainly made of high-density polyethylene (HDPE), fibreglass or inox steel. Only construction companies provide services of *in situ* construction of large capacity reinforced concrete reservoirs. A specific construction company was contacted and asked for information and advice on a suitable approach. Information provided by Engineer Carlos Schmidt, concerning workload prices for each constructive component, was essential to estimate the cost of each reservoir presented in Table 20. The following data was considered for the economic assessment of each RHS.

- Reinforced concrete walls, including shuttering: 271 € / m^3;
- Reinforced concrete groundsill: 157 € / m^3;
- Concrete slab coverage: 30 € / m^3;
- Plaster: 10.5 € / m^2;
- Excavation and transport: 7.5 € / m^3;

Information regarding the development of artificial ponds was provided by Engineer João Fonseca. For certain tank volumes, it is reasonable to consider such possibility, since it is more economically efficient. Specific price of construction of an underground storage reservoir, geomembrane coated, with surface and bottom outlet, fence and access, all included – 40 €/m^3.

Through the estimated workloads and respective costs, it was possible to produce Table 21.

Table 21 - Estimated workloads and respective costs of construction for reinforce concrete tanks, according to each dimension.

	Tank Volume (m^3)							
	52 505	**17 416**	**8 182**	**6 867**	**5 290**	**3 880**	**2 469**	**1 058**
Dimensions (m)	103*103*5	60*60*5	41*41*5	38*38*5	33*33*5	29*29*5	23*23*5	15*15*5
wall thickness (m)	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Walls (271€/m^3)	835 650€	279 950€	132 940€	111 925€	86 675€	64 000€	41 250€	18 250€
Groundsill (m)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Groundsill (157€/m^3)	9 500€	17 600€	34 600€	66 000€	131 950€	131 950€	131 950€	131 950€
Excavation (7.5€/m3)	443 375€	149 575€	71 575€	60 375€	46 925€	34 825€	22 630€	10 230€
Plaster (10.5€/m^2)	133 440€	49 985€	26 425€	22 900€	18 570€	14 560€	10 330€	5 645€
Coverage (30€/m^2)	321 520€	108 245€	51 675€	43 570€	33 825€	25 070€	16 250€	7 300€
Total (reinforced concrete, buried)	**1 929 690€**	**701 050€**	**360 670€**	**310 410€**	**249 030€**	**192 630€**	**133 935€**	**70 360€**
Total (reinforced concrete, semi-buried)	**1 608 170€**	**592 800€**	**308 990€**	**266 840€**	**215 200€**	**167 565€**	**117 690€**	**63 060€**
Total (artificial lake)	**2 100 215€**	**696 630€**	**327 275€**	**274 680€**	**211 615€**	**155 190€**	**98 765€**	**42 340€**

As expected, systems with irrigation capability of 90% and 80% of the total area, are much more expensive than the other. Technically, since water supply is not sufficient to meet water demand, these options are both economically and constructive unfeasible. Systems with 10% and 20% of irrigation capability were not considered, since they are extremely small to meet the primary goal of this case study.

Comparing the system costs with the system economic benefits for every tank sizes presented in Table 20 and Table 21Table 21 - Estimated workloads and respective costs of construction for reinforce concrete tanks, according to each dimension., it can be objectively evaluated the best economic solution to adopt. It is also important to assess the most cost-effective solution, through the ROI period. The ROI period is easily achieved since the water update rate was not considered:

$$ROI = \frac{Bi}{Ci} \quad \text{(Years)}$$

- ROI – Return On Investment Period (years);
- Bi – Benefit per year i (€);
- Ci – Cost per year i (€);

3.6. Summary and Discussion of Results

This chapter examines the results for all the possibilities presented, in accordance with their tank volume and respective RHS capability of irrigation, express in terms of percentage of total potential irrigated area.

Table 22 presents the system details essential for a supported and sustained decision making. For the reasons mentioned above, systems with a 90%, 80%, 20% and 10% capability were not considered.

Table 22 - Characteristics of proposed RHS and respective ROI period

	% of Irrigated Area					
	75%	**70%**	**60%**	**50%**	**40%**	**30%**
Tank Volume (m^3)	8 182	6 867	5 290	3 880	2 469	1 058
Irrigated Area (m^2)	17 226	16 078	13 781	11 484	9 187	6 891
Water Savings (m^3/year)	21 533	20 097	17 226	14 355	11 484	8 613
Water Savings (€/year)	56 253	52 503	45 002	37 502	30 001	22 501
System Cost* (€)	**360 670€**	**310 410€**	**249 030€**	**192 630€**	**133 935€**	**70 360€**
ROI* (years)	**6**	**6**	**6**	**5**	**4**	**3**
System Cost (€)**	**308 990€**	**266 840€**	**215 200€**	**167 565€**	**117 690€**	**63 060€**
ROI (years)**	**5**	**5**	**5**	**4**	**4**	**3**
System Cost* (€)**	**327 275€**	**274 680€**	**211 615€**	**155 190€**	**98 765€**	**42 340€**
ROI* (years)**	**6**	**5**	**5**	**4**	**3**	**2**

* For reinforced concrete tanks, buried;

** For reinforced concrete tanks, semi-buried;

*** For artificial lake;

As seen, it is important to mention that for the system with 50% capability, the assured irrigation area is around 1.1 ha, equivalent to the current active irrigation area of the FCT. In other words, this may be a viable solution if the RHS is considered to be sufficient to meet the future needs of the FCT watering sectors.

According to Table 22, it was possible to evaluate all scenarios and to compare all the associated features. Figure 37 analyzes the cost evolution according to each reservoir capacity, for the three construction approaches.

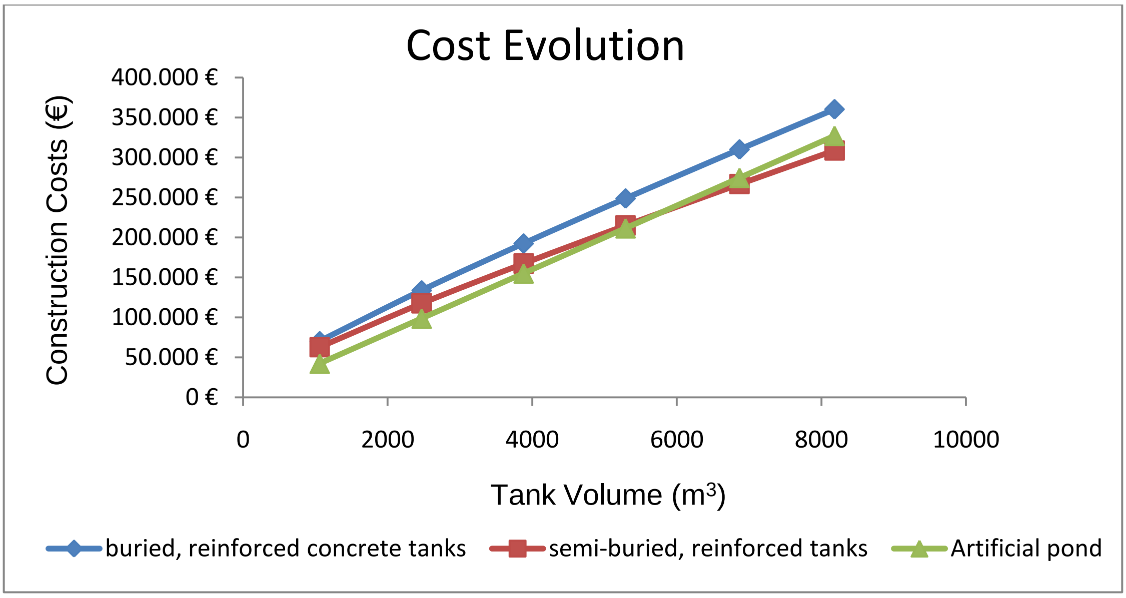

Figure 37 - Construction costs for each RHS according to the reservoir capacity.

Figure 38 analyzes the ROI period according to each reservoir capacity, for the three construction approaches.

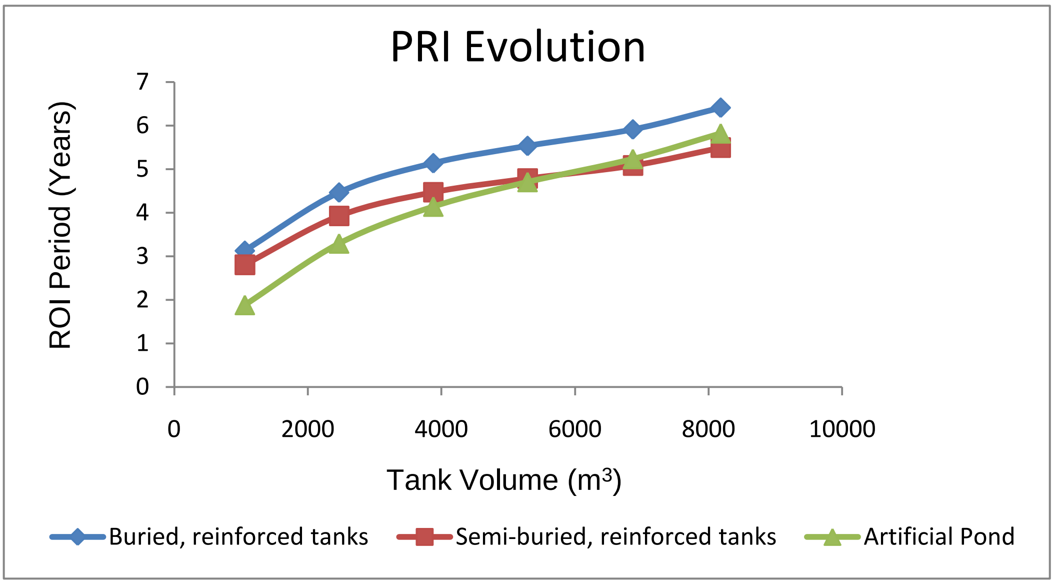

Figure 38 - ROI period for each RHS according to the reservoir capacity.

Analyzing Figure 37 and Figure 38, the construction of the RHS based in a buried, reinforced concrete reservoir is the most expensive solution. Between the two other possibilities, for a tank size inferior to 5 290 m^3, the most viable solution is the construction of an artificial pond. For tank sizes superior to 5 290 m^3, corresponding to a system capability of 60%, the most viable option is the construction of a semi-buried, reinforced concrete reservoir. However, the economic differences between the three presented solutions, for the same irrigation capability, are minimal. The ROI period is a very important factor for decision making, but one cannot forget other elements such as location or visual impact of the storage tank. Therefore, despite being the most expensive solution, the implementation of a RHS with buried reservoirs has the major advantage of not being visible to people and to not occupy space on the surface.

From Table 22 and Figure 38, it can be seen that the ROI period has a similar behaviour for all three construction options. As expected, the ROI period increases proportionally with the tank volume, due to the higher costs of construction.

Finally, analyzing all the provided information, it is conclusive that this case study presents a prominent feasibility and reliability rate, not only economically as well as environmentally, being water a more and more important and increasingly scarce resource. One might even say that for a project of this importance and dimension, the ROI period for all scenarios presented, with capabilities between 30% and 75%, is quite reasonable and should not hinder its implementation.

4. Conclusions

Traditionally, water was a cheap, safe and abundant resource, accessible to all, without any economic cost. However, this situation changed dramatically and the traditional approaches may not be sustainable due to increased pressures from climate change, population growth and intense urbanization, making water a scarce and a valuable resource, economically, strategically and environmentally.

Rainwater Harvesting (RWH) is an important strategy for better management of water resources and a way to contribute to mitigate catastrophic natural events such as floods and droughts. It has the potential to reduce reliance on mains water supply, especially for non-potable uses such as toilet flushing, irrigation, washing and fire fighting. There are also economic benefits for the general consumer, related to savings on water bills. Despite the lack of public awareness and acceptance, there is a great potential for RWH to become more widespread in Portugal. However, the absence of information regarding Rainwater Harvesting Systems (RHS) costs and maintenance requirements, associated to the current low prices of mains water supply, raises scepticism regarding its long-term financial effectiveness.

Worldwide legislation was also presented as well as the Portuguese legal framework, regarding rainwater utilization. In many countries RWH is being practised outside the legal framework without too much government involvement. Portugal is no different, since there is no specific legislation regarding this subject. However, the Associação Nacional para a Qualidade nas Instalações Prediais (ANQIP) developed technical specifications regarding hydric certification for the installation of RHS. Several success stories all over the world are reported, which could function as a starting point for other countries to adopt this strategy.

In the research work a detailed characterization of all Rainwater Harvesting Systems components was presented: the catchment surface (usually building roof tops), conveyance system, filtration system and first flush diverters, storage facility, delivery system (pumping system) and all treatment techniques. A range of key elements were also identified related to the runoff coefficients associated to every roof materials and to the tank installation: rainwater inlet to the tank, overflow device and backup water supply.

A case study was introduced, which main goal is to assess the feasibility of RWH for irrigation of green areas in the FCT/UNL campus. The followed methodology consisted in gathering information on six key variables: Rainfall Data; Determination of Irrigation Water Consumption; Water Demand; Determination of Green Areas with Active and Inactive Irrigation; Determination of the Roof Areas and Roofing Material. Methods for modelling these variables were discussed and suitable approaches selected. Regarding tank sizing, there are a number of different methods suitable for a proper dimensioning. For this particular case, the Rippl Method was selected, since it is the most commonly used in RWH.

A thorough characterization of the FCT irrigation system is also presented, allowing an accurate estimation of the weekly flow rate of potable water consumed during this process. In order to determine the rainwater supply all roof areas and roof materials were identified through a direct field survey. Comparing water demand with water supply, several scenarios were developed in order to present viable solutions for the implementation of a RHS in the FCT. The majority of them clearly evidence a significant reduction in the reliance of mains water supply.

Currently, in Portugal, few companies already provide these services. However, all the developed scenarios predict the installation of considerable size tanks and therefore only reinforced concrete and pre-fabricated concrete materials were considered.

A financial assessment was then produced, where only the construction costs associated to the water reservoir were considered, since it is the most expensive component of a RHS. The cost benefit analysis for every solution was essential to determine the ROI period and therefore to assist in a more rational judgement by the decision-maker. The system details and the provided information presented viable solutions to reduce consumption of potable water from the mains water supply.

This research work seeks to make aware for the importance of RWH and to encourage the implementation of RHS to reduce the use of drinking water for non-potable uses, and thus contributing to address water scarcity problems all over the world. Regarding the presented case study, the main conclusion is that there is a considerable inefficiency in water consumption, currently carried out by the FCT green area watering system. Too much water is being spent for the existing irrigation sectors and therefore, may the presented figures contribute to better management and programming of the irrigation system. Besides the economic inefficiency, one cannot ignore the involved environmental component, when using significant amounts of drinking water unnecessarily.

There is still much to do regarding this research area development. However, the first step concerning the implementation of a RHS is taken and now only future will tell if the FCT will be the first Portuguese University to give the example and to adopt an important strategy towards resources preservation and sustainability.

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ANNEXES

Annex I – Water Quality Parameters for Irrigation (Adapted from Decreto-Lei nº 236/98).

Parameter	Expressed in	MRC	MAC	Parameter	Expressed in	MRC	MAC
Aluminum (Al)	mg/l	5.0	20	Arsenic (As)	mg/l	0.10	10
Barium (Ba)	mg/l	1.0		Beryllium (Be)	mg/l	0.5	1.0
Boron (B)	mg/l	0.3	3.75	Cadmium (Cd)	mg/l	0.01	0.05
Lead (Pb)	mg/l	5.0	20	Chlorides (Cl)	mg/l	70	
Cobalt (Co)	mg/l	0.05	10	Copper (Cu)	mg/l	0.20	5.0
Chromium (Cr)	mg/l	0.10	20	Tin (Sn)	mg/l	2.0	
Iron (Fe)	mg/l	5.0		Fluorine (F)	mg/l	1.0	15
Lithium (Li)	mg/l	2.0	5.8	Manganese (Mn)	mg/l	0.20	10
Molybdenum (Mo)	mg/l	0.005	0.05	Nickel (Ni)	mg/l	0.5	2.0
Nitrates (NO_3)	mg/l	50		Salinity: EC TDS	 dS/m mg/l	 1 640	
SAR[1]		8		Selenium (Se)	mg/l	0.02	0.05
TSS	mg/l	60		Sulfates (SO_4)	mg/l	575	
Vanadium (V)	mg/l	0.10		Zinc (Zn)	mg/l	1.0	
pH	Sørensen's scale	6.5-8.4	4.5-9.0	Fecal coliforms	/100 ml	100	
Eggs of intestinal parasites	N/l		1				

(1) The sodium adsorption ratio (SAR) is explained by the following equation (concentrations are expressed in meq/l): SAR=*Na*/ [(*Ca*+*Mg*)/2] ^{½}

ANNEX II – Map of the Active and Inactive Irrigation Sectors (green) of the FCT Campus.

ANNEX III – Blueprint of the FCT Buildings.

ANNEX IV – Water Drainage System of the FCT Campus.

ANNEX V – Water Supply Network of the FCT Campus.

ANNEX VI – Water Bill Paid to Serviços Municipalizados de Água e Saneamento of Almada by FCT.

SMAS MUNICÍPIO DE ALMADA

Praceta Ricardo Jorge, 2-2A
Pragal - 2800-709 Almada
Nº Fiscal: 680 017 763
geral@smasalmada.pt - www.smasalmada.pt

Estimado Cliente:
Solicitamos o pagamento desta factura até à data limite abaixo indicada.
Para esclarecimentos de Facturação ligue o 212726125, das 9:00 h às 12:30 h e das 14:00 h às 17:30 h. Piquete/Avarias Tel. 212726161/ 212726152. Comunicação de roturas na via publica Tel. 800205712.

FACULDADE CIENCIAS TECNO DA UNL
RUA FRANCISCO COSTA . CAMPUS
CASAS VELHAS
2825-000 CAPARICA

TITULAR DA CONTA

FACULDADE CIENCIAS TECNO DA UNL
Nº Cliente / Conta: 13433 / 13272
NIF: 505954702

SALDO ACTUAL: 7.459,14 PAGÁVEL ATÉ:(*) 09 de Agosto de 2010 **DATA DE EMISSÃO: 2010-07-13**

(*) Diz respeito ao total facturado no período

MENSAGENS

Informamos que os contadores instalados em 1998, serão substituídos em 2010 (Portaria 21/2007 de 5 de Janeiro)
- Receba a Factura Electrónica, através de e-mail registando-se no Balcão Digital em www.smasalmada.pt.
- Adira ao pagamento da factura por Débito Directo utilizando os seguintes códigos numa caixa Multibanco: N.º de Autorização (ADC) 95455528970 e Identificação do Credor (IDC) 101632.
- Taxa de Recursos Hídricos (TRH) - O Dec.-Lei 97/2008 de 11 de Junho, fixado pelo Governo, obriga os Municípios a cobrar a TRH aos utentes dos serviços de água. Os SMAS iniciaram esta cobrança em Janeiro de 2009.
- Esclarecimentos da Tarifa de Resíduos Sólidos ligue o Tel. 800 206 017 - CMA, Departamento Ambiente.

CONTA CORRENTE - Número 100704604007338 €

Saldo Anterior	2010-06-15	7.419,65
Factura Água 40219872 - Instalação 18387	2010-07-12	7.459,14
Pagamento	2010-07-13	-7.419,65
Saldo Actual	2010-07-13	7.459,14

Caso já tenha regularizado a(s) factura(s) mencionada(s) no saldo, proceda de acordo com o montante indicado no período facturado.

Instalação Nr. 18387 RUA FRANCISCO COSTA ., CAMPUS CASAS VELHAS

Histórico Facturação

Gasto Médio diário em Euros (269,87)

Comunicação de Leituras - Período ideal 2010-08-06 a 2010-08-12. Referência Leitura 0948760465. Telefone 800201650.

Resumo de Facturação do Período de 2010-06-15 a 2010-07-12

Agua	
Quota Serviço	132,92
Consumo Água	4.006,08
TU Drenagem	1.602,43
TU Tratamento	834,60
T Resíduos Sólidos	584,22
Taxa de Recursos Hídricos	73,44
IVA	225,45
TOTAL	**7.459,14**

Divisão de Recursos Financeiros
22 JUL. 2010

TALÃO DE CONTROLO

TALÃO DE LEITURA ÓPTICA

PAGÁVEL EM: SIBS, JUNTAS FREG. OU SMAS ALMADA

SMAS MUNICÍPIO DE ALMADA

MB MULTIBANCO

ENTIDADE	20815	Data Emissão:	2010-07-13
REFERÊNCIA	311 419 546	Cliente / Conta:	13433 / 13272
MONTANTE	7.459,14	**Saldo actual:**	**7.459,14**
		Valor pagável até:	2010-08-09
		Total facturado no período:	**7.459,14**

O talão emitido pelo caixa automático faz prova de pagamento: **conserve-o.**

SMAS almada

2/2

INSTALAÇÃO Nr. 18387 RUA FRANCISCO COSTA., CAMPUS CASAS VELHAS U. COMERCIAL: SMAS Almada

Factura:	40219872		Total (Euros):	7.459,14
Tipo de Cliente:	Estado		Periodo Facturação:	2010-06-15 a 2010-07-12
Tarifa:	Estado		Tipo de Leitura:	Empresa

Tipo de Consumo	Contador Nº	Leitura Ant. (2010-06-14)	Leitura Act (2010-07-12)	Factor Multipl.	Consumo Medido	Factor Conv.	Consumo Medido	Real Adicional	C. Acerto Anterior	C. Estimad Periodo
Consumo de Agua	914114400	114120	116902	1,00000	2782,00 (M3)	1,000000	2782,00 (M3)	0,00 (M3)	0,00 (M3)	0,00 (M3)

Descrição	Esc. Tarifário	Per. Inicio	Per. Fim	Origem	Explicação	Esc. Periodo	Facturado	Valor Unit.	Valor I
QUOTA SERVIÇO									
Quota de Serviço		2010-07-01	2010-07-31	Real	100 mm		1,00	132,920000	132,92 2
CONSUMO ÁGUA									
Consumo Agua	>= 0	2010-06-15	2010-06-30	Real	1590 M3 em 16 dias	>= 0.00	1.590,00	1,440000	2.289,60 1
Consumo Agua	>= 0	2010-07-01	2010-07-12	Real	1192 M3 em 12 dias	>= 0.00	1.192,00	0,000000	0,00 1
Consumo Agua	>= 0	2010-06-15	2010-06-30	Real	1590 M3 em 16 dias	>= 0.00	1.590,00	0,000000	0,00 2
Consumo Agua	>= 0	2010-07-01	2010-07-12	Real	1192 M3 em 12 dias	>= 0.00	1.192,00	1,440000	1.716,48 2
TU DRENAGEM									
T. Util. Drenagem	>= 0	2010-06-15	2010-07-12	Real	2782 x 40.0%	>= 0.00	1.112,80	1,440000	1.602,43
TU TRATAMENTO									
T. Util. Tratamento		2010-06-15	2010-07-12	Real	2782 M3		2.782,00	0,300000	834,60
T RESIDUOS SÓLIDOS									
T. Residuos Sólidos	>= 0	2010-06-15	2010-07-12	Real	2782 M3	>= 0.00	2.782,00	0,210000	584,22
TAXA DE RECURSOS HÍDRICOS									
Taxa de Recursos Hídricos		2010-06-15	2010-07-12	Real	2782 M3		2.782,00	0,026400	73,44
IVA									
(1)IVA 5%		2010-07-01	2010-07-31	Real	2289.60		0,00	0,000000	114,48
(2)IVA 6%		2010-07-01	2010-07-31	Real	1849.40		0,00	0,000000	110,97