

RAINWATER HARVESTING SYSTEMS

Implementation Inside Karunya University Campus

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To my other half, my brother

Each of us is responsible for everything and to every human being.

Fiodor Dostoievski

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ABSTRACT

Management of different water resources is primordial in order to protect them and ensure that they can be used by any human being. In arid and semi-arid areas the lack of water is a problem, while in humid areas, the problems associated to the excess runoff of rainwater are also a problem.

One simple solution to reduce those problems is the implementation of rainwater harvesting (RWH) systems. Although RWH is an ancient method, it has only become popular again in the last 20 years. Rainwater may be harvested for two different purposes: to be stored and eventually be used directly, or to recharge groundwater. The elements of RWH systems are the catchment area, conveyance system, filter unit and the storage tank (or recharge facility, according to the purpose intended).

This work was about the implementation of RWH systems inside the campus of Karunya University (KU), which is located 25 km away from the city of Coimbatore, state of Tamil Nadu, India. Though the location of KU can be considered as humid, the district of Coimbatore is considered as semi-arid, and problems associated to the lack of water have been reported. The water consumed in KU is provided by Siruvani Water Company (who also supply water in the city of Coimbatore) and by the aquifers located under KU campus. The implantation of RWH systems in KU was planned for two main reasons: to store the rainwater and to use it to recharge the aquifers.

It was decided to implement a rainwater storage system in the main building of KU. The catchment area for this system will be a part of the rooftop of the main building (201 m²). This system will have a 25000 liter tank and the water that will be stored there will be used to supply a hand basin located in the main building and for gardening purposes, which currently represent the highest consumption of water inside KU. In order to assess the economical and hydraulic effects of the implementation of the system, it was used RainCycle software, which is a powerful and user- friendly programme.

In addition to the storage system, also a RWH system to recharge the groundwater was planned. For this project, the catchment area is the campus itself. Though further studies on the aquifer and soil characteristics are essential, 2 possible recharge points were taken into account and studied. The planned methods were recharge trenches, spreading techniques and recharge through an existing sump. This work focused on the calculation of the total rainwater runoff that comes outside the campus and the runoff that reaches the recharge points. For this purpose it was used SCS's Curve Number method. Rainwater runoff represents a problem for the houses located near KU during periods with high rainfall values, thus recharging groundwater using rainwater is a good solution as it improves groundwater quality and reduces the bad effects of runoff on the local population.

KEYWORDS: Rainwater Harvesting Systems, Storage of Rainwater, RainCycle© software v2.0, Groundwater Recharge, Runoff Calculation

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SYMBOLS AND ABBREVIATIONS

UNEP – United Nations Environmental Programme

NGO's – Non-Governmental Organizations

GIS – Geographic Information System

PVC – Polyvinyl Chloride

RWH – Rainwater Harvesting

KU – Karunya University

WLC – Whole Life Costs

PV – Present Value

NPV – Net Present Value

TWAD – Tamil Nadu Water and Drainage Board

RWP – Rainwater Pipe

PCC – Plane Cement Concrete

Rs – Indian Rupees

MAFF – Ministry of Agriculture, Fisheries and Food of England

SCS – Soil Conservation Service

CN – Curve Number

USDA – United States Department of Agriculture

ARC – Antecedent Runoff Condition

WMS – Watershed Modeling System

UTM – Universal Transverse Mercator

TR-55 – Technical Release number 55 from United States Department of Agriculture

1

INTRODUCTION

1.1 INTEGRATED MANAGEMENT OF WATER RESOURCES

Water is precious for life on earth. Fresh water is the basis for humanity, as it's needed for lots of human activities (irrigation purposes, factories, drinking, etc), both fauna and flora, and many other purposes. Water is also the *habitat* for fishes and other marine species, needed for the well-being of the global ecosystem, and is also used by mankind for many purposes, like electricity production, and way of merchandise transportations widely used.

Water is the most abundant compound of planet earth, and more than 70% of planet's surface is covered with water. The distribution of this water is typically accepted to be 97,2% of saline water, in oceans and seas, being the rest fresh water (2,8%). Fresh water can be found in rivers, lakes, brooks, icebergs and glaciers. Only 0,52% is available as surface water, as the largest amount is found in the solid form as snow, ice or frost, and some of the water in deep underground, and is inaccessible.

The hydrological cycle is the main concept of the science of hydrology. Hydrological processes by which water moves through the cycle include atmospheric movement of air masses, precipitation, evaporation, transpiration, infiltration, percolation, groundwater flow, surface runoff and streamflow. [1] Good management practices have to look for both surface and groundwater.

Historically, water has been a fixation point, as populations establish near water sources (seas, rivers, lakes). With the "discovery" of agriculture, mankind has found a way to improve life quality and fight the lack of food. Water consumption for agricultural purposes was high, but that was not seen as a problem, as there was always water in huge quantity. Due to this, water was used to dissolve everything and every kind of waste and wastewater was just sent to the nearest big water source. We can say that the low-cost supply of large quantities of water was one of the foundations of modern society. [2]

The uncontrolled use of water in the past never seemed to be problem as the population on earth was much smaller than it is today, and harmful products (e.g. pesticides) weren't used. Lately, the Earth's population has increased dramatically. For example, in 1950 the World population was 2521 millions, while in 2008 this number was 6707 millions. Since 250 years ago, as the earth's population has increased, pressure in the world's environment has also increased dramatically, moving them from small settlements to the big cities. Industrial processes have been widely used and, especially after World War II, there's been an explosive growth of energy use and introduction of many new products. This factors lead to serious problems in the global ecosystem and, of course, in water resources. A report from the UNEP (United Nations Environmental Programme), result of a workshop named "Environ-

mental Outlook in South Asia, in 1998, showed that the water resources are being poorly managed, and as a result, in India, for instance, *per capita* water availability decreased from 6000 cubic meters per annum in 1947 to around 2300 cubic meters in 1998. This report also referred to the aquifers in Mehsana and Coimbatore districts having become permanently depleted, since sufficient recharge has not been taking place.

The ever increasing number of earth's population and industrial expansion are leading to diverse amount of serious conflicts due to there being a lack of water. For instance, the states of Tamil Nadu and Karnataka, in India, have been in a dispute over the sharing of the Cauvery River since the 1970's. This conflict has already resulted in political agitation and riots, causing several deaths and displacing thousands of people. There are several river disputes in India, in constant disagreement over sharing the Yamuna river between Delhi and Haryana, and the sharing of Krishna River between Karnataka and Andhra Pradesh [3]. The International Water Management Institute has predicted that the use of water world wide will increase by 50% over the next 25 years. It's also predicted that by the year of 2025, 4 billion people will have lived under severe water stress. Water resources are expected to be the main conflict generator in XXI century.

In order to give an answer to these demands, it becomes mandatory to have a management plan for water resources, so we can protect both human interests and natural resources. The management of water resources involves the development, control, regulation, protection and beneficial use of surface and groundwater resources. Water resources management activities include policy formulation; national, regional and local resources assessment; regulatory and permitting functions; formulation and implementation of resources management strategies; planning, design, construction, maintenance, rehabilitation and operation of structures and facilities; scientific and engineering research, and education and training [1]. We can describe the general objective of water resources management as the maximization of the benefits obtained from the use and control of water resources.

Some examples of water resources management measures that are commonly used include the construction of dams, hydropower plants, flood control systems and irrigation systems. These measures must ensure benefits for the populations, but also must protect the surrounding ecosystem.

As water resources are used by all human beings, the management of these resources should include, among others, engineers, political officials, lawyers, economists, urban planners, agricultural scientists, chemists, biologists, geologists, meteorologists, computer analysts, etc. Obviously, the water users and public in general must be a part in the management process.

Depending on the region, management policies will be different. We could be facing problems of excess of water, being necessary the development of a stormwater management plan, reducing flood damage, or we could be facing problems of dry lands, where the water scarcity is noticed. Ahead in this paper, problems in arid and semi-arid regions will be studied.

One of the main themes about the management of water resources is the watershed management. This paper will have a chapter about this subject, describing the main problems and some concrete measures that can be taken so that we can have a better management plan for the water resources.

1.2 WATER RESOURCES MANAGEMENT COMMUNITY

The water resources management community includes a lot of different people and organizations, as it was said before. This community includes local, regional, national and international governmental

entities, private water suppliers, equipment suppliers, industries that use water, NGO's and, as said before, the other entire individual water users.

Water resources management is as technical as much as it is political, because water is public, belonging to the state, and is used by the people. In most of the cases, is the political decision that prevails, instead of technical decision. Political decision-makers face pressure both from environmentalists and from large business interests. To ensure a good decision, politicians must carefully evaluate all the options ponderously. Probably the biggest “discussion-maker” is the costs. On the one hand, economical interests want to earn as much as possible, putting the environmental issues in second plan. On the other, environmentalists sometimes don't think about economical problems attached to their intents, which can be in conflict with public need for low-cost water. It's not easy to evaluate the economic benefit of an environmental investment (e.g. system to prevent floods). However, there are some environmental decision tools that can help in this choice. A cost/benefit analysis is a good tool to help in the decision. In case of doubt, it is always better to decide in favor of the environment, because otherwise we might be doing something irrecoverable. Public-private partnerships can be set up, combining the economic benefits with water resources conservation, which must never be forgot.

1.3 LOCAL LEVEL INTERVENTIONS

As said previously, water users (general population) are among the more interested in a good management plan for their water resources. Management is made at different levels, from international to local level. Local level interventions are pivotal, as they can involve local populations, which are the primary users of those water resources. Local level interventions have the advantage of being easier than big national/international decisions, improving the quality of water resources not only at local level, but also in a more global level. Local populations, as they have a closer relation with the surrounding environment, will be more worried with the protection of natural resources (water resources included), what is also an advantage for local level management of water resources.

It's not easy to enroll all the parts of a local community in this process. The landowners are either the state, or privates. Farmers are among the biggest water consumers. They are sometimes difficult to convince about the benefits of water resources management. The public lands also require the responsible entity to be aware and cooperate in the management programme. Education and information are, therefore, crucial in this process.

A study of the World Bank on 35 watershed management projects (20 in Asia) involving implementation of predetermined physical and vegetative erosion control technologies indicates that, despite the expenditure of more than US\$500 million, results were less than satisfactory in halting erosion or improving people's livelihoods. This proves that the imposition of “grand-design” water resources management plans, designed and directed by outsiders with whom the population is expected to work with, seems to be ineffective in many situations. [4]

Integrated management of water resources involves the entire community, governmental agencies and non-governmental organizations. Lots of different professionals are involved in all the processes of the management practices. Primarily, it's responsibility of the governments to care about the water resources, making policies to protect them and improve the quality of these resources so that they can be used by the populations, and not affect the surrounding ecosystem. As shown, sometimes the measures don't work simply with the orders. It's necessary to educate at a local level, so that everyone can be a part of the management plan for the water resources, as water is fundamental and a (big) part of our lives.

1.4 WATERSHED MANAGEMENT

1.4.1 DEFINITION OF WATERSHED

Watershed, also known as drainage area, basin or catchment, describes an area surrounded by a ridge line, which drains its runoff through a single outlet (a river for example). Primarily, watersheds are divided by natural slope of the topography, but man-made structures, like storm sewers, may divert water flow across the drainage divides topography. Watersheds vary greatly in size. Usually, big watersheds are called river basins. Watersheds can be divided into sub-watersheds, and this sub-watersheds can be divided once again, and so on. Management practices vary according to the size of the watershed [5].

A good knowledge of the watershed is essential for a good management plan. The main characteristics of a watershed are:

- **Drainage Area:** reflects the volume of water that can be generated from rainfall. It's probably the single most important characteristic for hydrologic design;
- **Length:** is usually defined as the distance measured along the main channel from the watershed outlet to the basin divide. Since the channel does not extend to the basin divide, it is necessary to extend a line from the end of the channel to the basin divide following a path where the greatest volume of water would travel;
- **Slope:** inclination with respect to distance along the principal flow path;
- **Shape:** the way that a watershed looks like. Watershed shape reflects the way that runoff will go.

Other watershed factors are land cover and use, surface roughness and soil characteristics.

1.4.2 HYDROLOGIC PROCESSES IN A WATERSHED

Main hydrologic processes that occur in a watershed are precipitation, runoff and abstractions. These processes are a part of complex interactions between lithosphere, hydrosphere and the atmosphere.

Precipitation can be described as the total amount of water, both in solid (e.g. snow) or liquid (rain) state, falling from the atmosphere. Precipitation replenishes surface water bodies and recharge aquifer systems. After precipitation occurs, the hydrologic processes that occur in a watershed are the runoff and abstractions.

Runoff can be divided into surface runoff, sub-surface runoff and base flow. Surface runoff is the portion of rainfall which enters the streams directly after rainfall. Typically, surface runoff focuses on small water flows (e.g. rivulets), that will eventually join the main water flow, that characterizes the watershed. Sub-surface runoff (also known as interflow) refers to the water that penetrates the soil, but not deep enough to join any aquifer, moving almost at the same speed as the surface runoff. Surface and sub-surface runoff can be aggregated in direct runoff. Base flow is the share of runoff that comes from groundwater, being sometimes known as groundwater flow. It's not dependent on recent rainfall, as the water from this flow comes from the precipitation that infiltrates the soil and eventually reaches the water-table. This kind of movement of water is very slow. It takes long time for the water to join the main stream. Water coming from wastewater treatment plant can also be considered base flow [1].

Thus, runoff is the sum of direct runoff (both surface and sub-surface runoff) and base flow.

Abstractions are the water losses from the precipitation. Basically, water loss corresponds to the difference between rainfall and runoff. The different water losses are interception, evaporation and transpiration, evapotranspiration, and infiltration.

Interception corresponds to the part of rainfall that doesn't reach the ground. It may be intercepted by trees, buildings or some other object. Eventually, this water will evaporate and go back to atmosphere again.

Evaporation is the process of vaporization of precipitated water directly from plants or other surfaces. Transpiration is also a process of vaporization but corresponds to the losses from leaf pores, as a result of the respiration process. Both of these processes can be aggregated in a single one. It's called evapotranspiration and corresponds to the total loss of water from both evaporation and transpiration.

Infiltration is, as its name suggests, the downwards movement that the water does after reaching the surface of the earth. This process will result in replenishment of soil moisture, recharging of aquifers and ultimately supporting the stream flow in dry periods. Infiltration is an important theme for the study of the runoff. It is different from percolation, which refers to the transit of infiltrated water through the unsaturated zone. The quantity and rate of infiltration are functions of soil type, soil moisture, soil permeability, intensity of rainfall, among other factors.

1.4.3 WATERSHED MANAGEMENT

The management of a watershed comprises its two vital resources, land and water. Both resources are strictly linked as watershed management activities improve the productivity of land by increasing its humus and organic matter, which will improve infiltration and moisture holding capacities. Rapid increase in global population increases the stress over soil and water resources in a watershed. Thus, a good management is necessary. The main objectives for watershed management are:

- Flood control, reducing damage caused by sediments deposits to croplands;
- Protect, control the output and control the quality of runoff water from the watershed;
- Control soil erosion, reducing the sediment concentration in the runoff water;
- Protect the ecosystem in the watershed, improving the quality of forests and other green areas, and protecting wild life;
- Improve the quality of life for humans, improving the infrastructural facilities and increasing the output from land.

The application of the management practices implies the identification of the problem and its importance, the study of possible solutions, implementation and maintenance of those solutions and the evaluation of results.

We can divide the watershed management practices in two main groups – vegetative measures and engineering measures [4]. Both measures are equally important and necessary. Vegetative measures refer to measures as seeding and fertilizing of pastures, plantation of trees, woodlands, croplands, etc. Engineering measures are strip cropping, terrace construction, drainage structures, rainwater harvesting systems and reservoirs, among others. Vegetative measures are less costly and have as another advantage, the fact that can provide by-products (e.g. timber, food). These measures can be put on a wide range of physical sites with very little maintenance. The disadvantages of these measures are the initial growing time and the fact that they may be affected by seasonal changes. On the other hand, engineering measures are costly, don't give any by-product, have to be installed only in specific sites

and need constant maintenance, but they aren't affected by seasonal changes and their benefic effects are easily and readily measured and quantified.

Soil erosion control, as said before, is one of the main concerns in a watershed management plan. Soil erosion is caused by the detachment and removal of soil particles from land surface. We can distinguish between geologic erosion, caused due to natural causes, and accelerated erosion, which is triggered by the overexploitation of land surface. Soil erosion occurs due to 3 main causes – wind, water and gravity. Wind erosion occurs in arid and semi-arid areas, where the precipitation is low and the atmospheric temperature is high. Water erosion is caused by the impact of rain drops on the ground and by runoff. Water erosion caused by runoff occurs both in surface runoff and sub-surface runoff. Surface runoff causes scraping and transport of soil particles. Sub-surface runoff causes soil erosion in the form of pipe erosion. Soil erosion caused by gravity results in mass soil movement, which can be characterized as the instantaneous movement of larger volume of soil down the slope. Soil erosion, in all the three forms mentioned above, is caused by natural phenomenon (e.g. natural modification of the gradient of the flow, which will increase mass soil movement) and human activities (e.g. mismanagement of land resources, such as intensive farming, deforestation, etc.).

Groundwater refers to the part of water that goes down into the soil, filling in the voids formed by space between soil particles. It's important to know the groundwater resources while doing a watershed management plan. In the study of groundwater is essential to define an aquifer as a formation containing sufficient saturated permeable material which can yield significant quantities of water to wells and springs. An aquifer should have an ability to store and to transmit water. As groundwater is used commonly for drinking purposes, it has to be a part in watershed management.

A point of view that can't be forgotten in watershed management is the ecosystem approach. Ecosystem refers to all the living organisms, air, land and water. In the perspective of watershed management, ecosystem management emphasizes protection and restoration of natural resources, including fish and wildlife, vegetation, and various aquatic ecosystems, as streams, lakes and wetlands.

The community living in the watershed is the more interested part in a good watershed management plan. The ever-growing number of population especially in poor areas in south-Asia makes the number of subsistence farmers to increase dramatically, which may create serious problems in water resources in the watershed. Once again, education is essential, though in conditions of poverty, personal considerations generally override the community/common interest.

Although it would be desirable, not all the watershed management plans prove to be successful. First we have to see from which point of view we will evaluate whether the plan was successful or not. Views will differ among the different parts involved, as "success" for an engineer might not be considered as "success" by a farmer. To evaluate success or failure of the measures we have to look to the time frame that passed after the implementation. The later the final assessment is made, the better, as an improved draft of long term measures can be taken. Some of the reasons for failure in a watershed management are the fact that the management practices are design and implemented by "outsiders", that possibly don't know the watershed like those that live there, the fact of some management plans just look and act in a large-scale, instead of act in a smaller scale, which could give better results, and not enough information about the benefits of the measures, which could drive to more popular participation.

In order to reduce the possibilities of a failure in a watershed management plan, it's preferable to have small watershed management (knowing that a big watershed can be divided in smaller sub-watersheds). The management practices are basically the same as referred before, but they take more into account the opinion and experience of the population inside the small watershed. The Department

of Science and Technology of the Ministry of Science and Technology of India says that “planning and development of small watersheds calls for rigorous understanding about the occurrence and movement of water in the surface and sub-surface systems along with soil and nutrient losses in a small watershed” [11]. Thus, a programme on hydrology of small watershed was launched, where some of the main objectives were to generate data on hydro-meteorological, soil, nutrients and process related parameters at small watershed level in different agro-ecological zones of the country through instrumentation and to assess the impact of on-site and off-site management structures for soil and water conservation.

In order to assist in the management of those responsible for the watershed management plan, GIS (Geographic Information Systems) software can be used [6]. This software helps in the delineation of the watershed boundaries and some of them can help in the assessment of some of the watershed characteristics, such as elevation and help on the calculations related to the watershed (e.g. calculation of the runoff inside the watershed). Some of the software used for this purpose includes ArcGIS 9.3 and WMS 8.2. Both software is a powerful assessment tool and represents a good aid for those involved in the watershed management plan.

1.5 WATER CONSERVATION IN ARID AND SEMI-ARID REGIONS

According to different characteristics, we can distinguish different climatic regions. Characteristics such as temperature, pressure, humidity, evaporation, rainfall pattern and their amount, define a climatic region. The most common classification system for climatic regions is called Köppen climate classification, in honor of the Russian climatologist Wladimir Köppen. This classification divides climatic regions in five main groups, from tropical/megathermal climates, to polar climates. In order to have better conservation/management practices, it's necessary to know with what kind of region we are dealing with.

Arid regions are characterized by annual rainfalls less than 400 mm, and mostly during the summer months; high temperatures, that raise the value of evaporation, being this the cause for water loss; approximately constant infiltration capacity throughout the year, being, however, the water infiltrated into lower soil insufficient to make significant groundwater storage; very deep water-table, what makes groundwater exploration more expensive; stream flows are not continuous; development of sand dunes is the most common feature. An example of an arid climatic region is the city of Jaipur in the state of Rajasthan in India.

Semi-arid regions have as characteristics rainfall values between 400 and 750 mm per year; temperature higher than the normal, having the effects similar on those in arid regions, but in less proportion; evapotranspiration is the main reason for water loss; stream flows are continuous during rainy season, being not continuous during summer season; water-table exists at a moderate level. An example of a semi-arid region is the region of Murcia in Spain.

A phenomenon that happens in these two kinds of climatic region is drought, which represents creeping type disaster with the water deficit for longer duration [4]. It ruins the agriculture and disturbs the ecological balance of the region. The drought appearance is also responsible for affecting the groundwater quality. Although drought is not controllable, as it's not “man-made”, some measures can be done in order to control its effects. From a water conservation point of view, we can emphasize the adoption of more appropriate technology for operation of surface reservoirs; increase storage space for collecting additional water; use groundwater in a more effective way; conjunctive use of surface and

sub-surface water; inter basin water transfer; eliminate the water losses from the conveyance system; re-use of wastewater by making groundwater recharge; adopt more appropriate irrigation schedules; rainwater harvesting.

2

RAINWATER HARVESTING

As it was said, water resources are under big stress, especially in arid and semi-arid regions, where both surface water and groundwater are scarce. A good response to fight water scarcity is rainwater harvesting. Rainwater harvesting consists in collect and preserve the rainfall in order to use it for different purposes, such as human and livestock consumption, agricultural activities, sanitary waters, groundwater recharge, etc. Rainwater harvesting is not a recent theme, as our ancestors used it regularly. Extensive rainwater harvesting apparatus existed 4000 years ago in Palestine and Greece. After some time of less utilization of these techniques, rainwater harvesting became again a popular theme, especially in countries with water scarcity. An example is the island of Bermuda, where all new buildings have to have a rainwater harvesting system. Also in the Indian state of Tamil Nadu all the new buildings have to have a rainwater harvesting system.

Harvested rainwater can be used for storage for future use or to recharge of groundwater [13]. Decision about what usage water will have depends on the rainfall pattern or the particular region. Places with few dry periods are more suitable for water storage, while places where most of rain falls only in few months, being the rest of the year dry should recharge groundwater.

Typically, rainwater harvesting systems are constructed of three main elements, videlicet catchment area, conveyance system and storage device/recharge facilities [14]. Also a filter unit is advisable in most cases. The catchment area is the surface which receives rainfall directly and contributes the water to the system. According to the catchment area, water can be harvested in two specific ways, through rooftop harvesting and land surface harvesting. Other catchment surfaces may be used, such as parking lots for example. As rooftops are less exposed to pollutants, and as long as they are kept clean, they shall provide water with acceptable quality parameters, while water coming from land surface catchments is more expectable to bring some pollutants as well as bacterial contamination. Rooftop is suitable for human and livestock consumption, while surface water is more suitable for groundwater recharge or agriculture. The conveyance system refers to the conduits (pipelines) that will carry the water from the catchment to the harvesting system. Conduits are preferable to be in plastic materials (e.g. PVC), as water's pH values could be low, and could cause corrosion in metals. Storage devices exist when we want to store water. When the objective is to recharge groundwater, there are recharge facilities. Storage tanks may be either above or below the ground and should be closed in order to prevent external contamination. Storage tanks may be constructed in different materials like masonry or plastic. Recharge facilities refers to structures like dugwells or recharge pits, which are used to recharge groundwater.

2.1 STORING RAINWATER FOR DIRECT USE

Storage of water for direct use for human consumption is usually done in paved surfaces only, as the water harvested on those surfaces is relatively free of bacteriological contamination. One of the best places to collect the rainwater is in the rooftop of the buildings. The system has to be protected from contaminations such as leaves or debris, and the usage of a filter (e.g. mesh filter) is recommendable. A first-flush device is also advisable, in order to drain the water from the first rains out of the storage tank, as this water can bring contaminations like dust or other pollutants in rooftop or connecting pipes. According to the harvested water quality and final purpose, a filter might be necessary (e.g. sand filter). The design of the storage tank has to take in account the dry period, and should be designed to meet the requirements for this period. Some easy calculations have to be done to calculate the ideal tank size, as it will be shown later. Runoff coefficient will vary according to the surface and the different values can be found in tables.

Another way to harvest rainwater and store it for direct use is using land surface catchments. This technique is usually less complex than rooftop harvesting and allows collecting a bigger amount of water. It involves improving runoff capacity of the land surface through various techniques including collection of runoff with drain pipes and storage of collected water. This technique is mainly suitable for agricultural processes as the water quality might be affected by different kinds of impurities.

2.2 GROUNDWATER RECHARGE

Different kinds of recharge structures exist to ensure that rainwater will go underground, instead of draining away from the surface. Some structures promote the percolation of water through soil strata at shallower depth (e.g. recharge trenches, permeable pavements), and others conduct water to greater depths, where it will join groundwater (e.g. recharge wells). Existing structures like wells and pits can often be modified to be used as recharge structures and so, it's not necessary to construct any new structure [15].

2.3 BARRIERS TO THE WIDER IMPLEMENTATION OF RWH SYSTEMS

Although all the benefits associated to the implementation of a RWH system, there are still some issues that can act as a barrier to their wider implementation [16]. The main issues are:

- Low price of mains water: this is the main barrier, because if the water is supplied at a low cost, people will not be motivated to implement a RWH system;
- Climate variability: although we can have an idea on the rainfall pattern in the future based on past values, we will never have an exact value, what can affect the amount of water available to collect at a given time;
- Uncertainty over water demand patterns: the water demand is different from day to day, and trying to predict it in the future might be a problem;
- Relatively high implementation cost: the initial cost for of a RWH system may be an obstacle to its implementation

3

RAINWATER HARVESTING SYSTEMS WITH STORAGE PURPOSE – A CASE-STUDY IN KARUNYA UNIVERSITY

Karunya University is located in the locality of Karunya Nagar, 25 km away from the city of Coimbatore, in the state of Tamil Nadu, India. The region of Karunya is considered humid, but the region of Coimbatore is considered semi-arid and is facing problems with lack of water during some periods in past years. The University is surrounded by the mountains of Western Ghats, setting the scene characterized by the view of the green mountains. Karunya is located in the Siruvani watershed, which is a sub-watershed of Bhavani watershed, which itself is a sub-watershed of Cauvery watershed. In the Siruvani watershed there's a dam, which makes possible to provide water from there to the city of Coimbatore. All the region of Coimbatore is dependent of the water coming from Siruvani and the over-exploration of the water coming from this source is leading to serious problems, as well as the over-exploration of groundwater in some areas. The water coming from Siruvani has good quality, but some situations where the water supply was not enough were reported. Thus, water management measures are necessary in order to reduce the water consumption and over-exploration of groundwater. Rainwater harvesting emerges as a good, environmental-friendly measure that will reduce the water consumption coming from Siruvani and from the borwells, giving water with relatively good quality.

Karunya University is composed by 12 buildings inside the campus and plus 10 students/staff dormitories and guest house/restaurant. The total area of the campus is 27067 m². The Karunya University has around 7000 students, 450 professors and 230 supporting staff. The daily water consumption is shown in table 1:

Table 1 – Daily water consumption

Water source	Daily water consumption (m ³)
Siruvani water	15
Univ Borwell #1	137
Univ Borwell #2	120
Univ Sump #1	100
Univ Sump #2	90

Analyzing the values we conclude that most of the water consumed comes from the borwells and sumps located in the University campus. The water consumption from both borwells and sumps was calculated under the assumption that every student or staff inside the campus uses 60 liters per day.

The water coming from the borwells has low quality parameters and thus is used only for sanitary and gardening purposes (which represent the biggest *quota* of water consumption in the campus). Water for drinking/cooking purposes and to be used in labs, comes from the Siruvani Water Company, which supplies the water to Coimbatore city too.

Karunya University has 2 borwells, which are located near Ebenezer Auditorium and near the Sciences and Humanities block, and 2 sumps, which are located near the Sciences and Humanities block and near the main entrance of Karunya University campus. The borwells have, each one, a 7500 Watts pump that works 6 hours per day for the first borewell and 5 hours per day for the second. The first sump has a 7500 Watts pump working 4 hours per day, while the second has a 3750 Watts pump working 5 hours per day. The water used for drinking/cooking purposes and lab utilization comes from Siruvani Water Company and fulfils the quality parameters.

In order to improve the water resources nearby the University, if possible reducing the cost of water, and at the same time allowing more water with good quality to go to other places where it might be necessary, reduce the groundwater consumed and reduce the effects of excess rainwater might have, the implementation of a rainwater harvesting (RWH) system was planned as a part of a watershed management plan.

3.1 ROOFTOP RAINWATER HARVESTING SYSTEM FOR STORAGE PURPOSE

As part of water management practices inside the Karunya University campus, a system for rooftop RWH was planned. The main purpose of this system was to gain knowledge of how to build this kind of structure and educational purpose. Thus, economical results are not the prime concern, although should be taken in account. The system will be composed of the pipe network (conveyance system) that will lead the water from the rooftop to the tank that will work as storage structure. The purpose of the system is to harvest the rainwater in a part of the rooftop of the central building of Karunya University campus, corresponding to the old Electrical Sciences block. This building is the working place for 60 staff members (including professor's offices) and where 100 students have their classes. Presently the rooftop of the Electrical Sciences block has 16 pipes draining the rainwater from the rooftop to the ground. After the implementation of the structure, only the rainwater that is drained from four pipes will be utilized to store in the tank.

The main purpose of the RWH system is to store the water in the tank so it can be used in the future on a hand basin that is located 15 meters away from the storage tank. As the water consumption in the hand basin is only 200 liters per day, the stored water will also be used for gardening purposes in the months when the rainfall is higher. During dry months only the required water to supply to the hand basin will be supplied.

Note: Although presently the water used for irrigation is coming from the borwells, for the purpose of this work it was assumed that all the water that will not be consumed due to the implementation of the RWH system was coming from mains source previously.

3.1.1 RAINCYCLE© STANDARD V2.0 SOFTWARE

In order to construct the RWH system, the RainCycle© standard v2.0 software was used. This software is a spreadsheet-based application written for Microsoft Excel™ and is a powerful and user-friendly assessment tool. The function of the application is the hydraulic simulation and whole life costing (construction, operation/maintenance, etc) of RWH system for residential, commercial, industrial and public buildings. It is intended as an aid to decision making and can help to remove some of the uncertainty regarding the water supply/demand fluxes and cost issues surrounding RWH structures.

RainCycle© standard software was written primarily for RWH systems that collect, filter and store rainwater runoff from the surface of a catchment area, such as a roof. Simulations run for a period between 2 and 100 years, for both modeled rainwater harvesting system and an equivalent mains-only system so that a cost comparison can be made between the two options. Parameters as catchment area, rainfall patterns, storage tank volume and water demand pattern are user-definable and thus have to be obtained/calculated.

The main features of RainCycle© standard software are:

- Storage tank optimization routine, which allows the range of viable tank sizes to be identified early on the design process;
- Cost savings optimization routine;
- Simulation of the proposed RWH system up to 100 years. Main results are output as whole life cost (WLC) comparison between the modeled rainwater harvesting system and an equivalent mains-only system, percentage of water demand that the proposed system can meet and the pay-back period;
- Ability to take into account all associated costs, such as capital, maintenance/operating and decommissioning costs;
- Detailed hydraulic and financial simulation results.

In tables 2 and 3 is shown the data that is required in order to carry out a RWH system assessment.

Table 2 – Hydraulic data required for an assessment

Parameter	Units
Rainfall data	mm/day
Catchment area	m ²
Runoff coefficient	-
First-flush volume	l
Filter coefficient	-
Storage tank volume	m ³
Drain-down intervals	days
Power rating of pump	kW
Pumping capacity of pump	l/min
Water demand	m ³ /day

Table 3 – Financial data required for an assessment

Parameter	Units
Total capital cost	Rs
Maintenance/operation costs	Rs
Discount rate	%
Electricity costs	Rs/kW.h
Mains water costs	Rs/m ³

3.1.2 RAINCYCLE© STANDARD V2.0 SOFTWARE MODULES

System Map

The system map is the main navigation screen from which the rest of the applications can be accessed. The system map is divided into three sections, the title bar on the top, hydraulic modules that represent the stages that are involved in the collection, storage and use of harvested water in the middle and the analysis module on the bottom. In the title bar it's possible to see the System Diagram, which consists of a series of diagrammatic sketches that show the various components found in a typical RWH system and also the Global Settings.

Global Settings

Global Settings refer to the application-wide settings that can be configured. In the Global Settings menu it's possible to enable Status Boxes, set Analysis Runtime (range 2-100 years), select RWH System Cost Items (allows the user to include/remove any of the financial items associated with the RWH system), Select Currency and Select 1st Jan Day. In the hydraulic modules we have to input the data mentioned on table 2. Next the different hydraulic modules will be explained in detail.

Rainfall Profile

The objective of this module is for the user to input the annual rainfall values for the case study. The software allows the user to input either daily values or monthly values (in mm).

Catchment Surface

Here it's asked to the user to input the catchment plan area, runoff coefficient and first-flush volume (if any).

Rainwater Filter

In this module the user only have to input the rainwater filter coefficient.

Storage Tank

Here it's asked to input the storage tank volume as well as the drain-down intervals. These intervals correspond to the days that the tank needs to be emptied in order to facilitate maintenance activities. In this case it was decided that there will not be any drain-down interval. The tank storage volume was chosen to be 25000 liters as an initial approach.

Additional Inputs

This module is used only if the user wants to have any additional input of water. For this case-study no additional input was used.

Pump Details

This module is used to input the pump details. Both power capacity and pump capacity are requested.

UV Unit

A module for a UV unit is also present in the software. As the rainwater has typically good quality and it's not intended to be used for drinking purposes, this unit was not used in the present case-study.

Water Demand

Water demand module is extremely important, and one of the most difficult to type up. The software offers different pattern options with different water demand needs. A school demand pattern was chose. The next step is to identify workdays, weekend days and holydays.

Analysis Modules

The bottom layer in the software's system map is the Analysis Modules. Here all the analysis processes will be made, as well as comparing the whole life cost for both RWH system and a system with mains supply only. Next a description of the different modules is made.

Project Details

This module is used to enter both the company and client details relating to the system under study. The fields that are available in this module are date, company details, client details, project details, project description and project notes. These fields are replicated in the system report (except the project notes that are only for user information).

Whole Life Cost Details

This is the module where the life-cycle cost data for the system under study is stored. To input the data in this module it's necessary to know all the costs that will be involved in the system development. The costs involved in the calculations are:

- Capital Costs: in this field the total capital cost should be taken into account, including purchase of the system and components, excavation and installation costs, contractor's profit margin, etc.;
- Decommissioning Costs: this cost is assumed to occur in the end of the analysis runtime and refers to the removal/disposal of the system after it's no longer used;
- Operating Costs: all the costs associated to the operation shall be input in this field. Those costs are Discount Rate, Electricity Cost, Mains Water Cost and Disposal Cost;
- Disconnection Rebate: this field refers to the rebate that may exist sometimes, due to the diversion of rain water out of the sewage system;
- Maintenance Activities and Associated Costs: this field includes the costs of replacing/repairing the pump, routine scheduled maintenance activities, etc. The price of any maintenance activity has to be input as well as the frequency of this maintenance (e.g. a pump has to be replaced/repared every 5 or 6 years).

Optimize Tank Size

Before an in-depth analysis is made, the Optimize Tank Size module can be used to give an idea of the ideal tank size according to the specific rainfall profile, runoff coefficient, filter coefficient, first-flush volume, catchment area and water demand profile. The operator gives a maximum value for the volume of the tank to be simulated and the software gives both a table and a graphic with the values for the tank size *versus* the percentage of demand met. This module is extremely important, as it makes possible to decide the best option for a particular case-study.

Optimize Savings

Once a suitable range of tank sizes has been agreed on and all the capital and operation costs are concluded, it's possible to determine which tank size offers the best long-term performance using Optimize Savings module. In this module is possible to input until 10 different tank sizes with their respective capital costs. The analysis compares the potential cost savings, pay-back period and the percentage of demand met for the different tank sizes.

Optimize Other

This module is used to optimize the catchment area in order to obtain the maximum percentage of demand met.

Analysis Results

Shows the analysis results for the system under study, based on the data entered in the hydraulic and analysis modules. Results are presented both as long-term results (how the system performs over the whole analysis period as compared to a mains-only system) and short-term results (how the system performs on a yearly basis as compared to mains-only system). The Analysis Results module includes some sub-modules that include detailed hydraulic and financial information.

Print System Report

Allows printing a system report that is automatically generated saving time as it's not necessary to copy the results to another workbook or application.

I Want to Perform a...

This module opens a dialog box which allows the appearance of the application to be changed to suit the type of analysis being performed.

Data Entry Log

This module provides a summary of the key parameters and associated values.

Error Log

The Error Log keeps track of potential data input errors.

3.2 APPLICATION OF RAINCYCLE© STANDARD V2.0 SOFTWARE TO THE CASE-STUDY

3.2.1 GLOBAL SETTINGS

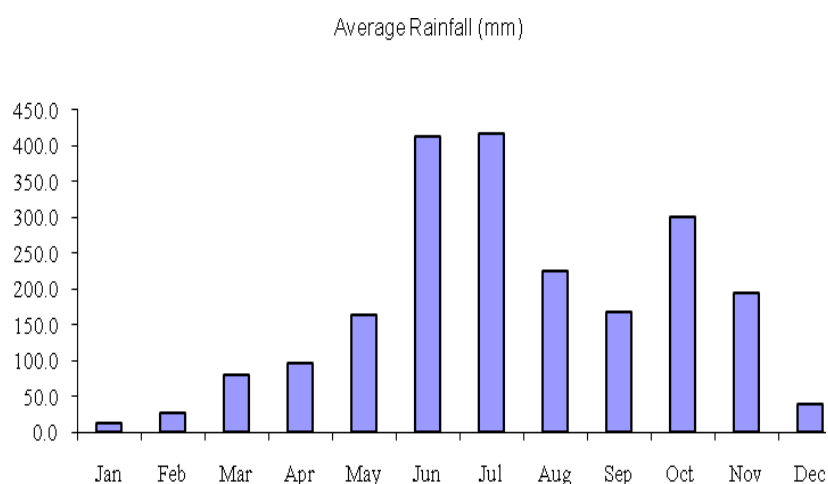
As mentioned before, the first thing to do while working with RainCycle software is changing the global settings. For the implementation of a RWH system in Karunya University campus, it was decided to have an analysis period of 20 years. All the financial costs/profits will be in Indian Rupees. For the analysis, the first day in January chosen was Friday (corresponding to the first day of 2010) and the selected RWH cost items were the capital costs, maintenance costs, pump operation and mains top-up.

3.2.3 RAINFALL PROFILE

Presently a station to measure the rainfall is being built inside the campus area in order to have exact data in the future. The values used in this case-study refer to a location 5 km away from the campus and can be used as they represent well the rainfall values in Karunya Nagar area. The rainfall values were obtained in the Tamil Nadu Water Supply and Drainage (TWAD) board. The values used refer to the years between 2003 and 2008. An average of the values was made and used to input in the spreadsheet as the rainfall monthly values. The TWAD board has the daily rainfall values, in mm, but only the monthly values were used, as they give an accurate result of the real rainfall. These values represent typical rainfall values for this area and can be assumed as average values for the different months. In order to have a more wide study, there will be made a study using the year with less rainfall (2003) minus 10 % of its monthly rainfall in order to simulate an extreme dry year. Also a year with high rainfall levels will be studied, using the data from the year with more rainfall (2006) plus 10 % of monthly rainfall. The values from 2003 to 2008 can be seen in annex. Next the average monthly rainfall values are shown.

Table 4 - Monthly rainfall in KU

Month	Rainfall (mm)
January	11.8
February	26.8
March	78.8
April	95.2
May	163.8
June	412.5
July	418.0
August	224.7
September	168.5
October	300.8
November	193.3
December	38.8
Total	2133.2



Picture 1 - Average monthly rainfall in KU (mm)

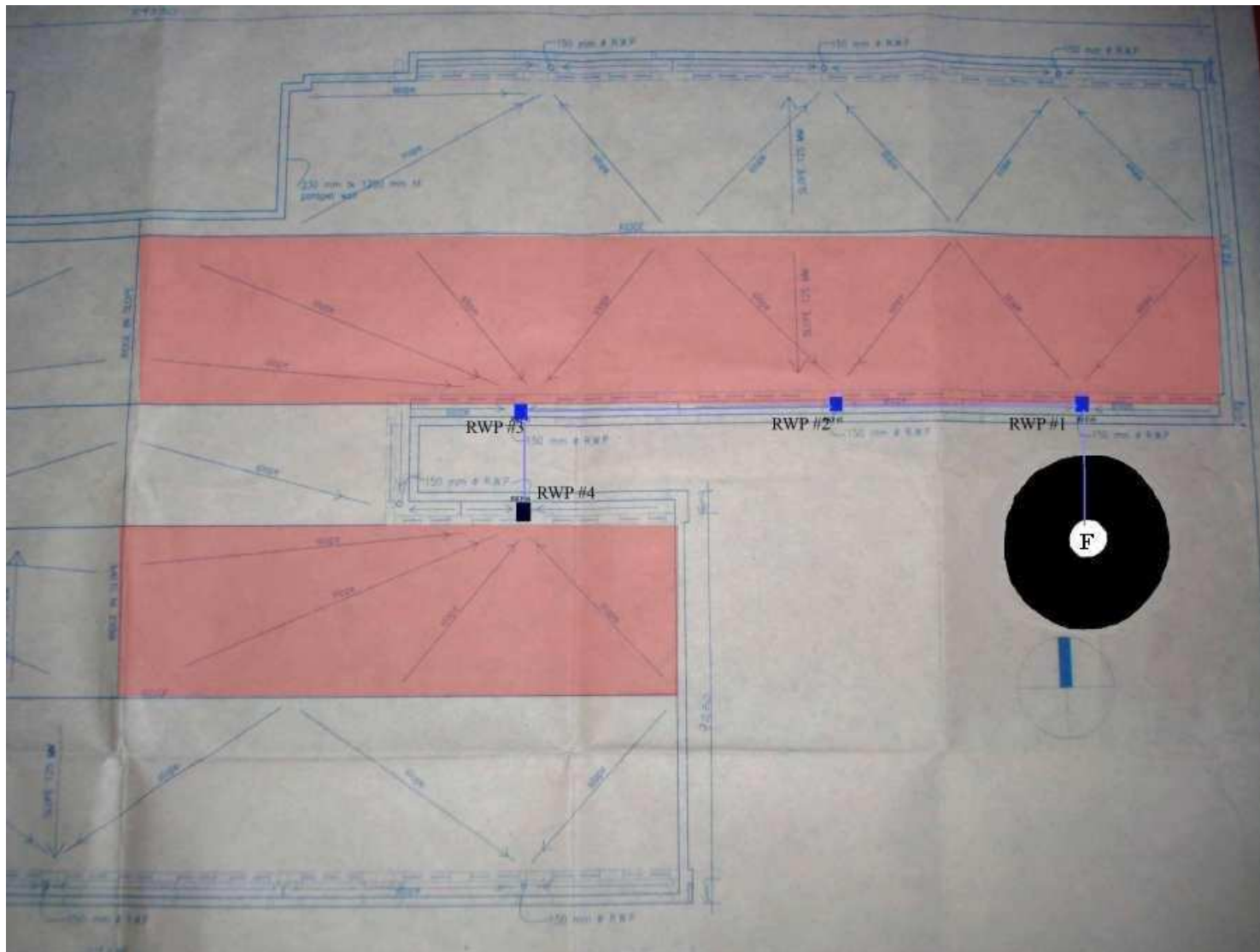
Analyzing the rainfall pattern for the region where KU is located, we see that there are few dry periods and thus the best option is to store the rainwater. In this case, recharging groundwater is also an acceptable solution, as the campus has a wide open area that makes easier to harvest the rainwater and use it to recharge the groundwater level, improving the groundwater level and quality. The months with the highest rainfall values (June and July) correspond to the months of the monsoon. In the months of December, January and February there's a dry period that will make the water level in the tank to low. The total annual rainfall is 2133,2 mm what makes the region of Karunya Nagar a humid

region. The water demand will be “decided” according to the rainfall in the different months meaning that in dry months only the most necessary water will be used (for the hand basin), while during wet months stored water will be used for gardening purposes.

3.2.4 CATCHMENT SURFACE

One of the most important values that one should know in order to design the RWH system is the catchment area that can be used to collect the rainwater. The building of Electrical Sciences has a big rooftop area (860m²), which will not be totally used as catchment area due to technical difficulties in bring the water from the opposite side of the building relatively to the place where the storage tank will be, and also because there's no need of such a big area for the storage tank/water demands in this case-study. Picture 2 shows the rooftop plan, showing the area that will be used as catchment area. Catchment area is the plan area of the roof top only, not the total area. The total plan catchment area is represented in red color in the picture. The total catchment area is obtained by the sum of the catchment area of 4 rainwater pipes. Rainwater pipes 1, 2 and 3 (in blue in the picture) have a total catchment area of 135 square meters, while catchment area of rainwater pipe 4 (in black) have a catchment area of 66 square meters, corresponding to a total area of 201 square meters. The pipes' entrance is protected with a grilled filter in order to prevent the entrance of bigger sediments. The total height of the building is 10,6 meters. The entrance of the rainwater pipes is located at a height of 9,6 meters.

The rooftop that will be used as catchment area is made of tiles and concrete. A typical value for runoff in this kind of roof is 0,80, meaning that 80 % of the rainfall that falls in the catchment area is collected. This value was adopted and input in the software. The first-flush volume was considered to be null, as the catchment area is cleaned regularly.



Picture 2 – Rooftop plan

3.2.5 CONVEYANCE SYSTEM

Eventually, only one pipe will connect to the storage tank. As the tank is close to rainwater pipe 1, it was decided that this would be the pipe connecting to the tank, through the filter unit (Picture 3). Each floor of the building has 3,2 meters height. Pipes 3 and 4 are separated by 2 meters. The connection will be calculated in order to have a slope of 10 percent. Existing pipe 4 will be cut in a height of 8,6 meters, where a “L” shape connection will be used and will be connected to pipe 3 at a height of 8,4 meters, in order to have a 10 % slope. The connection will be made by a “T” pipe in pipe 3. At this height, the “new” pipe will change direction, towards the direction of the storage tank. Pipes 1 and 3 are separated by 14 meters. Presently the rainwater pipes are surrounded by 2 walls of 5 cm thick, distancing 0,25 meters from the pipe. Between the walls surrounding the pipes, 2 other walls (with the same thickness) exist. This means, that in order to connect all the pipes into pipe 1, it will be necessary to make holes in 8 walls. These holes shall have the size to let the pipe go through it and, at the same time, they will act as supports to its weight. The slope is again selected to be 10 %. Knowing that the distance from pipe 3 to pipe 2 is 7 meters, it’s concluded that the junction point will be at 7,7 meters. The connection is again made by a “T” junction and from this point, the pipe will continue with the same slope to meet pipe 1. The distance from pipe 2 to pipe 1 is again 7 meters, meaning that the junction point is at a height of 7 meters. The same kind of junction that was used in the other cases is used here. From this point, the rainwater will go directly to the storage tank. The total height of the tank, relative to the ground level is 2.25 meters. The pipe shall not obstruct the way for the workers, as there’s an office after the location of pipe 1. The filter (where the pipe 1 will eventually connect) is located 4 meters away from pipe 1. Maintaining a slope of 10 %, the pipe can be cut at a height of 2.30 meters and connected to the filter. As the passage for the workers is only 30 cm large, it’s considered that these values can be accepted, as they will not obstruct the way to the workers.

While constructing the conveyance system it has to be taken into account that there will be necessary to have support points in different locations. Besides the holes in the walls that will act as supports, an extra support between every 2 rainwater pipes is recommended. Plus, in all the junctions, appropriate support must be given.

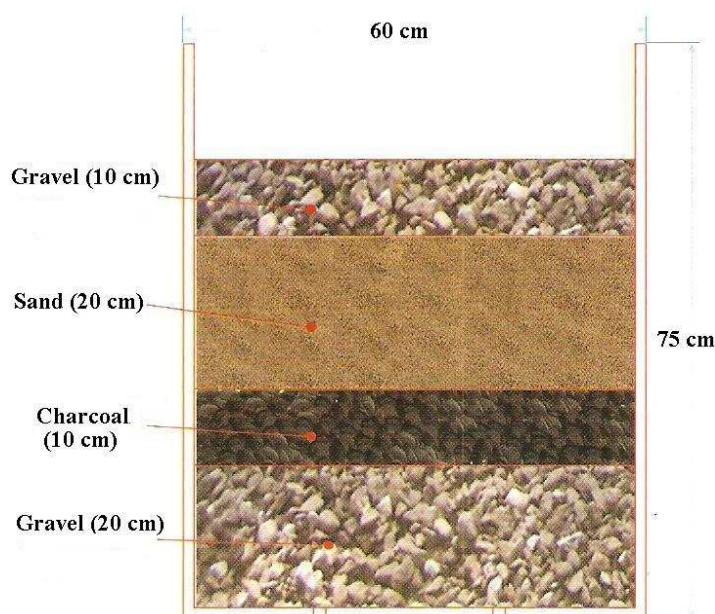


Picture 3 – Conveyance system

After being stored, the water has to go to two different places. It is necessary that the water goes to the hand basin and it is also necessary to connect the storage tank to a hose that will be use in gardening. It was decided that only one pipe will come out of the tank and that after passing the pump, it will be divided in 2, being the water flow controlled by a ball valve with T shape, that allows the water to flow either on both directs or only in one direction at a time. The total price of the conveyance system is Rs 2500 but it was not considered, as the University already has all the materials and the labor charge to implement it is already included in the price of the construction of the storage tank.

3.2.6 RAINWATER FILTER

The filter unit is an important part of a RWH system. Though in rooftop RWH, the rainwater comes with relatively good quality, the filter unit is advisable. The unit filters the rainwater, making it free from contaminants and suitable for storage. Filter unit can be made in ferrocement, preferably in cylindrical shape, being its construction easy. For a storage tank with capacity to store 25000 liters of rainwater, the recommendable size for the filter is a height of 75 cm and a diameter of 60 cm. For the RWH system in study, it was decided to do a typical sand-gravel-charcoal filter, consisting of gravel/broken granite chips/ good quality pebbles, medium sand and charcoal. The granite chips/gravel will be the first and last layers, while charcoal and sand will be in the between. The granite chips/gravel layer in the bottom of the filter will be 20 cm thick, followed by a 10 cm thick charcoal layer, 20 cm thick medium river sand and a fourth upper layer of 10 cm thick of granite chips/gravel. To avoid overflow of the initially harvested rainwater, a 15 cm vacant space was left in the top of the filter, being the top of the filter unit covered with a lid made of ferrocement. For this filter the value used as filter coefficient was 0,9, which corresponds to a typical value for this kind of filter. The filter media has to be replaced accordingly to the saturation level on it. It has to be prevented the clogging of the filter and the growth of bacteria/algae. In order to prevent this, the filter media shall be cleaned/replaced every 10 months. This value may change, accordingly to the usage and consequent saturation of the filter.



Picture 4 – Filter unit

3.2.7 STORAGE TANK

The storage system that will be constructed consists in a ferrocement storage tank with capacity for 25000 liters. The main objective is that the tank can have water the maximum time possible throughout the year, reducing (or eliminating) any overflow. It is expected that the tank can be completely filled during the months of October and November, assuming that it is empty. To see if this will happen, a simple calculation was made:

Catchment area = 201 m²

Rainfall (in October and November) = 494,2 mm

Runoff = 0,8

Volume of water harvested = 201 x 0,8 x 0,4942 = **79,5 m³**

As we can see, the rainwater during the months of October and November is more than enough to fulfill the tank. Even assuming an extremely low value for rainfall (150 mm) in these two months, the volume of rainwater harvested would be 24,12 m³.

There are various types and materials for the storage tanks. Plastic/fiber tanks are easy to find and are available in various sizes. The main disadvantages of these tanks are the very high prices and limited durability. Besides, after a period of time, these kinds of tanks may be unusable and their disposal leads to environmental problems. By the other side, masonry/concrete tanks are less expensive and cost-effective. Thus, ferrocement tanks emerge as cost-effective, durable, simple to construct, easy to repair/maintain and environmental friendly.

Ferrocement is a form of reinforced cement concrete in which the cement mortar is reinforced with layers of continuous and relatively small diameter wire mesh. The constituents of a ferrocement tank are steel, welded mesh, chicken wire mesh, cement and sand. Cylindrical tanks are preferable due to the fact that the hydrostatic pressure is distributed evenly and uniformly throughout the wall. Thickness of the wall may vary from 2,5 cm to 5,0 cm. For periodical cleaning and inspection of the tank, a square manhole of 60 cm x 60 cm sides will be provided on the dome of the tank which may be closed with a lid (also made of ferrocement). Care must be taken to prevent the entry of foul-water or insects to the tank through the manhole. Also, it should be ensured that the overflow pipe of the tank is covered with a mosquito net to prevent the entry of mosquitoes into the tank.

Another measure that should be used to protect the storage tank is having the iron fittings like tap and valve always neat and painted to avoid corrosion. Also the outer surface of the ferrocement tank may be painted periodically. The storage tank shall be always kept closed to cut off sunlight and thereby to prevent algal growth and bacterial contamination.

The tank to be constructed is designed to store 25000 liters of water. In order to know the dimensions of the tank, it was used a handbook on the construction of ferrocement tanks to store rainwater [7]. The handbook gives typical dimensions for a 10000 liters ferrocement tank and thus estimation has to be made in order to have the dimensions and material quantity for a 25000 liters tank [8].

The dimensions of the 25000 liter storage tank will be:

- Diameter: 3,26 m
- Height: 1.5 m

The storage tank will be constructed above the ground level (excluding the foundation) meaning that the total height of the storage system will be 2.25 m (0.75 meters from the filter unit and 1.5 meters from the storage tank itself). The foundation will be made in PCC (plane cement concrete) with a thickness of 30 cm, using 20 mm granite. The thickness of the storage tanks walls will be 4 cm and will have two layers of chicken mesh and welded mesh.

The construction prices for the different items are shown next.

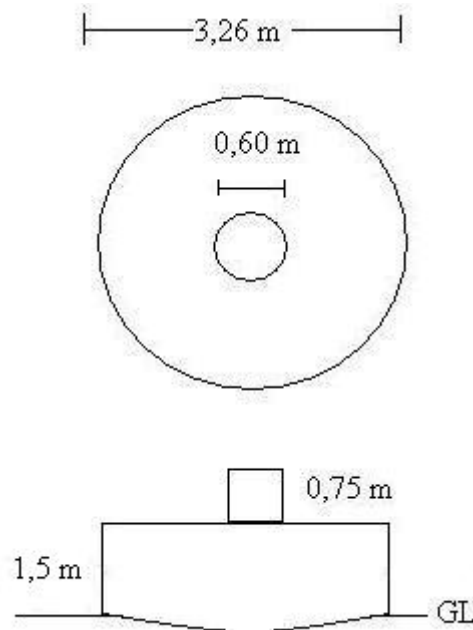
Table 5 – Construction Costs

Item	Quantity	Rate (Rs)	Total (Rs)
Basement Work	LS	LS	2500
Cement	26 bags	300	7800
Chicken Mesh	4.5 kg for 1 roll x 5	550	2750
Weld Mesh	16 gauge 1,22 meters x 1 roll	3000	3000
Weld Mesh	16 gauge 0,91 meters x 1 roll	2500	2500
8 mm Steel	85 kg	40	3400
6 mm Steel	50 kg	40	2000
Winding Wire	4 kg	75	300
Sand	5 m ³	1000	5000
Jelly	1,4 m ³	715	1000
Transportation	LS	LS	3000
Labor Charge (including accommodation and travel)	25000	0.7/Litre	16500
Supervision Charge	LS	LS	2500
Basement feeling and earth cutting	LS	LS	2500
Unforeseen Items	LS	LS	250
Total Construction Cost			Rs 55000

The construction of the tank is expected to take 2 weeks. After the construction, a curing period has to be introduced and only after that the tank may store rainwater. Although it's not included in the costs

table, the filter unit will also be constructed by the same company, not changing the final total price of the construction.

There was considered that there will no be any drain-down period. The periodical maintenance will be made during the dry season, when the tank will be empty or in its lower level.



Picture 5 – Storage Tank

3.2.8 PUMP DETAILS

The pump that is necessary for the RWH system in this study doesn't need to have a high elevation capacity, neither a high pumping capacity. Thus, it was selected a centrifugal jet pump, single stage with the follow characteristics:

Table 6 – Pump details

kW	Suc.Pre.Del. Pipesizes (mm)	Pumping capacity (l/min)
0,37	35x25x25	20

Suc. Pre. and Del. refers to suction, pressure and delivery pipe sizes. The selected pump has a cost of Rs 1800 and it's expected that it has to be replaced every 5 years.

3.2.9 WATER DEMAND

The purpose of the storage water is to be used in a hand basin located in the outside part of the main building and for gardening purpose. The hand basin is used by the workers of the nearby offices and workshops. The average water consumption in the hand basin is 200 liters per day during working days, while during weekends and non-working days there's the water consumption is 20 liters. The water for gardening purpose (the highest consumption inside the campus) will be used accordingly to the rainfall in the different months. The water for the hand basin shall be provided from the storage tank throughout the year. Only during the dry season, when the water level in the tank will be low/null, the water in the hand basin shall be provided from mains (if necessary). Knowing the number of working days in the University is possible to know the monthly water demand. In fact, the water demand is not exactly the water demand, but the water that can be supplied monthly through the RWH system. The water "demand" was calculated in order to have the fewer overflows possible and to have minimum days when the tank is empty. Thus, water demand corresponds to the water that the storage tank can supply in order to fulfill the requests mentioned.

Table 7 – Monthly water demand

Month	Working days	Weekend days	Water demand (m ³)
January	19	6	9,14
February	23	5	11,12
March	25	6	14,87
April	0	5	0,6
May	9	4	34
June	24	6	50
July	25	6	54
August	23	7	46,5
September	24	6	22
October	18	4	27,8
November	14	4	29,84
December	16	2	8,78
Total	225	59	308,65

In the months from April to November, it was assumed that the water consumption is independent relative to the type of day. This means that the water demand in a weekend or during a working day was the same. In the month of April there's not any working day. During this month it was assumed that only 20 liters per day were demanded, corresponding to some little consumption in the hand basin. During April the rainwater will not be used for gardening purposes, instead being used to raise the water level in the storage tank. During the month of May the demand will be 1200 liters in the first two weeks and 1000 liters in the second two weeks making a total demand of 34 m³. In June the consumption is 2000 liters during the first ten days of the month, while in the rest of the month the water

consumption will be 1500 liters. The first two weeks of July have a consumption of 2000 liters per day while the rest of the month and the entire month of August have a water demand of 1500 per day. In September the water demand will be 1000 liters in the first two weeks and 500 liters during the rest of the month. October will have a water consumption of 1000 liters in the first fifteen days and 800 liters in the last two weeks. In November the first ten days will have a consumption of 1200 liters per day, while in the rest of the month the demand will be 1000 liters per day (in the second two weeks of November the difference between weekend and working day consumption was taken into account). From December till March (the driest season of the year), the water in the tank has to be sufficient to fulfill the hand basin demand. In December, January, February and the first twenty days of March, the water demand/consumption is 500 liters during working days and 20 liters in non-working days (weekends and holydays). In the final days of March the water demand is assumed to be 750 liters per day.

The water demand will not be strictly as shown. The values used in this case-study correspond to average values of water consumption, assuming the average rainfall values. The essential in this system is that the water for the hand basin will be always available. The other objective is to reduce the overflow of rainwater. The demand in this case-study is basically the water that can be supplied through the RWH system. With this water demand both objectives are achieved, thus the system is operating near its optimal characteristics. The particular consumption will depend in the rainfall in the particular year and the water level in the tank. Those that will be responsible for the maintenance of the tank have to be careful so the tank doesn't go empty, as it would have extra-costs (the water in the hand basin would have to come from mains). Economical aspects of the system as well as two extreme cases (extreme dry and extreme wet years) will be shown after in this paper.

3.2.10 WHOLE LIFE COST DETAILS

Whole life costing is about identifying future costs and referring them back to present day costs using standard accounting techniques such as Present Value (PV). PV is the simplest and most commonly used discounting method available and is appropriate for application to RWH system which may have different time patterns of expenditure. During the analysis one have to know that PV has limitations and is sensitive to discount rates and assumptions of future costs and the timing of these costs. PV can be defined as the value of a stream of benefits or costs when discounted back to the present time (MAFF, 1999). The formula to calculate net PV is:

$$NPV = \sum_{t=0}^{t=N} C_t / (1+r/100)^t \quad (1)$$

where,

NPV = Net Present Value

N = Time horizon in years

C_t = Total monetary costs in year y

r = Discount rate in %

An evaluation of all the costs involved in the construction of a RWH system is, in most cases, the most important part of the work. People will not construct a RWH system if they just lose money with it. In this module only the economical costs are taken into account, as the environment costs/profits are more difficult to evaluate. For this case-study the most important thing was to gain the knowledge with the construction of RWH systems, and at the same time improve the environmental parameters in the region. Thus, economical costs were not the prime concern, although they were studied and evaluated.

The capital cost for the implementation of the RWH system is Rs 56.800. This capital cost includes the pump price, the conveyance system price (assumed to be null), as well as the construction materials and excavation works, plus the labor charges. Decommissioning cost was excluded from the analysis and so there will not be any expense related to this topic. Also disconnection rebate was considered to be zero, as such rebate doesn't exist in this case. The operation and maintenance costs are shown below.

Table 8 – Operation costs

Item	Units	Value
Discount Rate	%	3,5
Electricity Cost	Rs/kW.h	3,5
Mains Water Cost	Rs/m ³	35

Discount rate is a financial accounting technique commonly used by businesses to discount money with time in order to help make financial decisions that span several years. There's not a "correct" way to calculate the discount rate. For this analysis, the value of 3,5 % was adopted as a reasonable value.

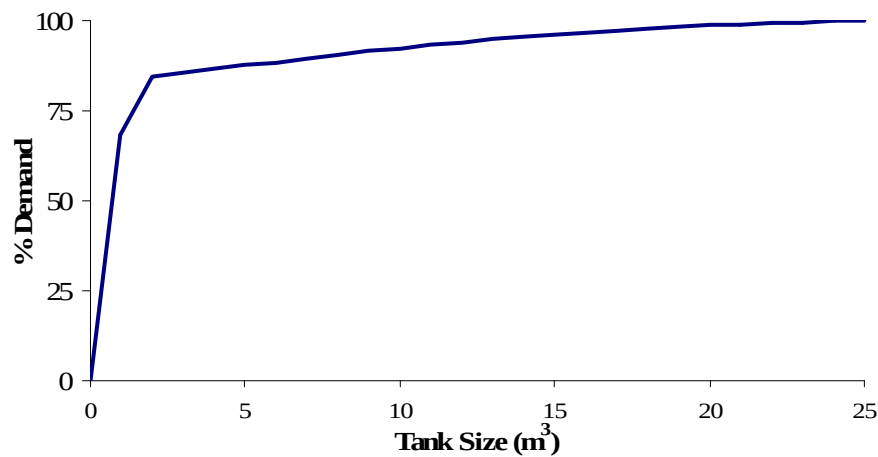
Table 9 – Maintenance costs

Item	Frequency	Cost (Rs)
Routine scheduled maintenance activities	Every year	700
Repair/replace pump	Every 5 years	1800
Clean/replace filter media	Every year	350
Clean catchment surface	Every year	-
Water quality analyses	Every 6 months	-

Cleaning the catchment surface was considered to have a null value, as this activity will be made by KU employees as a part of their normal work. Also water quality analysis was considered without any cost as these analyses will be a part of lab works in some KU courses. The schedule maintenance activities will also be made by KU employees, but the materials necessary for this purpose (like paint for the tank) will have to be bought. It was assumed that the pump has to be replaced every 5 years and that the filter media has to be cleaned every year.

3.2.11 OPTIMIZE STORAGE TANK SIZE

In this module it will be compared the tank size with the percentage of demand met. Although it's already decided that the storage tank will have a volume of 25000 liters, this optimization is useful so it's possible to compare the different tank sizes with the correspondent percentage of demand met. The water demand was "calculated" in order to have 100 % of demand met by rainwater. If in a particular year the water demand is higher than the average values shown in table 7, the demand met will not be 100 %, but less. If this happens the water may have to be delivered by mains source. Analyzing the graphic we can see that for a tank with a volume of 25 m³, the percentage met is 100 %. This analysis proves that for the rainfall profile in the region of Karunya Nagar and for the water demand in this particular case study, the best size for the tank is 25 m³ as it was decided to build.



Picture 6 – Tank size vs % Demand met

3.2.12 OPTIMIZE SAVINGS

In this module it will be compared the savings over 20 years, the payback period and the percentage of demand met. The analysis will be made between 5 different tank sizes with the respective capital costs.

Table 10– Tank size economic analysis

Tank Size (l)	Capital Cost	Savings over 20 years	Pay-back period (years)	Demand met (%)
10000	Rs 30.000	Rs 86 107	4	92,4
20000	Rs 40.000	Rs 86 018	5	98,7
25000	Rs 56.800	Rs 71 329	7	100,0
30000	Rs 62.000	Rs 66 129	8	100,0
35000	Rs 70.000	Rs 58 129	10	100,0

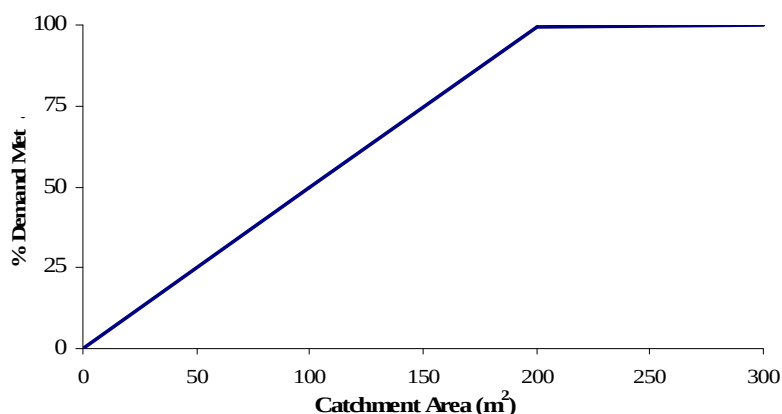
The chosen tank size (25 m^3) proves to be a good solution, as the percentage of demand met is the maximum possible and gives saving over 20 years in the amount of Rs 71.329. The pay-back period is 7 years, what can be considered as an acceptable pay-back period. The 30000 and 35000 liters tanks were just taken into account in order to have a more wide idea of the different prices for the tanks. Obviously they would never be an option in this case-study, as the water demand was decided in order to have 100 % of the demand met by a 25000 liter tank. These calculations didn't take into account the present value and this value might not be exactly true. In the Long Term Analysis module it was made a more precise calculation, taking into account all the cost present in the RWH system, as well as the net present value.

3.2.13 OPTIMIZE CATCHMENT AREA

Although it's not possible to change the catchment area due to technical difficulties, it's advisable to check if the catchment area that will be used will give a good value of percentage of demand met.

Table 11 – Catchment area vs % met

Catchment Area	% Met
0	0
100	49,8
200	99,5
300	100



Picture 7 - Catchment area vs % met

With a catchment area of 200 m^2 , 99,5 % of the water demand is met. This means that for this case-study the available catchment area (201 m^2) is a good value, as it will provide 100 % of the water demand.

3.2.14 LONG TERM ANALYSIS

The long term analysis module is where the long-term performance of the RWH system being modeled is compared to the performance of an equivalent mains-only system. The analysis was made for a period of 20 years and the summary of the values is shown next.

Table 12 - RWH system: results summary

Item	Value
RWH system WLC (NPV)	Rs 87 578
Total water demand (m ³ /20 years)	6173
Total water supplied (m ³ /20 years)	6173
% demand met by harvested water	100 %

The RWH WLC costs correspond to the capital cost (Rs 56.800) and maintenance costs (Rs 30.680) during the 20 years of the analysis. Capital costs represent practically 65 % of whole life costs, while maintenance costs represent the rest 35 %. As it was said previously, the system was designed to supply 100 % of water that is demanded.

Table 13 - Mains-only system: results summary

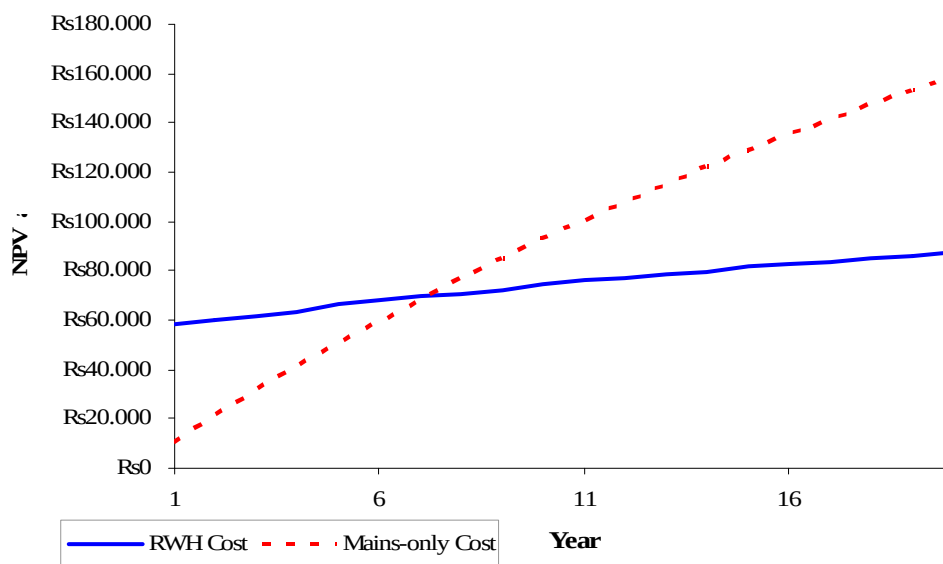
Item	Value
Mains-only supply WLC (NPV)	Rs 158 907
Total water demand (m ³ /20 years)	6173
Total water supplied (m ³ /20 years)	6173
Cost of water per cubic meter at PV (Rs)	25,74
% demand met by harvested water	100%

Comparing the WLC of a mains-only system with the RWH system under study, we know that with the RWH system we will have savings over 20 years in the amount of Rs 65.209 and the pay-back period will be 7 years with a discount rate of 3,5 %/year. Knowing the total amount of water supplied by both methods and the total price, it's possible to calculate the price of water per cubic meter. In a mains only system, the price will be Rs 25,74, while for the RWH system the price per cubic meter of water supplied will be Rs 14,19.

Table 14 - Long term analysis results

Long-Term Results Summary	Value
RWH system WLC @ NPV	Rs 87 578
Equivalent mains-only system WLC @ NPV	Rs 158 907

RWH system Savings over 20 years	Rs 71 329
Cost of water per cubic meter at PV (Rs)	14,19
RWH system pay-back period (years)	7



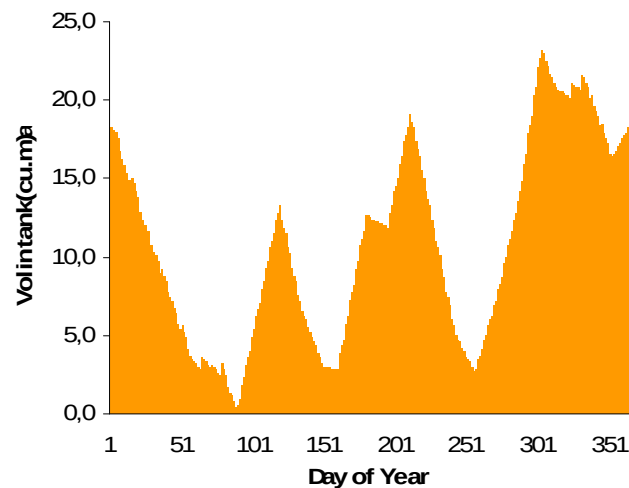
Picture 8 – NPV of RWH system and mains-only system over 20 years

3.2.16 HYDRAULIC RESULTS

The hydraulic results include rainfall profile graphics (already shown in Rainfall Profile module), runoff water coming from the catchment area, storage tank and water demand graphics.

Analyzing the runoff coming from the catchment area we conclude that we can harvest 343 m³ per year corresponding to 80 % of the total rainfall volume falling in the catchment area. Doing the opposite it is concluded that 20 % of the yearly rainfall is lost, corresponding to a volume of 86 m³ per year. After the loss of water in the catchment area, there will again some loss in the rainwater filter. The filter in this case study has a filter coefficient of 0,9, what means that 10 % of the water reaching the filter (34 m³/year) will not reach the storage tank.

The hydraulic results on the storage tank are very important, as it's possible to assess the days when there will be overflow or the days when the tank will be empty. The total amount of rainwater reaching the tank per year is 309 m³, after the losses on both catchment area and rainwater filter. Knowing the rainfall profile in the region under study, it was decided that there should be as less overflow as possible as well as no days when the tank would be completely empty. As said before, the water consumption was estimated under those assumptions. With the known rainfall profile and the water demand profile already shown, there will no be any overflow in the tank. Again, it has to be said that this values will change from year to year, as the rainfall profile will not be exactly the same nor the water consumption will have exactly the same values. The graphic with the volume of water in the tank throughout the year is shown next.



Picture 9 – Volume in the storage tank vs day of year

Analyzing the picture it's possible to conclude that there will not be any day where the tank is empty. We can conclude that in the month of March there's a dry period when the tank is almost empty. This time can be the time when the maintenance/cleaning activities of the tank are made. If necessary, the water supply to the hand basin will be made by mains top-up. In April the water level rises again, to values close to 15 m³ as this is a holiday month. In May, the volume of water in the tank decreases again but during the monsoon it is practically refilled again. During the months of June and July the demand is higher what makes the water level to decrease, but as the water demand gets lower (from August onwards) the tank gets full again. As said before the purpose is that the tank can be fulfilled completely during the months of October and November, what happens in the present study. During the dry season although the water demand is less, the storage tank gets almost empty, but the demand is met throughout the year.

The relationship between the water demand, water supply and water shortfall is shown in the next table.

Table 15 - Yearly hydraulic results

Month	Rainfall (mm)	Demand (m ³)	Harvested Water Supplied (m ³)	Shortfall(m ³)
Jan	11,8	9,1	9,1	0
Feb	26,8	11,1	11,1	0
Mar	78,8	14,9	14,9	0
Apr	95,2	0,6	0,6	0
May	163,8	34,0	34,0	0
Jun	412,5	50,0	50,0	0
Jul	418	54,0	54,0	0
Aug	224,7	46,5	46,5	0

Month	Rainfall (mm)	Demand (m³)	Harvested Water Supplied (m³)	Shortfall(m³)
Sep	168,5	22,0	22,0	0
Oct	300,8	27,8	27,8	0
Nov	193,3	29,8	29,8	0
Dec	38,8	8,8	8,8	0
Total	2133	308,7	308,7	0

The data shown in table 13 refers to the values of the “average year”. If the rainfall is less than the average values we will have some shortfall in the supply and if the rainfall values are higher we will have some overflow. Once again it has to be referred that the water demand will be accordingly to the rainfall in the particular year, being the average year values the most probable to happen.

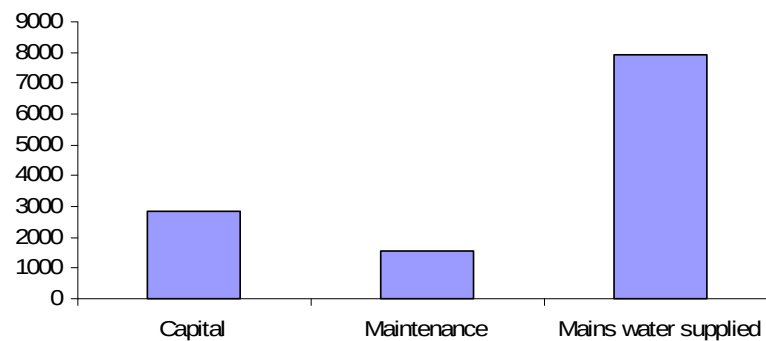
3.2.17 AVERAGE PER YEAR RESULTS

The average yearly running cost of the modeled RWH system is determined by summing the yearly cost of a number of individual elements. Not all those costs occur on an annual basis, e.g. capital costs that occur only once or the maintenance activities that occur in different time intervals. To report the costs on a “per-year” basis it’s necessary to normalize all the running costs. This can be done as follows:

- Per-year Capital Costs = Total capital cost / analysis runtime (years)
- Per-year Maintenance Costs = Cost of all maintenance activities over whole analysis / analysis runtime (years)

Summing these cost items gives the “average” yearly cost of the RWH system. The discount rate of 3,5 % was applied to all the costs. The average per-year results are shown next.

Table 16 - Average annual costs	
Cost Item	Cost (Rs/yr)
Capital	2 840
Maintenance	1 534
Mains water supplied	7 945
Savings (Rs/year):	3 566



Picture 10 – Average annual costs (Rs)

Both capital and maintenance costs refer to the RWH system. The annual costs of the RWH system are Rs 4374, while the total annual price of a mains only system is Rs 7.945. The average annual savings are Rs 3.566.

3.3 YEARS WITH EXTREME RAINFALL VALUES

In order to anticipate years with extreme rainfall values (both extremely dry and wet years) it's advisable to evaluate the performance of the RWH system in both conditions. Again, the main purpose is to reduce the overflow and have water in the tank throughout the year, at least to supply the hand basin. Both hydraulic and economical analysis will be made for both cases. The values used as extreme were obtained using the values of the years with both less (2003) and more (2006) rainfall and increasing or decreasing (depending on the case) 10 %. This can give a good approximation to years with extreme values.

3.3.1 EXTREMELY DRY YEAR

To simulate an extremely dry year, the rainfall values of 2003 were used and to those values 10 per cent more was subtracted. The rainfall values in a hypothetical dry year are shown next.

Table 17 - Rainfall in a dry year

Month	Rainfall in 2003 (mm)	Rainfall in 2003-10% (mm)
January	0	0,0
February	36	32,4
March	149	134,1
April	119	107,1

Month	Rainfall in 2003 (mm)	Rainfall in 2003-10% (mm)
May	1	0,9
June	220	198,0
July	184	165,6
August	87	78,3
September	14	12,6
October	267	240,3
November	142	127,8
December	10	9,0
Total	1229	1106,1

Analyzing the table 17 it's interesting to conclude that even on a hypothetical dry year the annual rainfall is above 1000 mm, proving that the specific region of Karunya Nagar has good rainfall values in different situations.

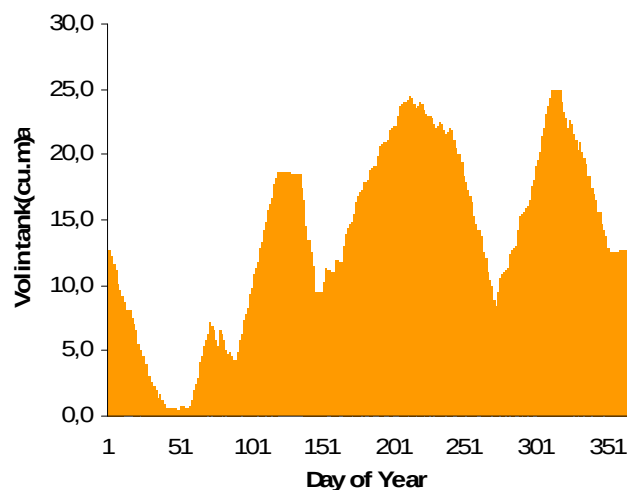
Knowing that the tank size has a storage volume of 25000 liters and the rainfall values in an extreme dry year it's possible to assess both economical and hydraulic parameters. The water consumption values that can exist in a dry year in order to the storage tank don't get empty are shown next.

Table 18 – Monthly water demand on a dry year

Month	Working days	Weekend days	Water demand (m ³)
January	19	6	9,74
February	23	5	6,92
March	25	6	16,32
April	5	3	0,6
May	9	4	9,44
June	24	6	20,22
July	25	6	17,62
August	23	7	13,96
September	24	6	15,1
October	18	4	22,9
November	14	4	14,32
December	16	2	8,78
Total	225	59	155,92

As already said, the water demand corresponds to the water that can be supplied through the RWH system ensuring that the water demand for the hand basin is always (or at least maximum time possible) fulfilled and that the overflow is reduced to its minimum value.

During the months of January and the first ten days of February, the water demand is 500 liters in working days and 20 liters during non-working days. In the rest of the days of February and the first two weeks of March, the water demand is only related to the hand basin (200 liters per day), while during the last two weeks the demand will be 1000 liters during working days and 20 liter during non-working days. In April and the first 15 days of May, the demand is only 20 liters per day as this is a holyday period. This period will refill the water level in the tank. The second part of the month of May and the first two weeks of June will have a water demand of 1000 liters during working days and again 20 liters during non-working days. The second part of June and the entire month of July will have a water demand of 700 liters daily during working days. The months of August and September will have 600 liters of daily water demand during working days. In the working days of November the water demand will be 1000 liters. During December the water demand is 500 liters during working days. The total annual water demand is $155,92 \text{ m}^3$, which represents practically half of the demand on an average year. This means that in a hypothetical dry year, the water that can be used through the RWH system represents half of the value comparably to a year with average rainfall values. The water level in the storage tank accordingly to the rainfall profile and the water demand is shown on picture 11.



Picture 11 – Volume in the storage tank vs day of the year

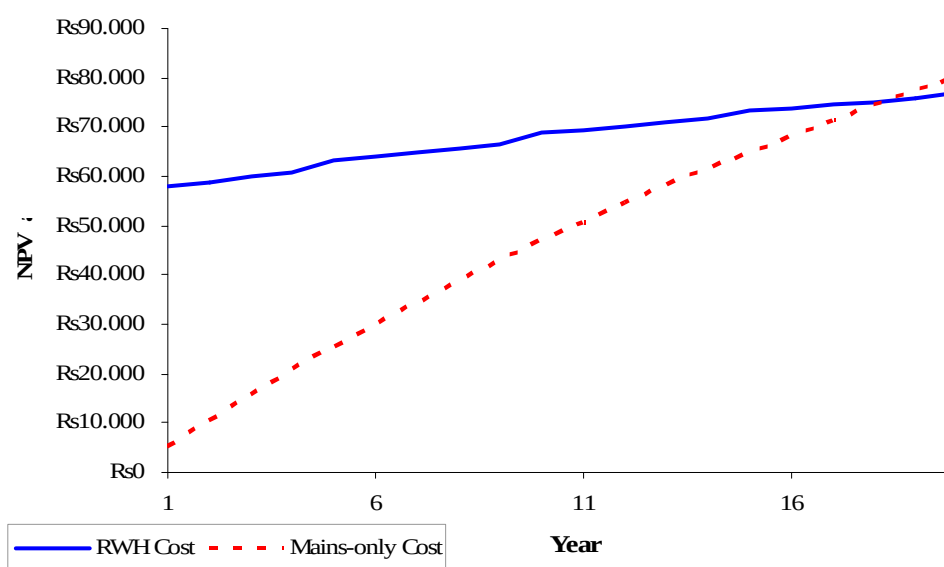
Analyzing the picture 10 we see that there's a dry period during the months of February and March and that during June, July, October and November the storage tank is practically full. The objective is that the storage tank can be full by the end of November so that more water will be available for the dry season.

Imagining an extreme case, where all the years would be as dry as in this case the economical aspects of the RWH system would be badly affected. The long term analysis for this hypothetical case was made.

Again, it was considered that the evaluation period would be 20 years and the maintenance costs were kept the same as for the average case. The long term analysis was made using the net present value (NPV).

Table 19 - Long term analysis results

Long-Term Results Summary	Value
RWH system WLC @ NPV	Rs 77 187
Equivalent mains-only system WLC @ NPV	Rs 80 275
RWH system Savings over 20 years	Rs 3 087
RWH system pay-back period (years)	18



Picture 12 – NPV of RWH system and mains-only system over 20 years

Analyzing the economical aspects in a long term perspective for the RWH system, assuming that all the years will be extremely dry, we can conclude that the pay-back period would occur only in 18 years. This is an extreme case and it's very unlikely to correspond to the truth in the future.

3.3.2 EXTREMELY WET YEAR

In order to simulate an extremely wet year that same principle used to simulate an extremely dry year was used. The year of 2006 was the year with higher rainfall values and to those rainfall values extra 10 percent were summed in order to simulate an extremely wet year. The values of both 2006 and 2006 plus 10 % are shown next.

Table 20 - Rainfall in a wet year

Month	Rainfall in 2006 (mm)	Rainfall in 2006+10% (mm)
January	42	46,2

Month	Rainfall in 2006 (mm)	Rainfall in 2006+10% (mm)
February	0	0
March	114	125,4
April	55	60,5
May	339	372,9
June	390	429
July	454	499,4
August	188	206,8
September	271	298,1
October	315	346,5
November	385	423,5
December	0	0
Total	2553	2808,3

Although the year of 2006 was the year with higher precipitation values, there were recorded two months when there was no rainfall (February and December). The monsoon months (June and July) are again the months with higher precipitation values, followed by the months of October and November. With this hypothetical rainfall pattern is possible to calculate how much water can be supplied through the RWH system. This supply will be considered as the water demand for the different months and was calculated like in the previous cases, under the assumption that the overflow would be minimum and that there will not be periods when the tank would be empty.

The water demand values during the different months of a wet year are shown next.

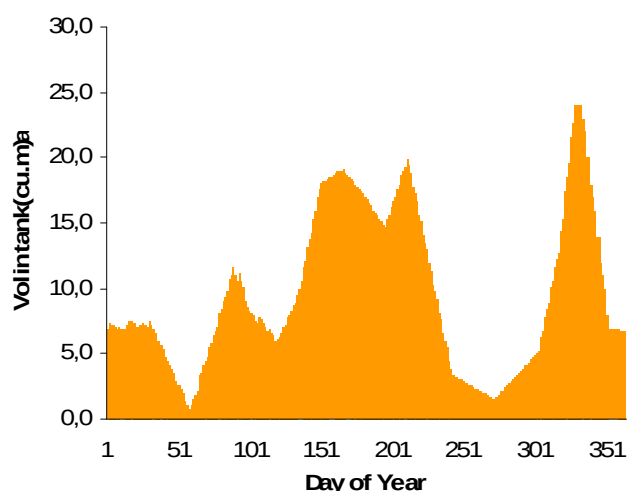
Table 21 - Monthly water demand on a wet year

Month	Working days	Weekend days	Water demand (m ³)
January	19	6	5,94
February	23	5	6,72
March	25	6	7,32
April	5	3	14,52
May	9	4	41,7
June	24	6	63
July	25	6	69,5
August	23	7	46,5
September	24	6	45
October	18	4	46,5

Month	Working days	Weekend days	Water demand (m ³)
November	14	4	37,5
December	16	2	17,28
Total	225	59	401,48

The water demand during the months of January, February and March will be 300 liters during working while during non-working days will be 20 liters. These months represent the driest period of the year, when the tank will be on its lowest level. The total demand during April is 14,52 m³ that comes from the consumption of 800 liters during the working days in the first 10 days of the month, while in the rest of the month the consumption is 500 liters during working days. In the months from May to November it was assumed that the water demand would be the same every day, independent of the type of the day. In May the demand is 1500 liters during the first 15 days, while in the rest of the month is 1200 liters. In June the demand is 2000 liters in the first two weeks and 2200 liters in the last two weeks. July has a water demand of 2500 liters during the first 15 days and 2000 liters during the rest of the month. August, September and the first 15 days of November have a water demand of 1500 per day. The rest of the month of November has a water demand of 1000 liters. In December the water demand is 1000 liters during working days, while during non-working days (both weekends and holidays) the water demand is 20 liters. Comparing the water demand/water supplied through the RWH system in a wet year and in an average year, we conclude that during a wet year is possible to supply almost more 100 m³ through the RWH system (308,65 m³ on an average year *versus* 401,48 on a wet year).

The water demand is a reflection of the water that the RWH system can provide. Knowing this it's possible to draw a graphic with the water level in the tank during the different day of the year. Again it has to be said that the water demand was calculated knowing the volume of the tank and the rainfall values. The main purposes were to avoid overflows and avoid days when the tank would be empty.

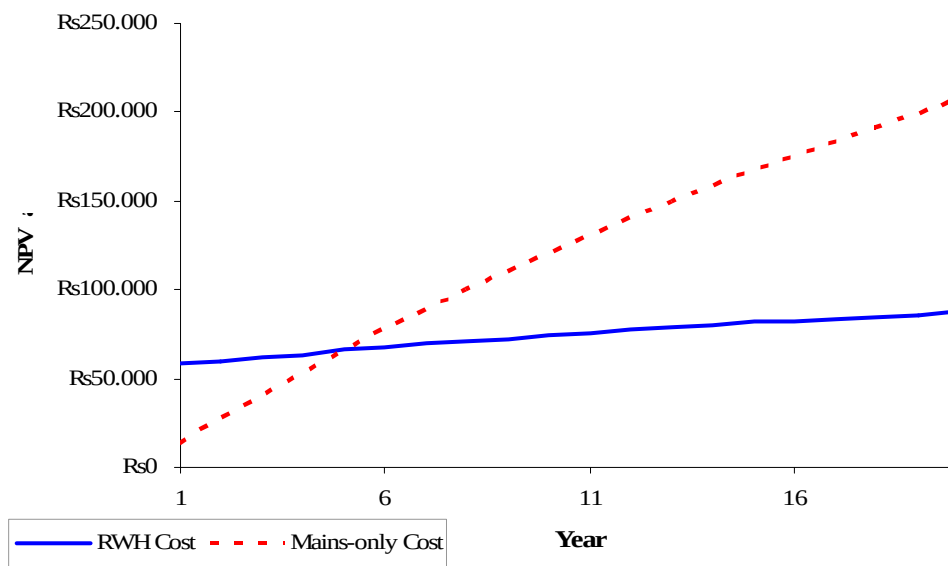


Picture 13 - Volume in the storage tank vs day of the year

Looking to the graphic we conclude that there will not be any day when the tank would be empty, but some overflow will occur in November. The value of the overflow is residual and thus was not considered to be a problem. During the end of February and September the water level in the tank reaches its minimum values. In the end of November the tank is full and ready for the dry period. Like in the case of an extremely dry year, an economical study to the RWH system assuming that all the years would have high rainfall values was made. The long-term analysis results are shown next.

Table 22 - Long term analysis results

Long-Term Results Summary	Value
RWH system WLC @ NPV	Rs 87 491
Equivalent mains-only system WLC @ NPV	Rs 206 700
RWH system Savings over 20 years	Rs 119 208
RWH system pay-back period (years)	5



Picture 14 – NPV of RWH system and mains-only system over 20 years

This hypothetical case of 20 years with high rainfall values proves to be the best in economical aspects. This is justified by the fact that the demand is calculated according to the rainfall volumes, meaning that more rainfall leads to more water used through the RWH system and, as a consequence, less water coming from the mains. The pay-back period of a RWH system in such conditions would be only 5 years but, as for the hypothetical case of extreme dry period, such rainfall profile is very unlikely to happen in the future.

3.4 ENVIRONMENTAL ACHIEVEMENTS AFTER RWH SYSTEM FOR RAINWATER STORAGE

Opposite to economic analysis, the environmental costs analysis is much more difficult to do. Is not easy to calculate how much money will be saved due to the fact that less water is being used from rivers or groundwater. For this paper only the environmental achievements will be mentioned, not taking into account the economical costs associated to environmental improvements, as that would imply studies in different areas, such as environmental management accounting.

The implementation of a RWH system will have different environmental improvements in the nearby are where it will be placed. A RWH system in a dry area will improve the water available in that area in two ways. First, the direct consumption of the rainwater will reduce the consumption of water coming from different sources and thus, as the second achievement, there will be more water available to recharge both groundwater and other water streams (e.g. rivers). Rooftop RWH systems to store the water prove to be a good solution in dry areas, as they are environmental friendly and help protect the water resources in that area.

In humid areas a RWH system will have a different utility. It will also save water from different origins but at the same time it will help preventing the effects of possible floods. The effect of a single rooftop RWH system might seem insignificant in order to prevent the effects of floods, but a conjunct of systems will certainly improve the response that a community can give to reduce all the bad consequences of a flood.

The poor people are the first to feel the consequences of both droughts and floods. In dry areas they will have difficulties to access clean and drinkable water, while in areas affected by heavy rains they will be the first ones to be affected as they live in the areas that are more likely to be affected by stormwater. A good watershed management plan, as part of integrated water resources management plan has to take into account the poor population. Both education and means have to be given to the population to improve their lives and at the same improve water resources.

4

RAINWATER HARVESTING SYSTEMS TO RECHARGE THE GROUNDWATER INSIDE KU CAMPUS

4.1 UNDERSTANDING GROUNDWATER

Contrary to what is sometimes believed, groundwater reserves are not lakes or streams under the surface. Groundwater refers to the water that is stored in the interstices of the soil or rock that form the earth. Only a few earth's types of crust materials possess enough porosity and permeability to contain and yield any sizeable amount of groundwater that can be made available for mankind.

An aquifer can be defined as a formation containing sufficient saturated permeable material which can yield significant quantities of water. An aquifer material must have enough pore spaces, and must be large enough so as to permit the extraction of water at useful rates. Thus, an aquifer should have the ability to store and transmit water at useful rates. Sedimentary materials constitute the largest percentage of earth's aquifers, including coarse unconsolidated materials and hard sedimentary rocks, like limestone and dolomite. *Aquiclude* may be defined as an impervious or almost impervious stratum that does not admit appreciable travel of water through it and hence does not yield appreciable quantities of water. A solid formation, such as solid granite which can neither contain nor transmit water is known as *aquifuge* whereas a formation such as sandy clay, which is saturated but retards groundwater movement and hence does not yield water freely to wells but can freely transmit water to adjacent aquifer, is termed *aquitard* and is characterized by the low hydraulic conductivity. Hydraulic conductivity can be defined as the property that says how easy is for the water particles to move through the pores of the soil. This property depends on the permeability of the material and on the degree of saturation.

Aquifers exhibit different properties regarding the occurrence and movement of groundwater. In some aquifers groundwater moves under pressure much greater than atmospheric pressure, while in some cases it is gravity the main force influencing the movement of groundwater. Based on those characteristics, aquifers can be defined as unconfined or confined.

An unconfined aquifer is sometimes referred to as water table due to the fact that the upper surface of the saturation zone is the water table. The term unconfined signifies the absence of any geological layer confining the zone of saturation (above the water table). At the water table, the hydraulic pressure head is equal to atmospheric pressure (i.e. zero). The hydraulic pressure head at any point within the unconfined aquifer is directly proportional to the depth of the point from the water table. The unconfined aquifer is in direct contact with the atmosphere through the zone of aeration. As said, the

upper part of an unconfined aquifer is the water table. The lower boundary is an impermeable layer (impermeable rock). A particular case of unconfined aquifer is known as perched aquifer. A perched aquifer is formed when the infiltrated rainwater is intercepted within the zone of aeration by an impermeable layer and a local zone of saturation is formed. The perched aquifer occurs at higher elevation than the “normal” aquifer, but its characteristics are similar. However, its extent is limited and thus the storage capacity is also limited.

Confined aquifer refers to an aquifer that has both upper and lower boundaries impermeable. It's a geological formation saturated with water. The groundwater within a confined aquifer occurs under pressure (known as confined pressure) greater than atmospheric pressure. When a confined aquifer is pierced by a well, the water rises in the well due to release of pressure within the confined aquifer. The level up to which water will rise in the well is known as potentiometric level. The potentiometric level indicates the magnitude of the pressure within the confined aquifer. Confined aquifers are also referred to as artesian aquifers and the confined pressure is also known as artesian pressure.

The main aquifer properties are the porosity of the soil, specific yield, grain size, saturation level, the hydraulic conductivity, storability and transmissivity. These characteristics explain the storage, transport and transmission of water inside the aquifer. In 1856, french engineer Henry Darcy made experiments related to the movement of water through a sand filter. He discovered that the velocity of water through a porous medium is directly proportional to hydraulic pressure difference between any two points within the medium and inversely proportional to the distance between two points. This is known as Darcy's Law. This Law is a powerful empirical tool used for quantification of groundwater resources as it can be used to calculate hydraulic conductivity of rocks, quantity of water flowing through the section of the aquifer, productivity of wells, etc.

4.2 NATURAL GROUNDWATER RECHARGE

The amount of water that can be extracted from an aquifer, not causing its depletion, depends on its natural recharge. Rainfall is the prime source for replenishment of moisture in the soil water system and thus of groundwater recharge. Moisture movement in the unsaturated zone is controlled by suction pressure, moisture content and hydraulic conductivity relationships. The natural groundwater recharge is, thus, the amount of moisture (water) that will eventually reach the water table. The natural groundwater recharge is dependent on the rainfall values and duration, soil characteristics, water table depth and the antecedent soil moisture conditions. Calculate the natural groundwater recharge is very difficult and all the methods to do so have are subject to large uncertainties and errors.

4.3 ARTIFICIAL GROUNDWATER RECHARGE

Artificial groundwater recharge can be simply described as the process by which the groundwater reservoir is augmented at a rate higher than in normal conditions of replenishment. Any man-made structure or facility that adds water to an aquifer can be considered as a groundwater recharge system [16]. Recharge groundwater artificially has different benefits, such as:

- Helps solving water problems in areas having inadequate water resources;
- Raises the groundwater level, making easier (and less expensive) to extract ground water for human purposes;

- Mitigates the effects of drought;
- Reduces the runoff which chokes the storm water drains;
- Reduces flooding of roads;
- Improves groundwater quality;
- Reduces soil erosion.

Recharging groundwater has good effects both in arid and in humid climates. In arid climates recharging helps keeping the water table level (or even increase it) giving more usable water to the population. In humid climates, especially during periods with high rainfall rates, artificially recharge groundwater helps preventing the flood effects that can go from simple problems to much more serious problems, such as the death of people [9]. In both cases, recharge groundwater will improve the groundwater quality and quantity, in comparison to natural groundwater recharge.

Typically, artificial groundwater techniques are used where:

- Adequate space for surface storage is not available (especially in urban areas);
- Water level is deep enough ($> 8\text{m}$) and adequate subsurface storage is available;
- Permeable strata is available at shallow/moderate depth;
- Adequate quantity of surface water is available for recharge to groundwater;
- Groundwater quality is bad and it's wanted to improve it;
- There's possibility of intrusion of saline water (especially in coastal areas);
- The evaporation rate is very high from surface water bodies.

4.4 ARTIFICIAL GROUNDWATER RECHARGE STRUCTURES

As previously said, rainwater harvesting systems can be used with two purposes: storage the rainwater for direct use or to recharge groundwater. The water to recharge groundwater can come from rainfall over the demarcated area, rooftops from where water can be collected and diverted for recharge, natural streams from which surplus water can be diverted for recharge, without violating the rights of the users and from wastewater treatment plants. This last source should only be used after ascertaining its quality. For the purpose of this work, only the rainwater will be taken into account as a source for recharge.

There are various kinds of recharge structures to assure that rainwater will percolate in the ground, instead of draining way. While some structures promote the percolation of water through soil strata at shallower depths (e.g. recharge trenches, permeable pavements), others are designed to conduct water to greater depths from where it joins the groundwater (e.g. recharge wells) [10]. Previously existing features like wells, pits and tanks can be modified to be used as recharge structures, eliminating the need to construct any structures afresh. The recharge structures generally used are:

- Pits: Recharge pits are constructed for recharging the shallow aquifers. Typically they are constructed 1 to 2 meters wide and 2 to 3 meters deep, and are filled with boulders, gravels and coarse sand;
- Trenches: are constructed when the permeable strata is available at shallow depths. Trench may be 0.5 to 1 meter wide, 1 to 1.5 meters deep and 10 to 20 (or more) meters long, depending upon availability of water. Trenches are filled with filter materials;
- Dug wells: Existing dug wells may be utilized as recharge structure and water should pass through filter media before putting into dug well.

- Recharge wells: Are constructed for recharging the deeper aquifers and water is passed through filter media to avoid choking of recharge wells. Typically they have between 100 to 300 mm diameter;
- Recharge shafts: For recharging the shallow aquifers which are located below clayey surface, recharge shafts of 0.5 to 3 meter diameter and 10 to 15 meters deep are constructed and filled with filtering materials such as boulders, gravels and coarse sand;
- Lateral shafts with borewells: For recharging the upper as well as deeper aquifers, lateral shafts of 1.5 to 2 meters wide and 10 to 30 meters long can be constructed, with one or two borewells. The lateral shafts is filled with boulders, gravels and coarse sand;
- Spreading techniques: When permeable strata starts from top then this technique can be used. Spread the water in streams by making check dams, cement plugs, gabion structures or a percolation pond are possible solutions.

4.5 PLANNING OF ARTIFICIAL RECHARGE PROJECTS

In order to perform a groundwater recharge project, some issues have to be taken into account first. The first step is identifying the area that will be used to collect the rainwater. All the recharge projects are site specific and can't be replicated to other areas, even if with similar characteristics [17]. After the selection of the recharge area, it's necessary to perform scientific studies and calculate the runoff inside the catchment area. The necessary scientific studies are:

- Hydrometeorological studies: Used to know the rainfall pattern, evaporation losses and climatological features. These studies are important, as they can predict the evaporation losses, indicating the best size for the recharge structure;
- Hydrological studies: Used to assess the amount of water that will be available to eventually be recharged;
- Soil infiltration studies: Soil and land use conditions control the rate of infiltration and downward percolation. In order to know the infiltration rates of different types of soils, tests have to be done;
- Hydrogeological studies: Used to know the different soil strata characteristics, and to draw maps with the location of different geological strata, their geological age sequence, boundaries/contacts of individual formations and the structural expressions. These maps also bring out correlation of topography and drainage to geological contacts. These studies shall also assess the aquifer geometry;
- Geophysical studies: These studies purpose is to help and asses the unknown sub-surface hydrogeological conditions economically, adequately and unambiguously. The application of geophysical methods is to bring out a comparative picture of the sub-surface litho environment, surface manifestation of such structures, and correlate them with the hydrogeological studies;
- Chemical analysis on source water: Bacteriological and chemical analyses are fundamental in order to assure that the water going to recharge groundwater has good quality. If the source of water is rainfall, there shouldn't be necessary lots of precautions, but some filtration unit is recommended.

One phenomenon that has to be minimized to recharge the groundwater is clogging. Clogging is the phenomenon by which the pores get obstructed and don't let the water percolate. The water to be recharged must be silt-free. Silt may be defined as the content of undissolved solid matter, usually measured in mg/l, which settles in stagnant water with velocities which do not exceed 0.1 m/hour. Clogging by biological activity depends upon the mineralogical and organic composition of the water

and soil floor and upon the grain-size and permeability of the floor. Some measures to minimize clogging include periodical removing of the mud-cake and dicing or scraping of the surface layer and the installation of a filter on the surface, the permeability of which is lower than of the natural strata (the filter must be cleaned/renewed periodically).

After the hydrogeological and geophysical surveys, the thickness of potential unsaturated zone for recharge should be worked out to assess the potential for artificial recharge in terms of volume of water which can be accommodated in this zone. The studies should bring out the potential of unsaturated zone in terms of total volume which can be recharged [18].

4.6 GROUNDWATER RECHARGE IN KARUNYA UNIVERSITY CAMPUS

The number of students in Karunya University is increasing year after year. This fact means that the water consumption will increase in order to answer to the demand. As the groundwater is the main water source in KU, its level is decreasing. Although in the present this fact doesn't represent a problem, it is expected that in a near future, groundwater level will be very low, making the water extraction much more costly and, on an extreme case, the aquifer that gives water to KU might go dry. This reason, only by itself would be enough to think about recharge the groundwater in KU. As seen previously, groundwater recharge through rainwater harvesting is a good measure to fight against both water shortage and to control excess of runoff during the periods with peak rainfall values. In Karunya area, a system to collect the rainwater and recharge it would have both effects.

Although being the most used water source in KU, groundwater doesn't have drinking quality. By recharging properly filtered rainwater into the aquifers, the groundwater quality will be improved and will help to prevent the lowering of the aquifer level. This means that less money will be spent on pumping the groundwater and that more water will be available to be used in different places than only inside KU campus. A full study about groundwater recharge inside KU campus is planned to be done in a near future.

Note: Due to lack of time to perform this full study and some difficulties to access the existing soil type maps, only the calculation of the surface runoff will be done on this paper, assuming some data that was not possible to access or obtain.

During the months with higher rainfall values, the houses located near KU are affected because of the runoff water coming from the campus. This happens because the campus acts like a big catchment area, with less tall vegetation and trees than the normal in that zone and because a part of the campus is made of tar roads and, obviously the buildings rooftops, which will have a runoff value much higher than normal soil. Most of the excess runoff goes directly through a channel that goes from the campus to a vegetation area located 1 km away. This runoff, when in excess, will also contribute for the soil erosion, what can eventually become a problem for farmers, local community and for the whole watershed area, if not controlled.

The main problem due to the excess rainwater surface runoff is that during periods with high rainfall values, the water overflows the channel, making a water layer in the road, which creates problems to the drivers and eventually reaches the houses next to the road creating all sorts of problems to the local population. These problems include for example water entering inside the houses, carrying all sorts of garbage, water entering inside the stables and on an extreme case, the water may affect the houses as in some cases they are made of very fragile materials.

In order to prevent excess runoff water to reach the main road and the nearby houses, improving the groundwater quality and preventing the aquifer level to go lower, groundwater recharging through rainwater harvesting was planned inside KU campus.

There are various different ways to calculate surface runoff values. For this work it was chosen to use the Soil Conservation Service (SCS) Runoff Curve Number (CN) method. Although presently the correct name is United States Department of Agriculture (USDA) Natural Resources Conservation Service, this method is still popularly known as SCS curve number. This is a simple method, widely used and efficient for determining the approximated amount of runoff due to rainfall [11]. Although the method is designed for a single storm event, it can be scaled to find average annual runoff values. The only data required for this method is the rainfall values and the curve number (CN). The CN is based on the area's hydrologic soil group, the land use, the soil treatment (e.g. has the soil been plowed or is it bare soil) and on its hydrologic condition (poor, fair, or good, depending on how easily water runs off the surface). This number is also dependent on antecedent moisture condition (AMC). AMC is an attempt to account for the variation in CN at a site from storm to storm. CN for the average AMC at a site is the median value as taken from sample rainfall and runoff data. The curve numbers given on table 23 are for average condition (AMC-II). There are also CN values for dry and wet conditions.

Hydrologic soil groups are used to classify the drainage potential of the soil. Group A soils absorb a lot of water and are deep, well drained and composed of sand or gravel. Conversely, group D soils do not absorb as much water and have a high runoff potential, and have a layer of high clay content near the surface or are shallow soils over bedrock or other material which do not absorb water. Land use refers to the different ground covers. The ground cover may be a road/street or a residential area, in an urban area, or pastor or woods in rural areas. Hydrologic condition refers to how dense or sparse the ground cover is, and thus how easily there will be runoff water. Obviously this definition only makes sense in some kinds of soil, such as agricultural cover, while in some types, like roads, it's meaningless. If the ground cover is relatively sparse, the hydrologic condition is called poor, while in the opposite case is called good (i.e. if the ground cover is dense). If there's a case in the between, the hydrologic condition is called fair. The runoff will be higher in areas classified as poor in hydrologic condition. Determine what's the hydrologic condition will depend on the different types of ground cover. For example, for brush or pasture, over 75 % ground cover is good and below 50 % is poor. For open space in urban areas, above 70 % is good. The CN data is provided as a table. A table with some different runoff curve numbers is shown in table 23.

Table 23 – Table of some runoff Curve Numbers (SCS, 1986)

Description of Land Use	Hydrologic Soil Group			
	A	B	C	D
Paved parking lots, roofs, driveways	98	98	98	98
Streets and Roads:				
Paved with curbs and storm sewers	98	98	98	98
Gravel	76	85	89	91
Dirt	72	82	87	89

Cultivated (Agricultural Crop) Land:

Without conservation treatment (no terraces)	72	81	88	91
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With conservation treatment (terraces, contours)	62	71	78	81
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Pasture or Range Land:

Poor (<50% ground cover or heavily grazed)	68	79	86	89
--	----	----	----	----

Good (50-75% ground cover; not heavily grazed)	39	61	74	80
--	----	----	----	----

Meadow (grass, no grazing, mowed for hay)	30	58	71	78
--	----	----	----	----

Brush (good, >75% ground cover)	30	48	65	73
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Woods and Forests:

Poor (small trees/brush destroyed by over-grazing or burning)	45	66	77	83
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Fair (grazing but not burned; some brush)	36	60	73	79
---	----	----	----	----

Good (no grazing; brush covers ground)	30	55	70	77
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Open Spaces (lawns, parks, golf courses, cemeteries, etc.):

Fair (grass covers 50-75% of area)	49	69	79	84
------------------------------------	----	----	----	----

Good (grass covers >75% of area)	39	61	74	80
----------------------------------	----	----	----	----

SCS method assumes that the ratios of actual to potential quantities are equal:

$$\frac{F_a}{S} = \frac{R}{P - I_a} \quad (2)$$

where,

R = Runoff (mm)

P = Rainfall (mm)

S = Potential maximum retention after runoff begins (mm)

I_a = Initial abstraction (mm)

F_a = Continuing abstractions (mm)

From continuity principle:

$$P = R + I_a + F_a \quad (3)$$

Initial abstraction (I_a) refers to all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation and infiltration. I_a is highly variable but generally is correlated with soil and cover parameters. Through studies of many small watersheds, I_a was found to be approximated by the following empirical equation:

$$I_a = 0,2.S \quad (4)$$

Due to the abstractions, there might be some rainfall that will not lead to runoff. Using formulas 2 and 3 we can say that:

$$R = \frac{(P - I_a)^2}{P - I_a + S} \quad (5)$$

This is the same to say that:

$$R = \frac{(P - 0,2.S)^2}{(P + 0,8.S)} \quad (6)$$

Potential maximum retention after runoff begins (S) is related to the soil and cover conditions. S is related to CN by:

$$S = \frac{25400}{CN} - 254 \quad (7)$$

As CN is dependent on antecedent rainfall conditions, there were established three different conditions: dry (CN I), normal (CN II) and wet (CN III). USDA (former SCS) established values for wet, normal and dry conditions. This values can be seen on table 24.

Table 24 – AMC values

AMC	Precipitation (mm)
I (dry)	< 36
II (normal)	36 - 53
III (wet)	> 53

The precipitation values refer to the accumulated precipitation in the previous 5 days from the day that is being calculated. This means that the AMC (and thus the CN) will be used accordingly to the rainfall in the past 5 days. While doing the calculations on Excel spreadsheet it's necessary to take this fact into account and care has to be taken, in order to obtain the final result (runoff) as daily value and not as the cumulative value.

Knowing CN II from the CN table, it's possible to calculate the other CN's using the following formulas:

$$CN(I) = \frac{4.2CN(II)}{10 - 0.058CN(II)} \quad (8)$$

$$CN(III) = \frac{23CN(II)}{10 + 0.13CN(II)} \quad (9)$$

It is very unlikely that the entire basin (in this case the campus) has the same kind of land use or the same soil type. This means that there will be different CN's for different areas inside the basin. As for the calculations of runoff only one value of CN is required, it is necessary to calculate the average CN for the basin in study. First is necessary to divide the basin (campus) into different areas according to the land use (previously done) and calculate the different CN's for those areas. After that a simple calculation is done, in order to know the overall curve number. This formula is shown next.

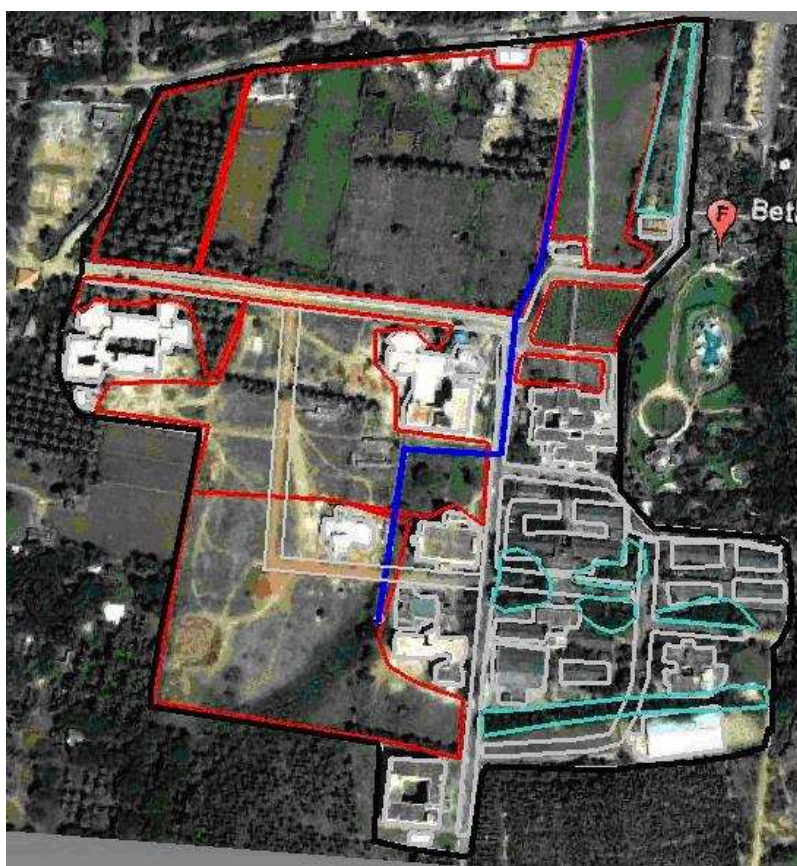
$$CN = \frac{1}{A} (A_1.CN_1 + A_2.CN_2 + A_3.CN_3 + A_4.CN_4) \quad (10)$$

where,

$$A = A_1 + A_2 + A_3 + A_4 \quad (11)$$

The first step when calculating the runoff inside KU campus is to evaluate the land use. This will be done using software WMS 8.2 (Watershed Modeling System). This software is a powerful tool to automate modeling processes such as basin delineation and GIS overlay computations, such as CN for example. The campus will be treated as a watershed in order to perform the study. Using the software, the total area of the campus was calculated and its value is 27.067 m². In order to obtain the land use map, it was designed the map of KU campus in the WMS 8.2 software. WMS software has access to a virtual world map (Windows Virtual Earth Locator[®]). This map has representations and satellite pictures for some parts of Earth. For the area under study, satellite pictures were not available in this map.

However, this data was available in software Google Earth[®]. In order to put the image from Google Earth into WMS it was necessary to copy the image and to geo-reference it. The coordinates can be input both in latitude and longitude in decimal degrees or in UTM (Universal Transverse Mercator). This system gives Earth coordinates as a 2-dimensional Cartesian coordinate system, with coordinates X and Y. Three different points were chose and the coordinates (obtained from Google Earth) were input in UTM in order to facilitate the calculations. After that it's possible to work on WMS software with real values and all the calculations (area, length, etc.) can be easily made. It was decided that only four different land uses would be considered: buildings, tar roads, trees and vegetation cover. The vegetation is not all exactly the same but as the area of the campus is small and, thus, the area of vegetation is very small, it was considered that all the vegetation cover has the same characteristics concerning to the calculation of CN. The land use map can be seen in picture 15.



Picture 15– Land use inside KU campus

In the above image, the campus area is represented in black, the channel is represented in blue, areas with trees are represented in light blue, buildings and tar roads are represented in grey and areas with vegetation cover are represented in red.. We conclude that buildings represent 13,7 % of the total area, tar roads 17,7 %, trees 5,2 % and vegetation cover represents 68,4 %.

Buildings and tar roads have the same value for CN, not depending, obviously on the soil group. Concerning the areas covered with trees and with grass, though further studies on the soil condition/characteristics are necessary it is known that most of the soil is made of sandy clay, and thus it was considered that the areas with trees were classified as type C concerning the hydrological soil group, and as fair concerning hydrological condition. Areas covered with grass were classified as C

concerning the hydrological soil group and as good concerning the hydrologic condition. Knowing this and using table of runoff curve number (SCS, 1986) it is possible to know the different CN's for the different land uses. After the determination of the different CN's it's possible to determine the overall CN using the formula previously shown. The different areas and different CN's as well as the overall area and CN can be seen on table 25.

Table 25 – Land use and CN inside KU campus

Land use	Area (m ²)	%	CN
Buildings	3710	13,7	98
Tar roads	3445	14,1	98
Grass cover	18512	67,0	74
Trees	1400	5,2	73
Total campus	27067	100,0	81

Grass cover refers to wild grass, treated grass and areas with *Jatropha* plant cover. The CN value for this land use was calculated taking into account this fact.

Now, knowing the daily precipitation values and the curve number, it's possible to calculate the total runoff inside the campus of Karunya University. It has to be mentioned that some runoff will enter the campus area coming from outside but as the calculations to determine this value are difficult and would require long time, only the runoff that is a "responsibility" of the KU campus was taken into account.

Knowing the average CN for the campus, using formulas (8) and (9) it's possible to calculate both CN I and CN III:

$$CN(I) = \frac{4.2 \times 81}{10 - 0.058 \times 81} \cong 64 \quad (12)$$

$$CN(III) = \frac{23 \times 81}{10 + 0.13 \times 81} = 91 \quad (13)$$

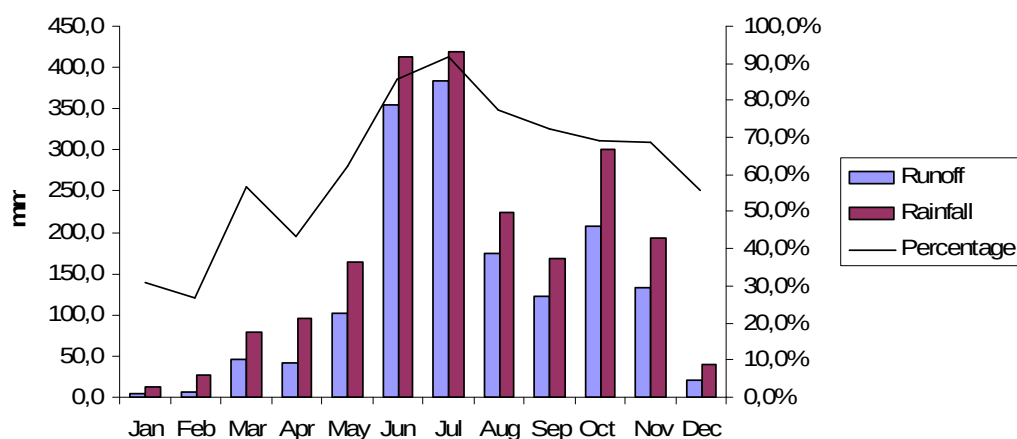
The calculation of the runoff was done on Excel, for the daily rainfall values from 2003 until 2008. The rainfall was considered in a cumulative way for 5 days, in order to choose the most appropriated CN value. When F_a value was negative, runoff was not calculated. Using formulas (2) and (6) we conclude that F_a can be calculated with the following formula:

$$F_a = \frac{S \cdot (P - 0,2 \cdot S)}{(P + 0,8 \cdot S)} \quad (14)$$

The runoff was then calculated for the daily rainfall values. The average monthly runoff values from years 2003 to 2008, for the different months, the respective rainfall and the percentage of runoff are shown next:

Table 26 - Average monthly runoff values in KU

Month	Average rainfall (mm)	Average runoff (mm)	% Runoff	Volume (m ³)
January	11,8	3,7	31,0%	99,3
February	26,8	7,1	26,6%	192,9
March	78,8	44,6	56,6%	1207,8
April	95,2	41,3	43,4%	1117,9
May	163,8	102,0	62,3%	2761,0
June	412,5	353,6	85,7%	9570,8
July	418,0	384,0	91,9%	10394,3
August	224,7	174,0	77,4%	4709,3
September	168,5	122,1	72,4%	3304,1
October	300,8	208,1	69,2%	5633,8
November	193,3	133,0	68,8%	3600,4
December	38,8	21,7	55,8%	586,5



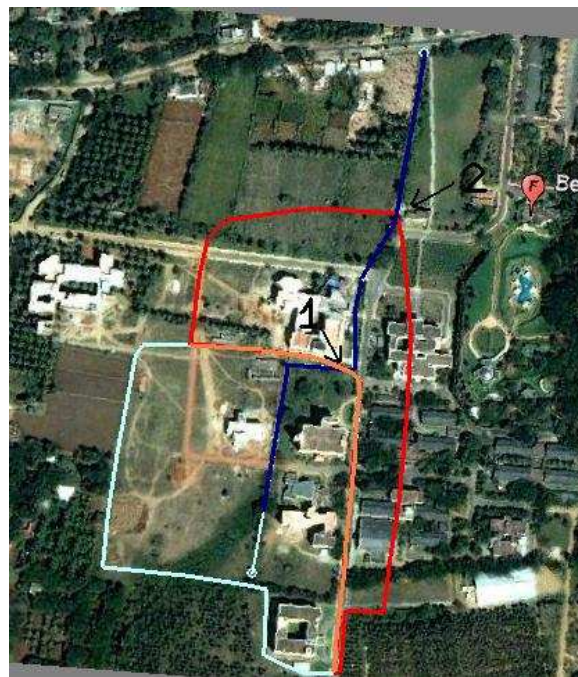
Picture 16– Average monthly runoff values in KU

Analyzing table 26 we conclude that the months with higher rainfall values are the months when more runoff will occur. This is understandable, as during rainy months, the soil will be more saturated with water, and thus less rainwater infiltration will occur, and runoff will be higher. The percentage of runoff varies from 26,6 in February, up to 91,9 in July. It's possible to conclude the effect of AMC looking to the runoff percentage in the month of December. Although the rainfall is Only 38,8 mm, the

runoff percentage is higher than 50 % (55,8 %). This happens due to the fact that the previous months of October and November have high precipitation values, decreasing the infiltration capacity of the soil. The value of runoff percentage in March is higher than expected. This might be due to the fact that only 6 years are being used on this analysis. As March tends to be a dry month, in two years of the analysis (2003 and 2007) there was not any rainfall (and thus neither runoff). By the other side, the years of 2006 and 2008 registered most of the rainy days in a consecutive way, which explains the unexpectedly high value or runoff percentage in March. The runoff value was calculated knowing that the campus area is 27.067 m². This value is multiplied by the runoff values (in mm), and the runoff volume was then obtained.

The total runoff from KU campus is now known. This value represents the total amount of water that comes out of the campus during rainy periods. As it is seen analyzing the values, during the monsoon months, large amounts of water will come out of the campus, creating problems in the nearby houses, as previously said. Thus, the recharge structure(s) and their location have to be studied. It's not possible to have one single recharge structure that can collect all the runoff coming from the campus, as this runoff goes in different ways. As previously mentioned there's a channel that collects a big share of the runoff water and, thus the recharge structures were studied in two different places along the channel.

The first thing to do is select the two spots and delineate theirs' "sub-basin" inside the campus. This "sub-basins" are the catchment area from where all the runoff will eventually go to the recharge point. There's no elevation data for the campus area and the difference on elevation values is very small. Though this fact, analysis *in situ* helped to delineate how the rainwater runoff will flow after reaching the surface. The limits of the 2 "sub-basins" for the 2 recharge points under study are shown on picture 17. Some buildings are "cut", meaning that half of the water coming from the rooftop is coming to one "sub-basin", while the other half is going to another different "sub-basin".



Picture 17– Catchment areas of the 2 recharge points

The catchment area of recharge point 1 is represented in salmon, while sub-basin for recharge point 2 is represented in red. In light blue is represented the common part of both sub-basins. A study for the construction of recharge structures on those points is done next.

4.6.1 RECHARGE STRUCTURE IN POINT 1

The data relative to catchment area of point 1 can be seen on table 27.

Table 27– Land use and CN relative to sub-basin of point 1

Land use	Area (m ²)	CN
Buildings	868	98
Tar roads	446	98
Grass cover	5537	74
Total	6851	79

The total catchment area of point 1 (6851 m²) represents 25 % of the total area of the campus. Doing the same procedure as done in the calculations for the total campus area, it's possible to calculate the runoff that will go till point 1.

First, CN I and CN III were calculated using formulas (8) and (9). The value of CN in dry conditions (CN I) is 61, while CN III (for wet conditions) is 90. Knowing this, the calculations were made and the results are shown next.

Table 28 – Average monthly runoff values for catchment area 1

Months	Average rainfall (mm)	Average runoff (mm)	% Runoff	Volume (m ³)
January	11,8	3,4	28,8%	23,4
February	26,8	6,6	24,5%	45,1
March	78,8	42,8	54,3%	293,5
April	95,2	39,6	41,6%	271,1
May	163,8	99,7	60,9%	683,3
June	412,5	349,4	84,7%	2394,0
July	418,0	380,2	91,0%	2604,7
August	224,7	171,0	76,1%	1171,5
September	168,5	118,7	70,5%	813,5
October	300,8	201,6	67,0%	1381,2
November	193,3	128,1	66,3%	877,9
December	38,8	21,7	55,8%	148,4

As it was expected, the runoff values for the catchment area of point 1 are slightly lower in comparison with the values for the total campus area.

After the runoff is calculated it's necessary decide what kind of recharge structure will be constructed. A good solution would be the use already existing structures such as borwells and sumps. But as shown previously on this work, these are not located near the recharge point 1. Borwells are located near Sciences and Humanities block (the building at far west of the campus) and near Ebenezer Auditorium, which is located next to the origin of the channel. One of the sumps might represent a solution as one is also located near the main entrance, which is a reachable distance from recharge point 2, but not for recharge point 1. Due to this, for point 1 it was decided to study the possibility to construct a recharge trench, knowing that the soil in the higher layers of the campus is mostly clay, meaning that the permeable strata is available at a shallow depth.

Recharging groundwater through recharge trenches is simpler when compared with other techniques (e.g. recharge wells). It's not necessary lots of precautions about the quality of the rainfall runoff as the water will be filtered. A recharge trench is basically a continuous trench excavated on the ground and filled with filter media (porous media like pebbles or brickbats). The recharge trench should be periodically cleaned of accumulated debris in order to maintain intake capacity. As said, recharge trenches are constructed when the permeable strata is available at shallow depths. To calculate the volume of the recharge trench it's necessary to know the catchment area, the runoff during peak rainfall in a period of 15 minutes and a factor of loose density (voids ratio) of the filtering media. For the purpose of this work, the voids ratio was assumed to be 0,5, which represents a typical value for the common materials used, such as pebbles or brickbats. The volume of the recharge trench is then given by:

$$V_{RT} = \frac{A.R}{D} \quad (15)$$

where,

V_{RT} - Volume of the recharge trench (m^3)

A - Catchment area (m^2)

R - Runoff during peak rainfall, during 15 minutes (m)

D - Voids ratio

The peak rainfall in Delhi during 15 minutes is 22,5 mm [17]. For this work, the rainfall value of 25 mm/15 min was adopted as a good approach to real rainfall values. As the peak rainfall will occur in July, it will be used the average runoff value for this month (91 %).

Replacing the letters by the real values we will have,

$$V_{RT} = \frac{6851.(0,025 * 0,91)}{0,5} \Leftrightarrow V_{RT} = 311,7m^3 \quad (16)$$

It was decided that the trench would be 1,5 m deep and 1 m wide. Knowing this and knowing the total volume necessary, it is concluded that the total length of the trench has to be 207,8 m. Implement a single trench with this length is not feasible in KU. Thus, it was decided that the best solution would be to implement 3 recharge trenches on each side of the channel, each with 20 m length, making a total length of 120 m and a total volume of 180 m³. As the trenches will not be enough during peak rainfall periods, they will be connecting to the channel by an over-flow channel. In order to divert the water from the channel to the recharge trenches, it is necessary to create some obstruction on the channel. As exact elevation values for the campus is not available (and thus there's no the elevation data for neither the channel nor the trenches location) the design of this structure was not made on this work.

The price of the recharge trenches will include the excavation work, the filter media and the construction of a blockage in the channel. Plus, maintenance costs have to be accounted. As the blockage structure was not designed, its cost will not be taken into account. The excavation cost is Rs 100 per cubic meter, meaning that the total excavation cost will be Rs 18 000. The filter media is easily obtained and the total price of filter media is assumed to be Rs 1500. Maintenance costs refer to the replacement of the filter media when clogging occurs. It is assumed that the filter media will be replaced every year, meaning that the annual maintenance costs will be Rs 1500.

4.6.2 RECHARGE STRUCTURE IN POINT 2

The data relative to the catchment area of point 2 is shown next.

Table 29 – Land use and CN relative to sub-basin of point 2		
Land use	Area (m ²)	CN
Buildings	1823	98
Tar roads	1207	98
Grass cover	8295	74
Trees	306	60
Total	11631	80

This catchment area represents 43 % of the total area of the campus. Doing the same calculations as previously done for the other catchment area, it's possible to calculate the total runoff that will reach the point 2. Note that these calculations were done assuming that there's not any recharge structure on point 1.

Table 30– Average monthly runoff values for catchment area 2				
Months	Average rainfall (mm)	Average runoff (mm)	% Runoff	Volume (m ³)
January	11,8	3,4	28,8%	39,7

Months	Average rainfall (mm)	Average runoff (mm)	% Runoff	Volume (m ³)
February	26,8	6,6	24,5%	76,6
March	78,8	42,8	54,3%	498,2
April	95,2	39,6	41,6%	460,3
May	163,8	99,7	60,9%	1160,1
June	412,5	349,4	84,7%	4064,4
July	418,0	380,2	91,0%	4422,0
August	224,7	171,0	76,1%	1988,9
September	168,5	118,7	70,5%	1381,1
October	300,8	201,6	67,0%	2344,9
November	193,3	128,1	66,3%	1490,4
December	38,8	21,7	55,8%	252,0

Although the daily runoff values are not exactly the same, the average monthly values of runoff between catchment are 1 and two are the same.

The total volume of rainfall runoff reaching point 2 is 18179 m³ per year. This value can be considered as a large amount, as a part of this runoff will overflow the channel and reach the main street and the nearby houses. As point 2 “receives” 43 % of the rainfall runoff from the campus it represents a good opportunity to reduce the overflow of rainwater and a good point for recharge. Two recharge structures were thought for recharge point 2. As this point is next to a plantation of *Jatropha* the runoff can be diverted, forming earth channels between the plantations. This will reduce the runoff water going outside the campus, increasing the water available for the plants and at the same time recharging the groundwater, because soils used for cultivation have higher infiltration capacity. This technique is denominated as spreading technique and is used when permeable strata start from the top. In order to divert the water it is necessary to construct some structure that will act as a barrier to the water. This structure may be a check dam or a gabion wall.

The second alternative is to divert the channel (or at least a part of it) in direction of the sump located near the main gate of KU. The sump is distanced less than 75 meters away from recharge point 2. Before recharge the water into the sump, it's necessary that the water passes through a settlement tank. This tank also acts as a buffer tank and it's designed in order to retain a certain amount of rainfall runoff. The capacity of the tank should be enough to retain the runoff occurring from conditions of peak rainfall intensity. The settlement tank will ensure that most of the bigger particles will settle, not entering the sump and causing clogging. As the sump is located at a shallow level, the rainfall runoff while percolating into the aquifer will be filtered in a natural way by the soil.

In KU campus the peak rainfall value is considered to be 25 mm/15 min and thus, the peak runoff in catchment area 2 is 0,02275 m. The process to calculate the settlement tank volume is similar to the one used to calculate the recharge trench volume. The difference is that to calculate the settlement tank volume it's not necessary to take into account the voids ratio. Thus, the formula to calculate the settlement tank is as follows:

$$V_T = A.R \quad (17)$$

where,

V_t – Volume of the settlement tank (m^3)

A – Catchment area (m^2)

R – Peak rainfall runoff in 15 min (m)

As it is intended to divert 50 % of the runoff water to the Jetropha plantation, only 50 % of the total catchment area 2 was used to calculate the volume of the storage tank. Thus:

$$V_T = \frac{11631}{2} \cdot 0,02275 = 132m^3 \quad (18)$$

A tank with a volume of $132 m^3$ was considered to be too big, so the decision about the size of the tank will be taken after it is decided how much money will be available for the project. In order to know the size and characteristics of the barrier that will be made on point 2, further data on the elevation of this area is necessary. Also further studies on the natural recharge rate on the Jetropha plantation have to be done.

A scheme of the water flow after the implementation of a barrier in point 2 is shown on picture 18.



Picture 18– Groundwater recharge on point 2

In blue it's represented the way that rainfall runoff will do after the construction a barrier on point 2. The light-blue line represents the present channel, while the dark square represents the settlement tank to be constructed near the sump located near the main entrance of KU campus. On red color it's represented the over-flow channel that will lead the runoff to the main channel again, in case the recharge structures can't hold the water. The calculations were done assuming that the runoff will go half to the settlement tank and the other half to be spread over the Jetropha plantations.

The cost of this structure includes the settlement tank, barrier in the channel and excavation work in the Jetropha plantation. These cost calculations were not made due to a large number of unknowns, which will decide the final price.

4.6.3 BENEFITS AFTER THE IMPLEMENTATION OF THE GROUNDWATER RECHARGE STRUCTURES.

The economical evaluation of the implementation of a groundwater recharge structure is complicated. Though the implementation and maintenance costs are relatively easy to do, the economical earnings demand a full study of the benefits achieved after the implementation of the recharge structures. These benefits include less money spent on energy for pumping the water from the aquifer, as the water table level may increase, savings due to the fact that the houses are not affected by rainfall runoff, etc. In this work, the economical benefits after the implementation of the recharge structures were not taken into account due to the fact that there was not enough time to perform an appropriate study of those values.

Besides the economical benefits, that also exist environmental achievements after the implementation of the recharger structures. Those achievements have already been described previously in this work. In the particular case of the recharge structures in KU campus, the environmental achievements are:

- Improving the groundwater quality;
- Preventing the lowering of the water table lever and, if possible, raise it;
- Reduction of the rainfall runoff going out of the campus, that affect traffic roads and the nearby houses;
- Augment of the water available in the Jetropha plantations inside the campus.

5

CONCLUSIONS

The purpose of this project was to study the possibility of the implementation of different rainwater harvesting (RWH) systems inside the Karunya University campus, located in Coimbatore district, in the Indian state of Tamil Nadu. The RWH systems that were studied consisted in a rooftop RWH system with the purpose of storing the rainwater and surface RWH in two different points, in order to recharge the groundwater. The first part of the work (rooftop RWH) is very important as, by law, all the new constructions in the Indian state of Tamil Nadu must have a rooftop RWH system.

A RWH system is made of three main elements, namely the catchment area, conveyance system and the storage or recharge unit. Also a filter unit is advisable in most cases. The rooftop RWH system was designed for the main building of KU. Although the total rooftop area is 860 m², only 201 m² will be used as catchment area. The designed storage tank will have a volume of 25000 liters and will have a total height of 2,25 meters (including the filter unit), which will allow the pipe network to be connected to the storage system without causing problems to the workers that work in the offices located near the storage tank. The filter unit will be a typical sand-charcoal filter with 0.75 m height and 0.60 m diameter. The main purpose of the stored water is to supply a hand basin that is located the main building. The water consumption related to the hand basin is not very high and thus it was decided that the stored water will also be used for gardening purposes that presently correspond to the highest water consumption inside KU campus.

The storage tank will be constructed in ferrocement, which represents an environmental-friendly solution and widely tested, proving to be a good option. The conveyance system will be a modification of the present piping network. Presently, four rainwater pipes are draining the rainwater from the catchment area, but it's intended that only one (the one located near the storage tank) will be connected to the storage tank. The four pipes will be connected, creating a 10 % slope in all the connections and providing proper support to the pipes, in order to prevent any problem. After being stored, the water will be pumped and distributed through 2 different pipes, one leading to the hand basin and the other leading to the gardens.

In order to assist with the design of the rooftop RWH system, it was used the RainCycle software. This software is a powerful and user-friendly spreadsheet-based tool. The data that has to be input in the software includes the rainfall profile, water demand, operation/maintenance costs, among others. The software compares the prices between different tank sizes and makes the economical comparison between the RWH system and a mains-only system for a desired time period. In this case, it was decided to evaluate the RWH system in a twenty years period. The total cost of the RWH system during twenty years is Rs 87 578, while the mains-only system price is Rs 158.907. Analyzing these values we conclude that the payback period of the rooftop RWH system is 7 years, and the savings over twenty years are Rs 71 329. Besides the economical analysis, the hydraulic analysis is also made with

the software RainCycle. For this case it was intended that the storage tank would never go dry and that the overflow would be reduced to its minimum. Knowing this and the rainfall pattern in KU it's concluded that the rooftop RWH system will save more than 300 000 liters per year. These results can be considered good, as a part of Coimbatore district suffers from water shortage problems and rooftop RWH systems emerge as a good solution for both big buildings and small houses. Further studies about rooftop RWH systems are necessary in order to assess the water quality after being stored. These analyses are important in order to know the final usage that the stored water might have (sanitary, gardening, drinking, etc.).

The second part of the work was related to groundwater recharge through rainwater harvesting. Two different recharge points were selected inside KU campus and using GIS and the knowledge of the campus, was possible to calculate the catchment area of both points. Due to the lack of information about the soil characteristics and the lack of time to perform those studies, the project focused on calculating the surface runoff, using the SCS CN method. This method is widely used and the data required is the rainfall values and the curve number (CN). The CN is based on the hydrological soil group, land use, hydrologic condition and antecedent moisture condition. In the KU area, the surface runoff is a problem as it affects the nearby houses and roads. By recharging the groundwater aquifers using the rainwater, these effects would be reduced and, at the same time, the groundwater quality would be improved and the lowering of the groundwater table level would be reduced, if not avoided.

In recharge point 1, the total annual runoff volume is 10707.8 m^3 , while in recharge point 2 the total annual surface runoff is 18178.7 m^3 . In recharge point 1 the recharge technique selected was recharge trenches. A recharge trench is basically a trench filled with filter media, which will facilitate the percolation of the rainwater through the soil strata. In order to recharge all the rainfall runoff, assuming peak rainfall values, it would be necessary to have a trench with 208 m length. A trench this long might not be possible to have inside KU campus. If not possible, a shorter trench can be used, ensuring that the overflow from the trench will not cause any problem. For recharge point 2 (that also includes the catchment area from point 1) two different techniques were considered, namely spreading the surface runoff and recharge the water through an existing sump well. It was assumed that half of the runoff would be spread in the nearby Jetrophia plantation and that the other half would be diverted to a sump well, after passing through a settlement tank. Further studies about the percolation capacity of the plantation soil and its elevation are necessary in order to know the recharge capacity and thus the dimension of the channels that will conduct the runoff. To recharge the water through a sump well, a settlement tank is necessary. Assuming peak rainfall values, the tank volume should be 132 m^3 to ensure that all the runoff would be recharged. If it's not intended to build a tank this big, an overflow channel must be built to prevent problems associated to the excess runoff.

The implementation of RWH systems is a good solution in both arid/semi-arid areas and humid areas as they save water and at the same time prevent the effects that excessive rainfall might have. RWH systems are environmental friendly, relatively easy to construct and can be an aid to the people that don't have access to water either to drink or with agricultural purpose. This project was made to be an educational project and the first part, related to rooftop RWH was completed, while in second part, related to the groundwater recharge, further studies are necessary before start the implementation of those systems.

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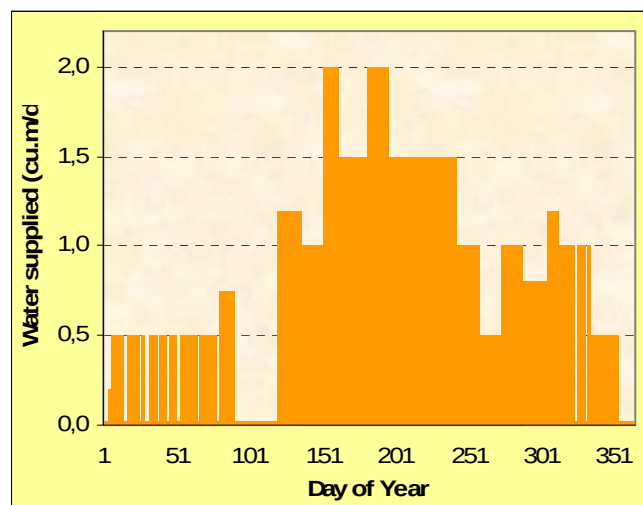
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ANNEX

Annex 1: Monthly rainfall values from 2003 to 2008 (mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003	0	36	149	119	1	220	184	87	14	267	142	10
2004	16	19	13	102	397	752	92	389	114	323	248	0
2005	1	13	30	181	108	252	869	183	245	287	251	124
2006	42	0	114	55	339	390	454	188	271	315	385	0
2007	11	0	0	95	80	612	648	405	279	200	81	79
2008	1	93	167	19	58	249	261	96	88	413	53	20

Annex 2: Water supplied from the tank per day.



Annex 3: Whole life costs per year, in Indian Rupees.

Year	Capital Cost	All Maintenance Costs	Decom. Cost	Pump Operating Costs	Mains Top-up Costs	Yearly Total Present Value	Cumulative Net Present Value	Yearly Total Present Value	Cumulative Net Present Value	RWH System Cum. Yearly Savings
1	56.800,00	1.750,00		6,66		58.556,66	58.556,66	10.802,75	10.802,75	-47.753,91
2		1.690,82		6,44		1.697,26	60.253,92	10.437,44	21.240,19	-39.013,73
3		1.633,64		6,22		1.639,86	61.893,78	10.084,48	31.324,67	-30.569,11
4		1.578,40		6,01		1.584,41	63.478,19	9.743,46	41.068,13	-22.410,06
5		3.093,62		5,81		3.099,43	66.577,62	9.413,97	50.482,11	-16.095,51
6		1.473,45		5,61		1.479,06	68.056,68	9.095,63	59.577,73	-8.478,95
7		1.423,63		5,42		1.429,05	69.485,72	8.788,04	68.365,78	-1.119,95
8		1.375,48		5,24		1.380,72	70.866,44	8.490,86	76.856,64	5.990,20
9		1.328,97		5,06		1.334,03	72.200,47	8.203,73	85.060,37	12.859,90
10		2.604,74		4,89		2.609,63	74.810,10	7.926,31	92.986,69	18.176,58
11		1.240,61		4,72		1.245,33	76.055,44	7.658,27	100.644,96	24.589,52
12		1.198,65		4,56		1.203,22	77.258,65	7.399,30	108.044,26	30.785,60
13		1.158,12		4,41		1.162,53	78.421,18	7.149,08	115.193,33	36.772,15
14		1.118,96		4,26		1.123,22	79.544,40	6.907,32	122.100,66	42.556,26
15		2.193,13		4,12		2.197,24	81.741,64	6.673,74	128.774,40	47.032,76
16		1.044,56		3,98		1.048,53	82.790,18	6.448,06	135.222,46	52.432,29
17		1.009,24		3,84		1.013,08	83.803,25	6.230,01	141.452,47	57.649,22
18		975,11		3,71		978,82	84.782,07	6.019,33	147.471,80	62.689,73
19		942,13		3,59		945,72	85.727,79	5.815,78	153.287,58	67.559,79
20		1.846,55	0	3,47		1.850,02	87.577,81	5.619,11	158.906,70	71.328,89

Annex 4: Different stages of the construction of the storage tank.

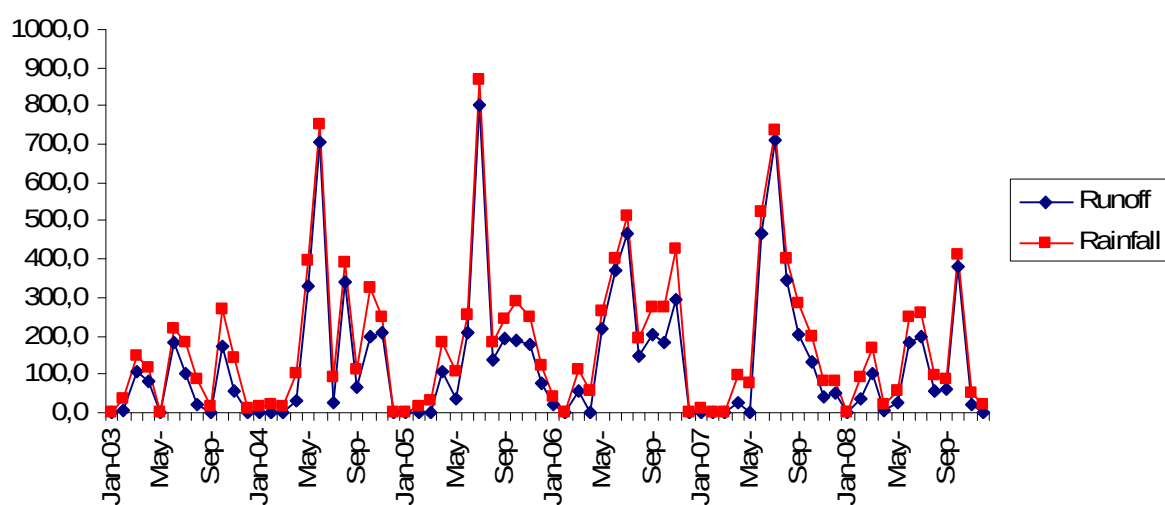




Annex 5: Monthly values for rainfall and runoff

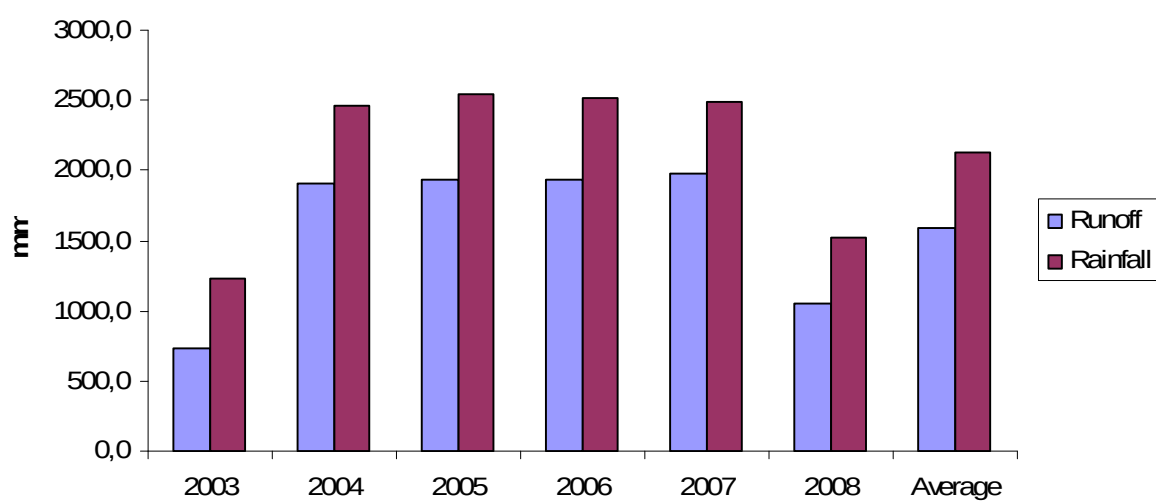
Month	Runoff (mm)	Rain (mm)
Jan-03	0,0	0,0
Feb-03	6,9	36,0
Mar-03	108,0	149,0
Apr-03	80,9	119,0
May-03	0	1
Jun-03	184,6	220,0
Jul-03	103,7	184,0
Aug-03	20,6	87,0
Sep-03	0,0	14,0
Oct-03	172,8	267,0
Nov-03	56,9	142,0
Dec-03	0,0	10,0
Jan-04	0,0	16,0
Feb-04	0,0	19,0
Marc-04	0,0	13,0
Apr-04	30,8	102,0
May-04	330,0	397,0
Jun-04	707,7	752,0
Jul-04	24,9	92,0
Aud-04	338,0	389,0
Sep-04	65,8	114,0
Oct-04	198,5	323,0
Nov-04	209,8	248,0
Dec-04	0,0	0,0
Jan-05	0,0	1,0
Feb-05	0,0	13,0
Mar-05	2,4	30,0
Apr-05	108,1	181,0
May-05	36,1	108,0
Jun-05	208,3	252,0
Jul-05	801,8	869,0
Aug-05	136,3	183,0
Sep-05	195,2	245,0
Oct-05	188,3	287,0
Nov-05	177,7	251,0
Dec-05	77,6	124,0
Jan-06	22,0	42,0
Feb-06	0,0	0,0
Mar-06	54,3	114,0
Apr-06	0,0	55,0
May-06	220,2	264,0
Jun-06	371,5	401,0
Jul-06	464,5	511,0

Month	Runoff (mm)	Rain (mm)
Aug-06	148,7	194,0
Sep-06	204,8	272,0
Oct-06	180,9	275,0
Nov-06	294,5	425,0
Dec-06	0,0	0,0
Jan-07	0,0	11,0
Feb-07	0,0	0,0
Mar-07	0,0	0,0
Apr-07	24,7	95,0
May-07	0,3	78,0
Jun-07	469,3	524,0
Jul-07	712,9	738,0
Aug-07	345,7	402,0
Sep-07	204,8	282,0
Oct-07	130,0	200,0
Nov-07	40,6	81,0
Dec-07	52,4	79,0
Jan-08	0,0	1,0
Feb-08	35,8	93,0
Mar-08	103,1	167,0
Apr-08	3,3	19,0
May-08	25,4	58,0
Jun-08	180,2	249,0
Jul-08	196,3	261,0
Aug-08	54,5	96,0
Sep-08	61,8	88,0
Oct-08	378,3	413,0
Nov-08	19	53
Dec-08	0,0	20,0



Annex 6: Annual values for rainfall and runoff

Year	Runoff (mm)	Rain (mm)
2003	734,3	1229,0
2004	1905,6	2465,0
2005	1931,9	2544,0
2006	1939,4	2511,0
2007	1980,7	2490,0
2008	1057,6	1518,0
Average	1591,6	2126,2



Annex 7: Detail of the runoff calculation for the KU campus

	Rainfall (mm)	Cumulative	CN	S	Ia	Fa	R	Runoff
24-07-2003	5	5	64	142,875	28,575	-28,2337	0	0
25-07-2003	6	11	64	142,875	28,575	-20,0401	0	0
26-07-2003	13	24	81	59,58025	11,91605	10,04637	2,037585	2,037585
27-07-2003	10	34	91	25,12088	5,024176	13,4555	15,52032	13,48274
28-07-2003	17	51	91	25,12088	5,024176	16,24482	29,731	14,21068