REPUBLIC OF RWANDA

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FEASIBILITY STUDY OF RAINWATER COLLECTION SYSTEMS ON PUBLIC BUILDINGS IN KIGALI CITY AND OTHER TOWNS IN RWANDA

Final Report

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EXECUTIVE SUMMARY

The government of Rwanda has developed strong policies and strategies embedded in the Vision 2020 and EDPRS in order to achieve water and sanitation goals. The policy for water and sanitation identifies the sub sector constraints and proposes measures to achieve policy objectives of improving the living conditions of the population through optimal use of water resources and access of all to water and sanitation services.

The Rwanda Vision 2020 commits to the following tasks with regards to water and sanitation:

- Access of all to drinking water and sanitation
- Integrated and sustainable water resources management with focus on secured satisfactory water needs
- Water collection, conservation and utilization for an economic development.

The Vision of water and sanitation Sector as developed by MININFRA includes commitments for rainwater harvesting and reuse. It is stated in the followings points:

- The entire population will have access to clean drinking water and sanitation services;
- The water rainfall collection and retention techniques will be mastered and utilized for agricultural use;
- The natural water reservoirs especially forests at high altitudes will be renewed and managed more appropriately;
- The water resources will be rationally managed and harmoniously integrated with regards to the national master plan on the space use;
- The population will be able to ensure the equitable and sustainable resource management;
- The production, protection, distribution and sanitation water infrastructures will be maintained by all users;
- Urban and rural areas will be in a healthy acceptable conditions;
- All households will have to acquire appropriate practices in hygiene and sanitation;
- Each town or development pole needs to acquire waste water and solid waste treatment units.

Rwanda has a bi-modal rainfall pattern with average annual rainfall of 1280 mm. The Country experiences a short rainy season from September to November and a long rainy season from February to May. The short dry season runs from December to January and the long dry season from June to mid-September. This climate and the availability of rainfall make RWH a potential of the source of water for various domestic uses in Rwanda.

Though rainwater harvesting can provide affordable water for household use, agriculture, environmental flows and prevention of flood damage, rainwater harvesting techniques uses are not yet mastered and disseminated in Rwanda.

Most public buildings in Kigali City and other towns in Rwanda are facing a serious runoff problem that causes flooding of roads, streets, and losses of people's properties, therefore creating some conflict situation between the authority and neighboring properties. Therefore, the collection of rainwater for different uses such as cleaning, watering, toilets flushing, etc becomes necessary for several reasons, in particular the prevention of possible flooding due to rainwater causing erosions in the surroundings and the destruction of the infrastructures like roads and buildings.

Within the perspective of solving some of the problems highlighted above and stepping up to sustainable use of water resources, MININFRA contracted the Consultant to undertake a feasibility study of rainwater collection systems on public buildings in Kigali City and other towns in Rwanda.

This feasibility study had the following main objectives:

- Inventory of rainwater collection systems on public buildings in Kigali City and other towns in Rwanda;
- Categorization of public buildings and identification of appropriate rainwater collection systems per categories;
- Hydraulic design of rainwater collection and storage and structural design of tanks for sample buildings in each category;
- Cost estimation for installation of proposed rainwater collection systems per each category.

The categorization of rainwater harvesting systems depends on factors like the size and nature of the catchment area, structure and height of the building and possible intended configuration of collection and distribution of rainwater. Three categories have been defined in this feasibility study.

Category 1 includes high-rise buildings with strong structural elements that can support rooftop tanks whenever necessary. These might be made of one isolated or twin high buildings concentrated at the same location so that their roof area is within the range of small to medium area and the collection can be easily centralized at one reservoir. Category 2 includes buildings of educational institutions, hospitals, stadiums, airports, and other large facilities. They can be compounds made of simple buildings, with one story, or storied buildings with many houses spread at different locations which make a total larger catchment area. Category 3 includes simple isolated houses with small roof areas like offices of cells, sectors, etc. They have a small roof area which can allow collected rainwater to be conveyed easily in an elevated tank installed near the building.

In this feasibility study a total of 796 public buildings were inventoried in Kigali City and other towns in Rwanda. Among the inventoried buildings, 23 buildings (2.9%) were classified in category 1, 390 buildings (49.0%) in category 2 and 383 buildings (48.1%) in category 3. As for existence of rainwater collection systems, if all categories are combined, 19 (2.4%) buildings were found to have operating RWCS, 191 (24.0%) buildings had partial RWCS while 586 (73.6%) buildings had no RWCS.

Appropriate rainwater collection systems were proposed for each category of the buildings and a hydraulic design of storage reservoirs was also performed for sample buildings within all defined categories.

Detailed cost estimations for installation of proposed rainwater collection systems were done for sample buildings within each category. The cost estimation showed that a total budget of about 28 billion Rwandan Francs (28,000,000,000 RWF) should be mobilized if MININFRA is to set up the proposed systems for all inventoried public buildings without rainwater collection systems (RWCS) in Kigali City and other towns in Rwanda. It was found that in Kigali city RWCS for buildings of category 1 will require a budget of about 700 million Rwandan Francs while categories 2 and 3 will require respectively about 7.5 billion and 600 million Rwandan Francs.

The feasibility study showed that most public buildings in Kigali City and other towns were classified in categories 2 and 3 according to criteria defined in the study and the installation of rainwater collection systems for categories 1 and 2 is a bit more complex and expensive than for category 3.

A strategic plan for implementation of the study was also proposed in which it was suggested to start with construction of RWCS on buildings of category 1 in Kigali city because their total cost is too little compared to category 2 and they are at strategic locations which can help showcase the implemented technology. In other towns many public buildings were classified in category 2 and it was suggested that MININFRA can start with RWCS of category 2.

It has been found in this feasibility study that rainwater harvesting has not been fully utilized in Rwanda despite its proven uses for domestic, agricultural, commercial and environmental purposes. By implementing the outputs of this feasibility study the Ministry of Infrastructure will contribute to achieving the objectives of policies on water and sanitation as embodied in the Rwanda Vision 2020.

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ABBREVIATIONS

BM: Bending Moment
BRD: Rwanda Development Bank
EDPRS: Economic Development and Poverty Reduction Strategy
GI: Galvanized Steel
MDGs: Millennium Development Goals
MINAFET: Ministry of Foreign Affairs
MINEDUC: Ministry of Education
MININFRA: Ministry of Infrastructure
RECO&RWASCO: Rwanda Electricity Corporation and Rwanda Water and Sanitation Corporation.
RWH: Rainwater Harvesting
RWCS: Rainwater Collection System
PVC: Polyvinyl Chloride
WC: Water Closet

I. BACKGROUND AND RATIONALE

1.1. Introduction

Within the framework of the rational use of the water resources, the Ministry of Infrastructure (MININFRA) in charge of the inheritance of government took the initiative to build systems for collection of rainwater on public buildings especially those located in Kigali city for the re-use in various activities.

Therefore, the collection of rainwater for different uses such as cleaning, watering, toilets flushing, etc becomes necessary for several reasons in particular the prevention of possible flooding due to rainwater causing erosions in the surroundings and the destruction of the infrastructures like roads and buildings.

The ministry of infrastructure solicited proposals to provide consulting services for the feasibility study of rainwater collection systems on the public buildings in Kigali city and in other towns.

This report summarizes the feasibility study of rainwater collection systems on the public buildings in Kigali city and in other towns. The purpose of the study was to analyze the feasibility of construction and installation of rainwater collection systems, designs of the systems, and to establish the cost estimation of proposed systems. Rainwater harvesting systems have been proposed to provide water for toilets and urinals flushing, cleaning and watering for various buildings.

1.2 Physical context and hydrographic setting of Rwanda

Rwanda is located in the Great Lakes Region and covers an area of 26, 338 Km^2. The country is characterized by topography which gradually rises from the East at an average altitude of 1,250 m to the North and West where it culminates in a mountain range called " Congo-Nile Ridge" varying from 2.200 m to 3,000 m and a volcano formations, the highest being 4,507 m high.

Rwanda possesses a dense hydrographical network. Lakes occupy 128,190 ha, rivers cover an area of 7,260 ha and waters in wetlands and valleys cover a total of 77,000 ha. The country is divided by water divide line called Congo-Nile Ridge. To the West of this line lies the Congo River Basin which covers 33% of the national territory and which receives 10% of the total national waters. To the East lies the Nile River Basin, whose area covering 67% of the territory, delivers 90% of the national waters.

1.3 Access to water resources in Rwanda

Rwanda is endowed with abundant water resources but the facilities and systems to ensure access to safe water are insufficiently developed and the rate of access in the country was estimated at 69% in the urban and peri-urban areas while 55% in the rural area in 2005.

Currently, access to potable water in urban and peri-urban areas is 76% whilst 68% of the rural populations are served. In regard, to sanitation, 8% of the urban population is having access to latrines and good sanitary condition with 10% in rural areas. There is still a long way to go since 24% of the people do not have access to potable water in the urban areas and 32% in rural areas.

1.4 Climate and potential for Rainwater Harvesting (RWH) in Rwanda

Rwanda is marked by a continental equatorial climate zones: (i) the high altitude region; (ii) the central plateau region and (iii) the eastern plateau and the western lowlands. The altitude ranges from approximately 1,200 meters on the eastern plains and rises steadily to 3,000 meters in the volcanic mountains to the northwest.

The climate of Rwanda is temperate tropical type with an average temperature of 19ºC. The annual rainfall varies from 700 mm to 1400 mm in the East and in lowlands of the West, from 1200 mm to 1400 mm in central plateau and from 1300 mm to 2000 mm in the high altitude region with an average of 1200 mm per year.

Rwanda has a bi-modal rainfall pattern with average annual rainfall of 1280 mm. The Country experiences a short rainy season from September to November and a long rainy season from February to May. The short dry season runs from December to January and the long dry season from June to mid-September.

This climate and the availability of rainfall make RWH a potential of the source of water for various domestic uses in Rwanda.

1.5 Rationale of Rainwater Harvesting

Water is at the heart of Millennium Development Goals (MDGs) numbers 1, 3 and 7, and is indirectly associated with the success or otherwise of all the other Goals. But for Africa to meet the MDGs, bold and targeted actions will be required in the water sector. To address this, the African Water Vision for 2025 has set to develop the full potential of Africa's water resources for sustainable growth in the region's economic and social development, of which rainwater harvesting (RWH) and storage forms a major component.

An important component towards meeting the African Water Vision is the need for managing rainwater resources for "drought proofing" communities subject to regular climatic variability and uncertainty. Rainwater harvesting and storage has been recognized as one way of achieving this. At the Pan-African Conference on Water in Addis Ababa, 2003, and at the African MDGs on Hunger meeting in 2004, rainwater harvesting was identified as among the important interventions necessary towards meeting the MDGs in Africa.

In Rwanda the sectoral policy on water and sanitation is based on vision 2020, millennium development goals and poverty reduction strategy. The policy provides for decentralization in line with the national decentralization policy, institutional aspects, integrated watershed management, monitoring and assessment and participatory approach to water and sanitation among other sectoral reforms in Rwanda.

One of the programs of this policy is on water supply and sanitation program in rural areas. In order to achieve the millennium goals and the 2020 Vision, the Government of Rwanda launched 15 years water and sanitation program in rural area. This program aims to improve the population rate with access to water, presently at 44%, and increase the sanitation rate, presently at 8%, to 66% in 2010, to 80% in 2015 and 100% in 2020.

1.6 Vision 2020 and Opportunities for RWH in Rwanda

The 2020 Vision aspirations are that all Rwandans will have access to safe drinking water in 2020. According to the waste management, at least 80% of the Rwandan population will have easy access to adequate waste management systems and will have mastered individual and community hygiene practices.

The government of Rwanda has developed strong policies and strategies embedded in the Vision 2020 and EDPRS in order to achieve water and sanitation goals. The policy for water and sanitation identifies the sub sector constraints and proposes measures to achieve policy objectives of improving the living conditions of the population through optimal use of water resources and access of all to water and sanitation services.

The Rwanda Vision 2020 commits to the following tasks with regards to water and sanitation:

- Access of all to drinking water and sanitation
- Integrated and sustainable water resources management with focus on secured satisfactory water needs
- Water collection, conservation and utilization for an economic development.

With regard to achieving the Millennium Development Goals, Rwanda committed itself to reducing by half the percentage of the population that has no sustainable access to drinking water supply and sanitation by 2015.

However, Rainwater harvesting techniques uses are not yet mastered and disseminated. Water used in agriculture sector is insignificant, because irrigation is not yet well developed.

The Vision of water and sanitation Sector as developed by MININFRA includes commitments for rainwater harvesting and reuse. It is stated in the followings points:

- The entire population will have access to clean drinking water and sanitation services;
- The water rainfall collection and retention techniques will be mastered and utilized for agricultural use
- The natural water reservoirs especially forests at high altitudes will be renewed and managed more appropriately
- The water resources will be rationally managed and harmoniously integrated with regards to the national master plan on the space use
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- Urban and rural areas will be in a healthy acceptable conditions
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- Each town or development pole needs to acquire waste water and solid waste treatment units

1.7 RWH in urban environment

Water is an integral part of urban life. In our homes, we use water for drinking, washing and watering our gardens. Away from home, we swim and fish in water, and sail on water. At the beach or paddling a canoe on a river, we appreciate good quality water. We value water for its usefulness, its recreational benefits and its place in the landscape and environment.

Urbanisation changes the way water flows through a catchment, and this can have a range of adverse impacts on the water environment, including:

- poor water quality and degraded aquatic ecosystem health within rivers and creeks from the disposal of stormwater and wastewater

- changes to the pattern of flow in streams and rivers
- increased frequency and magnitude of flooding
- demand for potable water exceeding the sustainable supply, and impacting on the availability of water for users.

These are significant issues facing urban water managers and urban communities, although there are many potential solutions. One option receiving increasing attention is water recycling and reuse. Water for reuse in urban areas can be sourced from rainwater, stormwater, greywater and effluent from sewage treatment plants (STPs).

Rainwater harvesting can provide affordable water for household use, agriculture, environmental flows and prevention of flood damage. Various technologies to harvest rainwater have been in use for millennia and new ones are being developed all the time. They include macro-catchment technologies that handle large runoff flows diverted from surfaces such as roads, hillsides, pastures, as well as micro-catchment technologies that collect runoff close to the growing crop and replenish the soil moisture. Rooftop harvesting structures have the advantage to collect relatively clean water, while weirs and dams on ephemeral watercourses can store relatively larger volumes and for longer periods.

1.8 RWH in Kigali City and other towns of Rwanda

In Kigali the capital city of Rwanda and other towns within the country, water has become increasingly a scarce resource. Research showed that the Kigali water supply system (by RECO-RWASCO) has the capacity to provide only about 40,000 m^3 which is about 66.6% of the total daily water requirement of 60,000 m^3. However, Rwanda has sufficient rainfall ranging from 800-1200 mm annually, depending on the region, which makes it suitable for sustainable rainwater harvesting.

The population of Kigali City and other towns in Rwanda is expected to increase and this would increase the stress on their water supply networks. However, the Country has enough potential for rainwater harvesting.

Most public buildings in Kigali and other towns are also facing a serious runoff problem that causes flooding of roads, streets and people's properties therefore creating some conflict situation between the authority and neighbours of such public buildings.

In areas with dispersed populations and where the costs of developing surface or groundwater resources are high, rainwater harvesting and storage have proved a more affordable and sustainable intervention. However, despite its proven uses for domestic, agricultural, commercial and environmental purposes, rainwater has not been fully utilized in Rwanda.

The EDPRS Logframe (2007 – 2011) of Kigali City committed in its water sector to do a complete study for rainwater collection and reuse. This will be measured by the number of public buildings and new residential houses that collect and reuse rainwater. In addition, the cadastral department imposed to each person seeking for a construction permit to have a clear system for rainwater collection presented on plans of the house.

No data were found on indicators of implementation of this policy in Kigali city which is a bit advanced to other towns which seem to have no actions undertaken for RWH. Below are some pictures of buildings that were visited in Kigali city. Some have a partial rainwater collection system and others have no rainwater collection system.

Picture 1.1: Building with partial rainwater collection system – Rainwater is collected but conveyed into drainage channel without being used

Picture 1.2: Building with no rainwater collection system

The collection of rainwater for different uses such as cleaning, watering, toilets flushing, etc becomes necessary for several reasons in particular the prevention of possible flooding due to rainwater causing erosions and the destruction of infrastructures like roads and buildings.

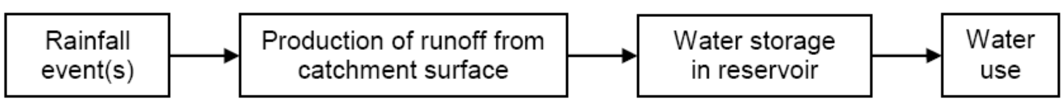
Through this feasibility study, the Ministry of Infrastructure will contribute to enforcing the policies on water and sanitation as embodied in the Rwanda Vision 2020.

II. DEFINITIONS AND CONCEPTS

2.1 Rainwater harvesting (RWH)

Rainwater harvesting (RWH) primarily consists of the collection, storage and subsequent use of captured rainwater as either the principal or as a supplementary source of water. Both potable and non-potable applications are possible. Examples exist of systems that provide water for domestic, commercial, institutional and industrial purposes as well as agriculture, livestock, groundwater recharge, flood control, process water and as an emergency supply for fire fighting. The concept of RWH is both simple and ancient and systems can vary from small and basic, such as the attachment of a water butt to a rainwater downspout, to large and complex, such as those that collect water from many hectares and serve large numbers of people. The fundamental processes involved in rainwater harvesting are demonstrated in figure 2.1.

Figure 2.1 Flowchart demonstrating fundamental rainwater harvesting processes



All rainwater harvesting systems share a number of common components:

1. A catchment surface from which runoff is collected, e.g. a roof surface.
2. A system for transporting water from the catchment surface to a storage reservoir.
3. A reservoir where water is stored until needed.
4. A device for extracting water from the reservoir.

The main uses for harvested rainwater are:

1. A supplementary source of non-potable water, e.g. for WC flushing.
2. A supplementary source of potable water if well treated, or

Many countries have begun to show a resurgent interest in the use of rainwater harvesting techniques. Although not a solution in itself, it is widely believed that these systems can form part of a new urban water management paradigm that is more sustainable than the traditional methods.

Rainwater harvesting systems are also a part of the Sustainable Drainage Systems approach. Runoff arising from impervious surfaces (principally roofs) can be stored in rainwater tanks for subsequent potable and non-potable use. Providing that storage is available at the beginning of a storm event, these systems can act as attenuation devices, reducing both peak flow rates and effective runoff volumes under favorable conditions.

2.2 Greywater

Greywater is defined as domestic wastewater that does not contain faecal matter. At large buildings, such as hotels, there are two options for treatment and reuse: either of combined wastewater or of separately collected grey water.

Greywater from bathrooms, kitchens and laundry rooms is only moderately polluted in comparison with black water from toilets and urinals. It contains far less solids, germs and nutrients. Its treatment is far easier. By reduced fresh water consumption and wastewater disposal, economical as well as environmental benefits are achieved.

2.3 Mains water supply

Mains or potable water supply consists of standard systems of producing, treating, and supplying potable water to people using often centralized piped systems.

The extent to which the public water supply system is incorporated into RWH models is usually restricted to measuring the amount of mains top-up water required when there is insufficient harvested rainwater available to meet demand. For models that incorporate a financial assessment this would also include the associated volumetric mains supply and sewerage charges.

III. STUDY METHODOLOGY AND TOOLS

3.1 Methodological approach

When assessing a RWH system there is a number of issues that require consideration. For instance the associated costs and benefits, and whether the objectives of the system could not be better met by investing in an alternative option. Depending on the purpose of the system, questions regarding performance could include:

- What percentage of existing water demand is likely to be met by harvested rainwater?
- What is the unit cost of water supplied from the system and how does this compare with the cost of other water conservation measures?
- How long will the system take to pay for itself?
- What will the ultimate return on investment be?
- What are the associated risks? For example, what if the level of rainfall is less than expected?

The following steps were followed in this study to carry out the feasibility and design of the RHW systems:

1. Collection of existing and new data

In this step we collected the existing documentation on the number and locations of public buildings concerned by our study. We acquired a list of all public buildings in all provinces. From that list we selected the buildings located in Kigali City and in other towns concerned by our study.

The new collected data include but not limited to:

- **Catchment area and runoff coefficient**

The collection surface is the "footprint" of the roof. In other words, regardless of the pitch of the roof, the effective collection surface is the plan area covered by collection surface. Obviously if only one side of the structure is guttered, only the area drained by the gutters is used in the calculation. The surface areas of the concerned buildings were measured on field.

The runoff coefficient has been taken as 0.90 and 0.80 for galvanized iron sheets and tiles roofs respectively.

- **Future precipitation patterns**

The rainfall profile, that determines the future available rainwater, has been found using available meteorological data for precipitation from Kanombe Airport station and. Average monthly precipitations over 42 years (from 1964 to 2006) have been used in the modeling tool.

- **Average daily water demand**

The first decision in rainwater harvesting system design is the intended use of the water. If rainwater is to be used only for irrigation, a rough estimate of demand, supply, and storage capacity may be sufficient. On the other hand, if rainwater is intended to be the sole source of water for all indoor and outdoor domestic end uses, a more precise estimate is necessary to ensure adequate supply.

The main proposed uses of rainwater in this project are flushing of sanitary installations and cleaning. The estimated demand took also into account the number of users and the average time they spend in the building.

2. Inventory of rainwater collection systems on public buildings and their categorization

In this step we carried out an inventory of rainwater collection systems on public buildings. The buildings were put into categories depending on their height and catchment area (which will govern the type of rainwater collection system), their roof construction materials, and the space availability within the building surrounding.

3. Identification of appropriate RW collection systems of inventoried buildings

After putting the buildings into different categories according to the previous phase we identified and proposed suitable systems of rainwater collection to each category of buildings.

4. Modeling, Calculations and design of proposed systems

This step dealt mainly with hydrological and hydraulic modeling and structural design of the systems proposed into phase 3. The following methods were used:

- ❖ Estimation of the available rainwater and hydraulic design of storage capacity:

The hydrological performance of a rainwater tank is related to the size and characteristics of the contributing catchment, level of rainfall and demand on the system. The capacity of the RWH tank is important both economically and operationally since it influences the following variables:

- Volume of water conserved;
- Installation costs;
- Length of time rainwater is retained, which affects the final quality of the water supplied;
- Frequency of system overflow, which affects the removal rate of surface pollutants;
- Volume of water overflowing into the surface drain or soakaway.

❖ Structural design of storage tanks and pipe systems;
❖ Cost estimation of the proposed systems.

5. Cost estimation

After identification of appropriate collection system the cost estimation was done for each category of buildings. The cost of the system depends mainly on proposed components of system and construction materials.

3.2 Used Tools

1. RainCycle Software was used for detailed simulations of proposed RW collection systems for each category of buildings.

Overview of Primary Analysis Features

RainCycle is a detailed hydraulic and financial simulation of any rainwater harvesting (RWH) system for a time period of up to 100 years on a day-by-day basis. It has got the following analysis features:

- Allows for the use of site-specific data on 18 key parameters
- Incorporates all of the hydraulic components found on the majority of RWH installations
- Takes into account all associated costs, such as capital (build), maintenance/operating and decommission costs
- Long-term analysis results are output as: whole life cost comparison between the RWH system and an equivalent mains-only system, percentage of water demand that the proposed RWH system can meet and pay-back period (the amount of time it takes before the system becomes cost-effective)
- Average per-year hydraulic and financial results also available
- Tank size optimisation routine allows the range of viable tank sizes to be identified early on in the design process

- Cost savings optimisation routine enables the whole life cost and hydraulic performance of up to 10 storage tanks to be compared simultaneously, allowing the best choice of tank to be identified and selected for a more detailed investigation
- Can also optimise for quickest pay-back period or greatest water efficiency savings
- Catchment size optimisation routine automatically calculates the minimum catchment area required to meet a given percentage of water demand
- Sensitivity analysis module allows the robustness of the RWH system to be assessed, helping to identify areas of possible risk and/or potential improvement
- Monte Carlo simulation module uses random sampling of probability distributions to automatically assign different (but realistic) values to key parameters and is capable of running thousands of independent simulations of the proposed system. This allows for a very thorough assessment of system performance under a wide range of operating conditions. Results are output as probability distribution graphs that enable the user to ascertain the chances of the system satisfying a set of criteria, such as the probability of meeting a given percentage of water demand, the probability of the system paying for itself within a given number of years and so forth
- Scenario modelling: allows the user to manually change the values of a number of key parameters and to instantly see how this affects system performance. Results can be recorded/compared and are automatically presented in the System Report for printing
- Contains a total of 12 hydraulic and 19 analysis modules

Main Hydraulic Components

- 12 user-definable hydraulic parameters allow for a comprehensive system assessment. Parameters are: daily rainfall profiles, catchment surface area, catchment runoff coefficient, first flush volume, rainwater filter coefficient, daily additional water inputs other than rainwater (if any), storage tank volume, tank drain-down intervals (e.g. to facilitate maintenance), power rating & capacity of pump, UV unit power rating & operating time and daily water demand profiles
- Multiple values (below average/low, average/expected, above average/high) are enabled on a number of the hydraulic parameters in order to allow the sensitivity analysis, Monte Carlo simulation and/or scenario analysis modules to be used
- Pre-defined water demand patterns are available for school and commercial/industrial buildings

Main Financial Components

- 6 user-defined financial parameters are available: capital cost, decommission cost, discount rate, electricity cost, mains water cost (both supply and sewerage charges) and disposal cost, if any (i.e. additional trade effluent charges)
- Multiple values (below average/low, average/expected, above average/high) are enabled on a number of the financial parameters in order to allow the sensitivity analysis, Monte Carlo simulation and/or scenario analysis modules to be used
- Inclusion of a discount rate allows for proper financial accounting to be undertaken and the true Net Present Value (NPV) of the assessed RWH system to be calculated. This feature is almost always missing from similar software
- Ability to plan and cost all future maintenance activities. Can take into account both recurring activities and one-off items
- Takes into account down-pipe disconnection rebate, if applicable

2. **AutoCAD and ArchiCAD** softwares were used for drafting of technical plans

IV. INVENTORY OF RAINWATER COLLECTION SYSTEMS AND CATEGORIZATION OF PUBLIC BUILDINGS

This section is articulated on 3 main components of the study which will be discussed in detail in subsequent paragraphs.

- Categorization of public buildings;
- Identification of appropriate RW collection systems per category of buildings;
- Inventory of RW collection systems on public buildings

4.1 Categorization of public buildings

Typically, a rainwater harvesting system consists of three basic elements: the collection system, the conveyance system, and the storage system. Collection systems can vary from simple types within a household to bigger systems where a large catchment area contributes to an impounding reservoir from which water is either gravitated or pumped to water treatment plants, header tanks or distribution pipes.

The categorization of rainwater harvesting systems depends on factors like the size and nature of the catchment area, structure and height of the building and possible intended configuration of collection and distribution of collected rainwater. The configuration of collection and distribution refers to the way water is collected and used which can be either through tap stands connected to storage tanks or through a distribution network that can be set up to function automatically parallel to existing network. The proposed categories are described below.

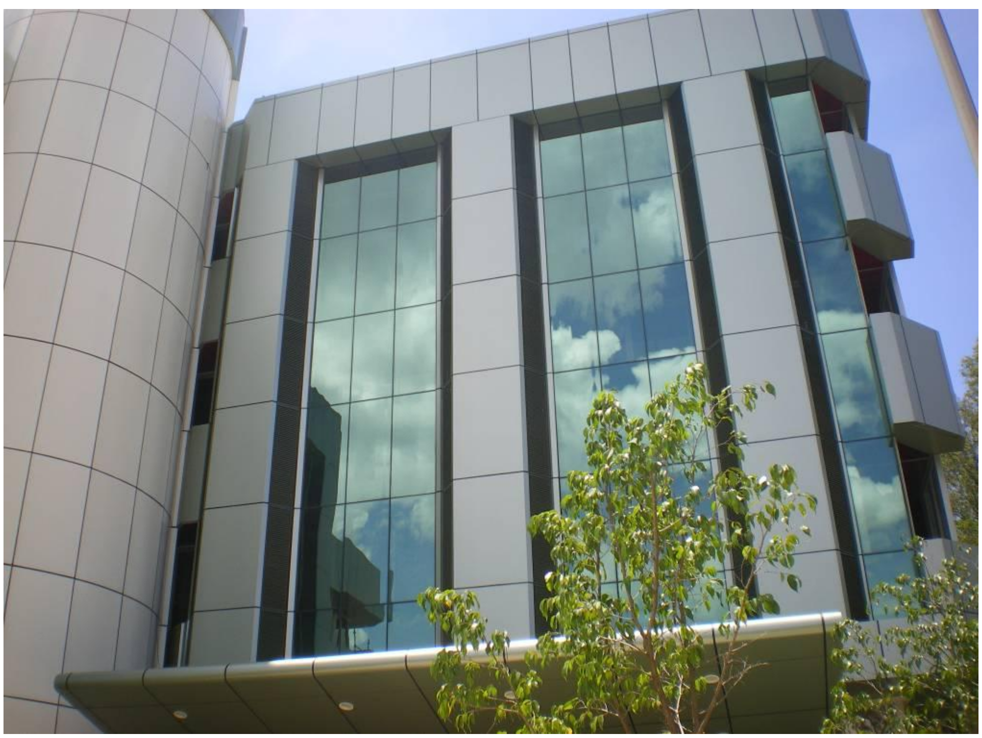
4.1.1 High-rise buildings: Category 1

In high-rise buildings, roofs can be designed for catchment purposes and the collected roof water can be kept in separate cisterns on the roofs or in underground reservoirs for non-potable uses.

This category will include one and above storey buildings with strong structural elements that can support rooftop tanks whenever necessary. This might be made of one isolated or twin high buildings concentrated at the same location so that their catchment is within the range of small to medium surface area (500 to 1,000 m^2) and the collection can be easily centralized to one reservoir.

Within this category were put buildings of ministries like MININFRA, MINEDUC, MINAFET, etc which are storied with reinforced concrete structures that can support a rooftop tank. Below are some photos of the visited buildings of this category.

Picture 4.1: High-rise building – MINAFFET Building at Kimuhurura



Picture 4.2: High-rise building – BRD Building at Nyarugenge

4.1.2 Larger buildings: Category 2

When the buildings are larger, the overall system can become a bit more complicated, and can require for example storage in underground reservoirs, treatment and then use for non-potable applications. While the collection of rainwater by a single household may not be significant, the impact of thousands or even millions of household rainwater storage tanks can potentially be enormous.

This category includes buildings of educational institutions, hospitals, stadiums, airports, and other large facilities. They can be compounds made of simple buildings, with one floor, or storied buildings with many houses spread at different locations which make a total larger catchment area. This large roof area imposes to have a large storage reservoir in which water from each individual building is conveyed. The catchment area is in the range of 1,200 to 6,000 m^2 and above.

They can also have different storage reservoirs depending either on the size of the catchment area, if it is too big, or if individual buildings are far distant from each other so that conveying collected water in one reservoir is difficult. Below are some photos of visited buildings in this category including health centers, schools, markets, etc.

Picture 4.3: Muhoza Health Center – Nothern Province

Picture 4.4: Kamembe Market – Western Province

4.1.3 Simple buildings: Category 3

A Simple building is an isolated building with small catchment area which can allow collected rainwater to be conveyed easily in one elevated tank installed near the building. The main components in a simple roof water collection system are the cistern itself, the piping that leads to the cistern and the accessories within the cistern.

This category includes simple houses with small roof areas ranging from 100 to 500 m^2 like offices of cells, sectors, etc. They have few users and few sanitary facilities which are often installed outside the building. A simple system of tank and pipes will be sufficient for collection and distribution of rainwater. Below are some photos of visited buildings within this category.

Picture 4.5: Simple isolated building – Byumba sector offices

Picture 4.6: Simple isolated buildings – Gasaka and Ngoma offices in Huye sector

Picture 4.7: Simple isolated building - Office of Muhoza sector

Picture 4.8: Simple isolated building - Office of Nyamagabe tribunal court

4.2 Inventory of rainwater collection systems (RWCS) on public buildings

The inventory of rainwater collection systems was conducted on public buildings in Kigali city and other towns in Rwanda using the lists of public buildings provided by MININFRA. In Kigali City all public buildings as provided on lists by MININFRA were inventoried. In other provinces the districts that host secondary towns were visited and in each district public buildings included on the same lists were inventoried.

The model used for data collection gathered the following information for each building:

- Catchment area (roof surface area) of the building. It was measured by the person who visited the building or found on plans of the building where available;
- Existence of rainwater collection system;
- Type of existing rainwater collection system;
- Sanitary facilities within the building;
- Number of users of the building;
- Category of the building.

Tables below summarize the results of the inventory of public buildings by provinces and districts. Complete tables of the inventory are presented in annex 1.

4.2.1 Inventory of RWCS on public buildings in Kigali City

In Kigali city, public buildings located in all sectors of the 3 districts were inventoried. Tables below summarize the inventoried public buildings by district.

PROVINCE:KIGALI CITY			
DISTRICT: GASABO			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	29	20
With partial RWCS	7	16	5
With RWCS	4	1	1
TOTAL	**11**	**46**	**26**

DISTRICT: NYARUGENGE			
Number of Buildings per category	**Category1**	**Category 2**	**Category 3**
Without RWCS	2	29	15
With partial RWCS	4	12	7
With RWCS	0	0	0
TOTAL	**6**	**41**	**22**

DISTRICT: KICUKIRO			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	21	17
With partial RWCS	1	15	4
With RWCS	0	0	1
TOTAL	**1**	**36**	**22**

RWCS: Rainwater collection system

Partial RWCS: means that the building has got only gutters and downspouts but water is conveyed to drainage channels without being used.

4.2.1.1 Summary of RWCS on public buildings in Kigali City

In total 211 public buildings were inventoried in Kigali City. Among the inventoried buildings 18 were in Category 1, 123 were in Category 2, and 70 were put in Category 3. As for existence of rainwater collection systems, if all categories are combined 7 buildings were found to have operating rainwater collection systems (RWCS), 71 buildings had partial RWCS while 133 buildings were with no RWCS. Table below summarizes the inventory for Kigali city.

PROVINCE: KIGALI CITY			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	2	79	52
With partial RWCS	12	43	16
With RWCS	4	1	2
TOTAL	**18**	**123**	**70**

RWCS: Rainwater collection system

Partial RWCS: means that the building has got only gutters and downspouts but water is conveyed to drainage channels without being used.

4.2.2 Inventory of RWCS on public buildings in Southern Province

In southern province, public buildings in towns of Huye, Nyamagabe, Nyanza, Ruhango, and Muhanga were inventoried. Tables below summarize the inventoried public buildings by district.

PROVINCE: SOUTHERN			
DISTRICT: HUYE			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	9	12
With partial RWCS	0	8	0
With RWCS	1	0	0
TOTAL	**1**	**17**	**12**
DISTRICT: NYAMAGABE			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	4	5
With partial RWCS	0	1	0
With RWCS	0	0	0
TOTAL	**0**	**5**	**5**
DISTRICT: NYANZA			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	7	8
With partial RWCS	1	3	0
With RWCS	0	0	0
TOTAL	**1**	**10**	**8**
DISTRICT: RUHANGO			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	15	20
With partial RWCS	0	11	4
With RWCS	0	0	0
TOTAL	**0**	**26**	**24**

DISTRICT: MUHANGA			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
With RWCS	0	0	0
Without RWCS	0	5	31
With partial RWCS	0	8	8
TOTAL	**0**	**13**	**39**

RWCS: Rainwater collection system
Partial RWCS: means that the building has got only gutters and downspouts but water is conveyed to drainage channels without being used.

4.2.2.1 Summary of RWCS on public buildings in Southern Province

In total, 161 public buildings were inventoried in towns of southern province. Among the inventoried buildings, 2 were in Category 1, 71 in Category 2, and 88 under Category 3. As for existence of rainwater collection systems, if all categories are combined, 1 building was found to have operating rainwater collection system (RWCS), 44 buildings had partial RWCS while 116 buildings were with no RWCS. Table below gives the summary of the inventory in southern province.

PROVINCE: SOUTHERN			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	40	76
With partial RWCS	1	31	12
With RWCS	1	0	0
TOTAL	**2**	**71**	**88**

RWCS: Rainwater collection system
Partial RWCS: means that the building has got only gutters and downspouts but water is conveyed to drainage channels without being used.

4.2.3 Inventory of RWCS on public buildings in Northern Province

In Northern Province, public buildings in towns of Musanze and Gicumbi were inventoried. Table below summarizes the inventoried public buildings by district.

PROVINCE: NORTHERN			
DISTRICT: MUSANZE			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	4	61
With partial RWCS	0	10	1
With RWCS	0	3	0
TOTAL	**0**	**17**	**62**

DISTRICT: GICUMBI

Number of Buildings per category	Category 1	Category 2	Category 3
Without RWCS	0	21	48
With partial RWCS	1	5	2
With RWCS	0	2	0
TOTAL	**1**	**28**	**50**

RWCS: Rainwater collection system
Partial RWCS: means that the building has got only gutters and downspouts but water is conveyed to drainage channels without being used.

4.2.3.1 Summary of RWCS on public buildings in Northern Province

In total, 158 public buildings were inventoried in Northern Province. Among the inventoried buildings 1 was in Category 1, 45 were in Category 2, and 112 were put in Category 3. As for existence of rainwater collection systems, if all categories are combined, 5 buildings were found to have operating rainwater collection systems (RWCS), 19 buildings had partial RWCS while 134 buildings were with no RWCS. Table below gives the summary of the inventory in Northern Province.

PROVINCE: NORTHERN			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	25	109
With partial RWCS	1	15	3
With RWCS	0	5	0
TOTAL	**1**	**45**	**112**

4.2.4 Inventory of RWCS on public buildings in Western Province

In Western Province, public buildings in towns of Rusizi, Rubavu, and Karongi were inventoried. Table below summarizes the inventoried public buildings by district.

PROVINCE: WESTERN			
DISTRICT: RUSIZI			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	50	28
With partial RWCS	0	14	2
With RWCS	0	1	1
TOTAL	**0**	**65**	**31**
DISTRICT: RUBAVU			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	16	19
With partial RWCS	0	4	1
With RWCS	1	3	0
TOTAL	**1**	**23**	**20**
DISTRICT: KARONGI			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	7	13
With partial RWCS	0	1	1
With RWCS	0	0	0
TOTAL	**0**	**8**	**14**

RWCS: Rainwater collection system
Partial RWCS: means that the building has got only gutters and downspouts but water is conveyed to drainage channels without being used.

4.2.4.1 Summary of RWCS on public buildings in Western Province

In total, 162 public buildings were inventoried in Western Province. Among the inventoried buildings 1 was in Category 1, 96 were in Category 2, and 65 were put in Category 3. As for existence of rainwater collection systems if all categories are combined 6 buildings were found to have operating rainwater collection systems (RWCS), 23 buildings had partial RWCS while 133 buildings were with no RWCS.

Table below gives the summary of the inventory in Western Province.

PROVINCE: WESTERN			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	73	60
With partial RWCS	0	19	4
With RWCS	1	4	1
TOTAL	**1**	**96**	**65**

RWCS: Rainwater collection system
Partial RWCS: means that the building has got only gutters and downspouts but water is conveyed to drainage channels without being used.

4.2.5 Inventory of RWCS on public buildings in Eastern Province

In Eastern Province, public buildings in towns of Nyagatare, Ngomba, Kayonza, and Rwamagana were inventoried. Tables below summarize the inventoried public buildings by district.

PROVINCE: EAST			
DISTRICT: NYAGATARE			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	18	12
With partial RWCS	0	4	16
With RWCS	0	0	0
TOTAL	**0**	**22**	**28**
DISTRICT: NGOMA			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	10	7
With partial RWCS	1	7	2
With RWCS	0	0	0
TOTAL	**1**	**17**	**9**
DISTRICT: KAYONZA			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	7	4
With partial RWCS	0	1	0
With RWCS	0	0	0
TOTAL	**0**	**8**	**4**

DISTRICT: RWAMAGANA			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	5	7
With partial RWCS	0	3	0
With RWCS	0	0	0
TOTAL	**0**	**8**	**7**

RWCS: Rainwater collection system
Partial RWCS: means that the building has got only gutters and downspouts but water is conveyed to drainage channels without being used.

4.2.5.1 Summary of RWCS on public buildings in Eastern Province

In total, 104 public buildings were inventoried in Eastern Province. Among the inventoried buildings 1 was in Category 1, 55 were in Category 2, and 48 were put in Category 3. As for existence of rainwater collection systems if all categories are combined 34 buildings had partial RWCS while 70 buildings were with no RWCS. Table below gives the summary of the inventory in Western Province.

PROVINCE: EASTHERN			
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**
Without RWCS	0	40	30
With partial RWCS	1	15	18
With RWCS	0	0	0
TOTAL	**1**	**55**	**48**

RWCS: Rainwater collection system
Partial RWCS: means that the building has got only gutters and downspouts but water is conveyed to drainage channels without being used.

4.2.6 Summary of inventory of RWCS on public buildings in Kigali City and other towns

In this feasibility study a total of 796 public buildings were inventoried in Kigali City and other towns in Rwanda. Among the inventoried buildings, 23 buildings (2.9%) were classified in category 1, 390 buildings (49.0%) in category 2 and 383 buildings (48.1%) in category 3.

The table below summarizes the inventory of rainwater collection systems on public buildings in Kigali City and other towns.

SUMMARY FOR KIGALI CITY AND ALL OTHER TOWNS				
Number of Buildings per category	**Category 1**	**Category 2**	**Category 3**	**TOTAL**
Without RWCS	2	257	327	**586**
With partial RWCS	15	123	53	**191**
With RWCS	6	10	3	**19**
TOTAL	**23**	**390**	**383**	**796**

RWCS: Rainwater collection system
Partial RWCS: means that the building has got only gutters and downspouts but water is conveyed to drainage channels without being used.

As for existence of rainwater collection systems, if all categories are combined, 19 (2.4%) buildings were found to have operating RWCS, 191 (24.0%) buildings had partial RWCS while 586 (73.6%) buildings had no RWCS.

4.3 Proposed appropriate rainwater collection systems for each category

A basic rainwater collection system includes a roof, gutters or roof drains, and a piping system to convey the water to and from a storage tank or cistern. Storage tanks can be inside or outside, above or below ground, or partially above and partially below ground. However large catchment areas can have more complex systems for collection and distribution of rainwater.

4.3.1 Rainwater collection system for Category 1 – Indirect pumping system

This category includes one and above storey buildings. A better configuration is to have underground large reservoirs that store water and distribute it by pumping to header tanks (rooftop tanks) installed on roofs so that water is conveyed to various sanitary installations in the building by gravity. The use of header tank is advantaged by the fact it is designed to accommodate little quantity of daily water demand that is required within the building. Figure below shows the system configuration

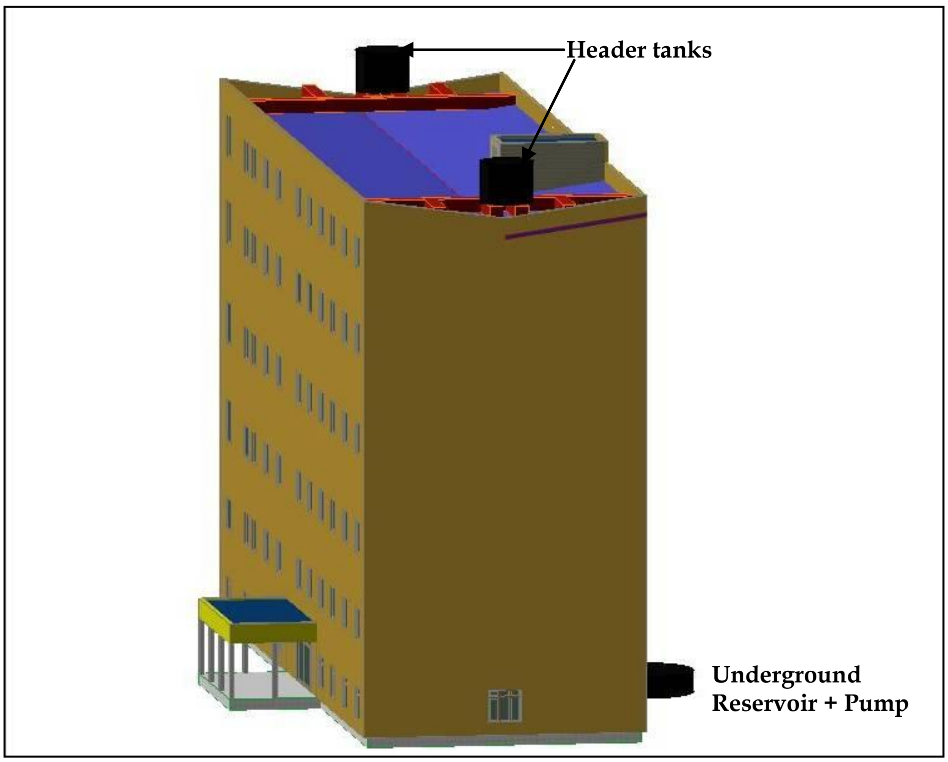


Figure 4.1: Rainwater collection system for category 1

In this configuration, water is distributed into sanitary facilities by gravity through a network which is installed separately from the existing one of potable water.

A complete network of pipes and valves is installed so that water is distributed automatically whenever necessary.

Apart from gutters and downspouts with their accessories, the system will require an underground reservoir, a pump, header tanks and distribution pipes all together with their accessories. Figure below portrays the distribution by gravity of rainwater from a header tank (rooftop tank).

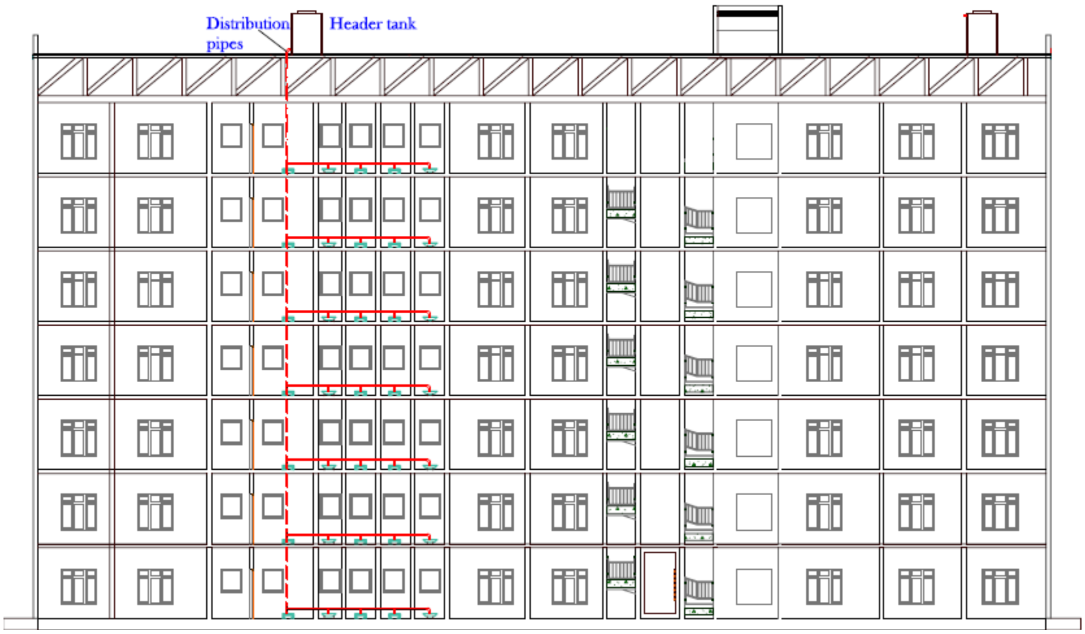


Figure 4.2: Distribution of rainwater from a header tank into sanitary facilities

4.3.2 Rainwater collection system for Category 2 – Direct pumping system

This category includes buildings of educational institutions, stadiums, airports, and other large facilities. These buildings have larger catchment areas which lead to large storage reservoirs for collected rainwater.

A better configuration is to have underground large reservoirs that store water and distribute it by direct pumping to various sanitary installations in the building. The use of a header tank is disadvantaged by the following reasons:

- the buildings need much quantity of daily water demand which will require large header tank;
- the buildings may be far distant so that the header tank would not have enough head pressure to supply water within all of them.

Apart from gutters and downspouts with their accessories, the system will require an underground reservoir, a pump, and distribution pipes all together with their accessories. Figure below portrays the system configuration.

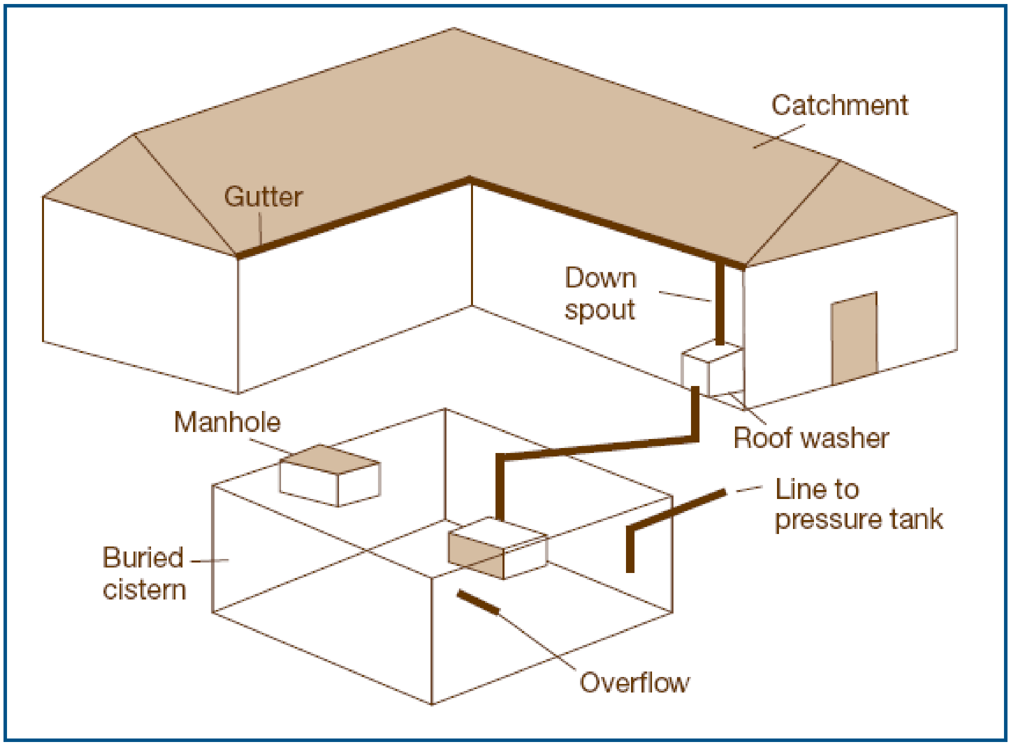


Figure 4.3: Rainwater collection system for category 2 - A larger building with an underground reservoir for storage of collected RW

4.3.3 Rainwater collection system for Category 3 - Simple roof water collection system

Category 3 includes simple houses with small roof areas. The main components in a simple roof water collection system are the cistern itself, the piping that leads to the cistern and the accessories within the cistern.

A simple system of an elevated small tank can be installed near the building to store water from downpipes connected to gutters that are installed on the roof. Distribution pipes connect to the tank and supply water by gravity through tap stands that can be installed to selected points of water collection. Another possible configuration is to convey water by gravity from the tank to sanitary installations in a parallel network to the existing in the building.

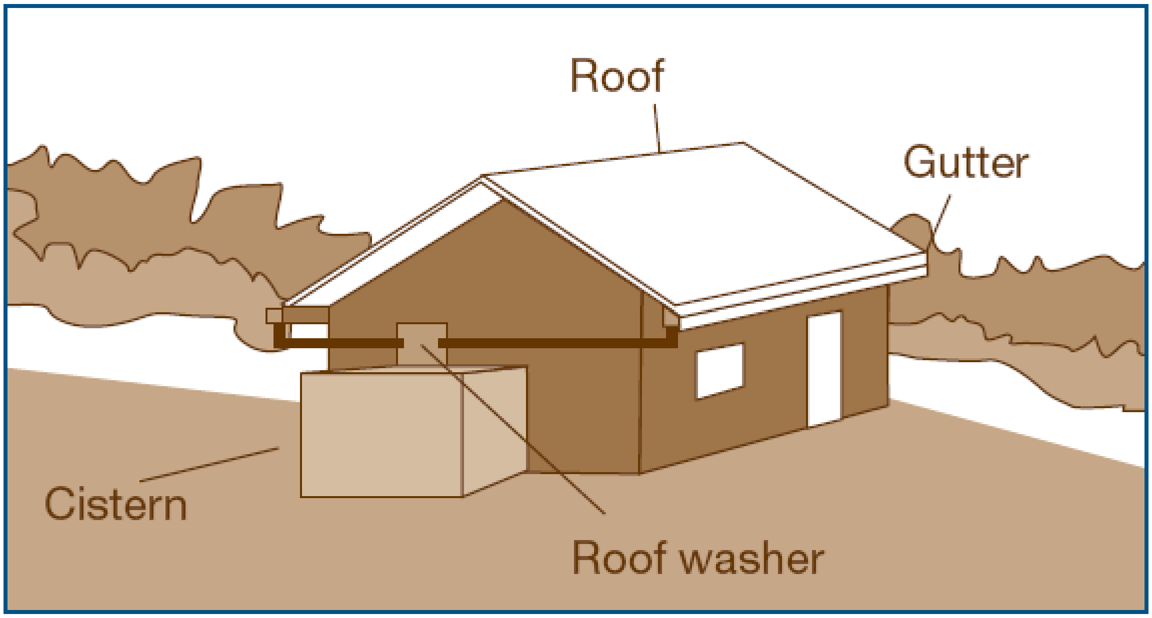


Figure 4.4: Rainwater collection system for category 3 - A simple rainwater harvesting design with an external storage tank

V. HYDRAULIC MODELING OF COLLECTION AND STORAGE FOR SAMPLE BUILDINGS

5.1 Presentation of modeling tool

RainCycle Software was used for detailed hydrological and hydraulic modelling of proposed RWCS for each category of buildings. RainCycle is a detailed hydraulic and financial simulation of any rainwater harvesting (RWH) system for a time period of up to 100 years on a day-by-day basis.

5.2 Performing an Analysis with RainCycle Standard

5.2.1 The RainCycle Standard Analysis Process

There is no universally agreed 'right' way to design and analyse a rainwater harvesting system but there is a sequence of logical steps that, if followed, will increase the likelihood of making a successful design. This section contains a number of flow-charts which lead the user through these steps (see figures 2.1 - 2.3) and divides the design and analysis process into 3 distinct steps:

1. Step 1: determine range of suitable tank sizes
2. Step 2: determine cost savings of tanks from (1) and choose optimum size
3. Step 3: examine analysis results of selected tank from (2) and assess performance.

Accept/reject/amend proposed system as appropriate.
Note that in practice there is no strict requirement to carry out steps 1 and 2, although doing so is likely to lead to a more robust design. It is entirely possible to analyse a system in which the tank size and associated costs have already been determined before an analysis is conducted.

As well as the flow- charts, advice is given on how to generate/obtain the required data. General figures are also provided for a number of parameters; these can be used in the absence of more site-specific information.

Pre-Analysis Assessment

Before any analysis is conducted, it is advisable to make explicit the aims and objectives of the proposed system. Important issues to address could include:

- What are the intended uses for the harvested rainwater? Will they be non-potable only or does the water require treatment to potable standards?
- Does the system require a UV treatment unit?

- What level of risk/responsibility is likely to be acceptable?
- What are the reasons for wanting a RWH system? Are they purely financial (potential water bill savings) or is there an environmental element? E.g. conservation of water resources.
- Is a short pay-back time important, or is a longer period acceptable?

Essentially it is important to have a clear idea in mind as to what the rainwater harvesting system is intended to do, the minimum level of performance that will be deemed satisfactory and what level of risk is likely to be acceptable (e.g. financial risk). The hydraulic and financial criteria that any RWH system will have to meet are entirely up to the individual or organisation considering the system. RainCycle Standard is ideally suited to determining whether or not these criteria can be met, and under what circumstances.

5.2.2 Step 1: Determine range of suitable tank sizes

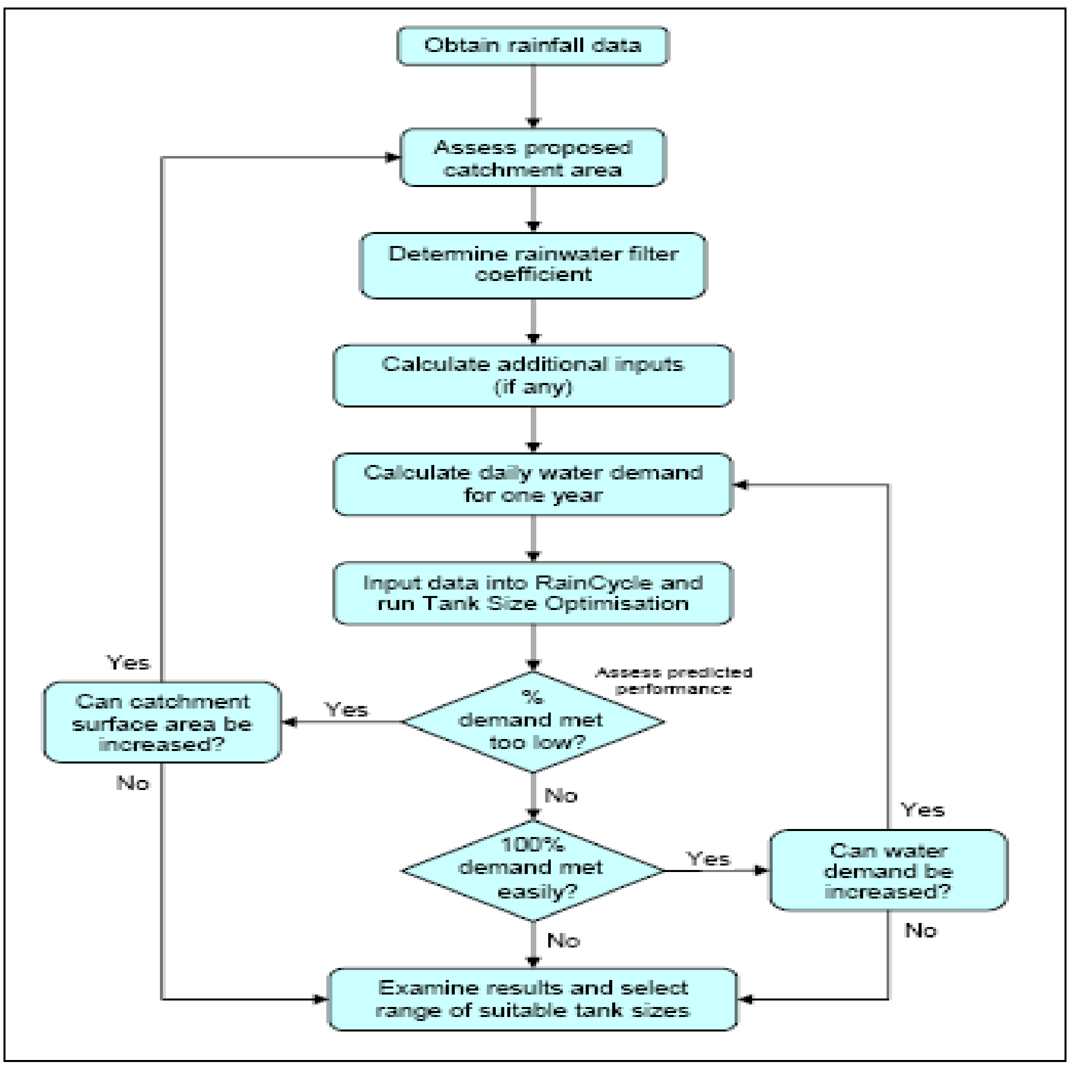


Figure 5.1 - Step 1 flowchart

5.2.2.1 Obtain Rainfall Data

The amount of rainfall available for collection is one of the key factors in the success (or otherwise) of any rainwater harvesting system. It is therefore important that the rainfall data used is as accurate as possible. Since rainfall patterns vary from region to region, the rainfall data should relate to the catchment area under study.

Generally speaking there are 3 types of rainfall data available. In terms of decreasing accuracy, they are:

1. Daily rainfall statistics (mm/day)
2. Monthly rainfall statistics (mm/month)
3. Yearly total rainfall (mm/year)

Daily rainfall statistics are not always available for every location in Rwanda and even if they are they can be difficult to locate. Monthly rainfall statistics are easier to obtain and data sets for average monthly rainfall depths in operating meteo-stations in Rwanda have been used with RainCycle.

Finally, in the absence of more accurate information, a single yearly average figure can be used. Note that this is not recommended since it does not take into account seasonal variations in rainfall patterns.

5.2.2.2 Assess Proposed Catchment Area

Determine Catchment Plan Area

The catchment area is the surface (usually a roof) that will collect and channel rainwater to the storage tank. It is necessary to calculate the plan area of the catchment surface i.e. the length multiplied by the width if one were looking down on the catchment from directly above. Figure below shows the calculation of catchment area.

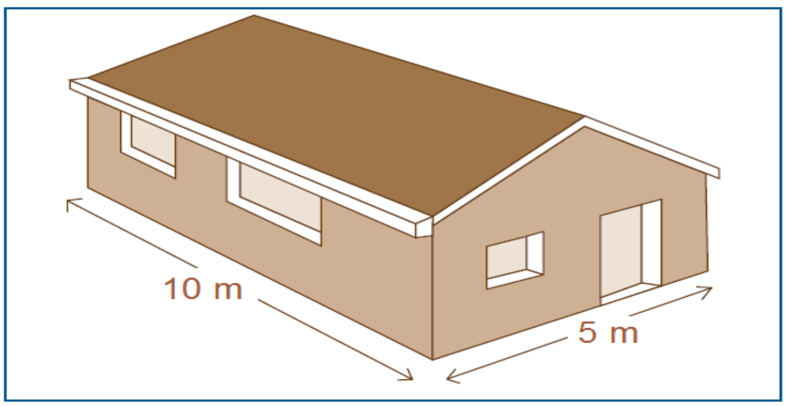


Figure 5.2: Calculation of catchement area

Determine Runoff Coefficient

The runoff coefficient determines how much water will flow from the catchment surface when it rains and how much is lost. Not all of the rain landing on a roof (or other surfaces) will end up in the pipe collection system. Surface wetting (the small fraction of rainfall that 'sticks' to a surface when it starts to rain), evaporation, ponding in depressions and the type of surface material all effect the level of effective runoff. Table below shows typical runoff coefficients for various roof types as well as some other common surfaces.

Table 2.1 – Typical runoff coefficients for various surface types

	Coefficients		
Surface Type	**High**	**Expected**	**Low**
Pitched roof tiles	0.90	0.85	0.75
Flat roof with smooth surface	0.60	0.55	0.50
Flat roof with gravel or thin turf (<150mm)	0.50	0.45	0.40
Asphalt or similar surface	0.90	0.85	0.80
Block pavements with wide joints	0.70	0.60	0.50
Gravel roads and driveways	0.30	0.20	0.15

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

5.2.2.3 Determine Rainwater Filter Coefficient

Filter coefficients are best obtained from manufacturers or suppliers of rainwater harvesting components. In the absence of more specific data, a coefficient of 0.90 can be used.

5.2.2.4 Calculate Additional Inputs (if any)

Additional inputs refer to storage tank inputs other than rainwater, such as greywater from baths and showers. Note that this would imply the use of a dedicated greywater system, which should be designed by a qualified engineer. It is not recommended that greywater be stored in a system that is intended for rainwater only. If the system under investigation is designed to only accept rainwater then greywater should *not* be input into the storage tank.

5.2.2.5 Calculate Daily Water Demand for One Year

If recorded water usage data for the building under study exists then it should be possible to calculate the daily water demand from this. RainCycle comes with a Demand Calculator sub-module that can be used to create a daily demand estimate.

It is strongly recommended that a site-specific water demand profile be determined. This is especially true for commercial, industrial and public premises since water usage here can vary widely from building to building. It is not advisable to use 'average' figures or data obtained from a different building. This is less of an issue for domestic dwellings since water usage per person tends to be more consistent, although site-specific data should still be obtained if possible. The Demand Calculator sub-module, which is accessible from the Water Demand screen, can be used to calculate demand values for domestic dwellings as well as commercial/industrial premises

Important Note: The water demand estimate should only refer to that which is intended to be met by the rainwater harvesting system e.g. toilet flushing and washing machine supply. Do not include demand which is to be met by other means such as drinking water which is to be supplied only from the mains.

5.2.2.6 Input Data into RainCycle and Run Tank Size Optimisation Analysis

Input the catchment surface area and first-flush volume (if any) as well as values for the rainfall, runoff coefficient, filter coefficient, additional inputs and water demand. Once the data has been input correctly, go to the 'Optimise Tank Size' module; enter a sensible figure in the *Max. Tank Size to Simulate* field (e.g. 20 m^3 for a domestic system) and click the Analyse button.

5.2.2.7 Examine Results and Select Range of Suitable Tank Sizes

Once the optimisation analysis is complete, examine the results table and corresponding graph, both of which are located in the bottom half of the screen. If the system performance is satisfactory then select an appropriate range of tank sizes. Aim to select tank sizes that meet a respectable amount of the water demand but that aren't excessively large, in order to keep capital costs to a minimum. For domestic systems, tanks are usually available in sizes of 1-6m^3 so try and choose sizes that fall within this range. There is a wider range of sizes available for commercial and industrial systems and the most appropriate ones need to be selected with some care. For instance, if a 30m^3 tank can meet 85% of demand and a 15m^3 tank can meet 80% then the best choice would be the 15m^3 tank. The extra 5% that the 30m3 tank could supply is unlikely to compensate for its increased cost over the smaller tank.

All in all, try and choose the smallest tank sizes that can meet an acceptable amount of the water demand. Any commercial/industrial RWH system that can supply 70-100% of the required volume is generally considered to provide a good level of service. Domestic systems tend to perform less well than this because of their inherent small catchment sizes (usually a house roof) and in general they can satisfy between 20-50% of non-potable demand.

5.2.3 Step 2: Determine cost savings of selected tank sizes from Step 1 and choose optimum size

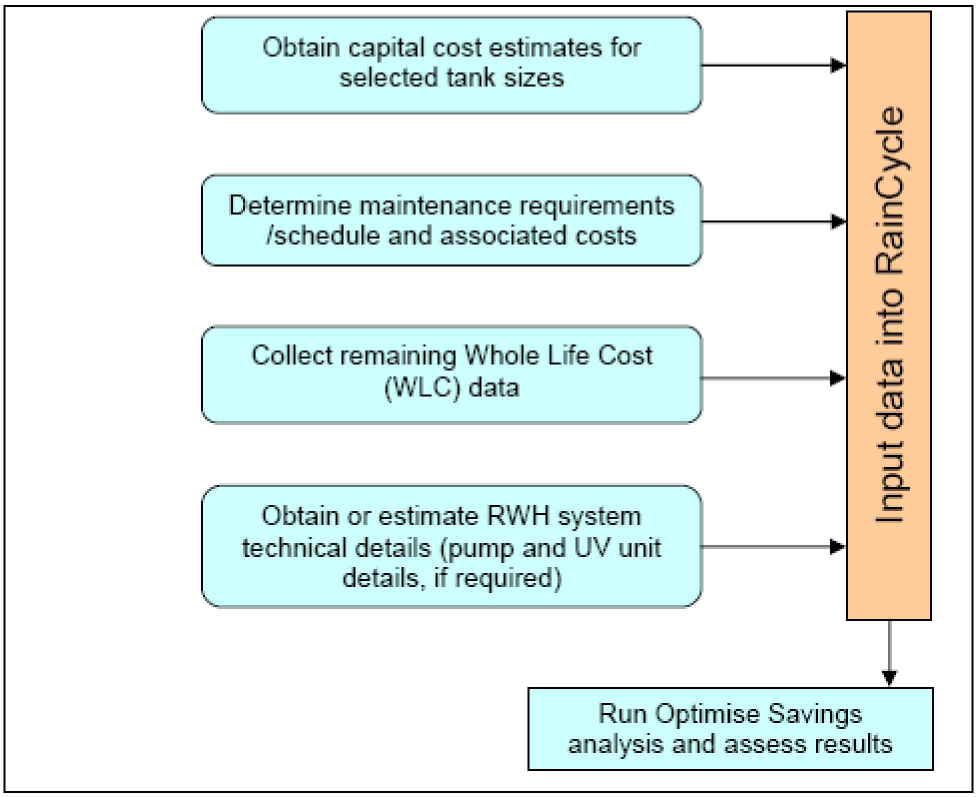


Figure 5.3 - Step 2 Flowchart

5.2.4 Step 3: Examine analysis results and assess performance

Whether or not performance is acceptable will depend on the criteria used to judge the system and these will vary from case to case. Potential monetary savings are obviously an important consideration but there are also the implied environmental benefits to take into account and so, even if the system has a long pay-back time or even runs at a loss, it may still be worth implementing from an environmental perspective.

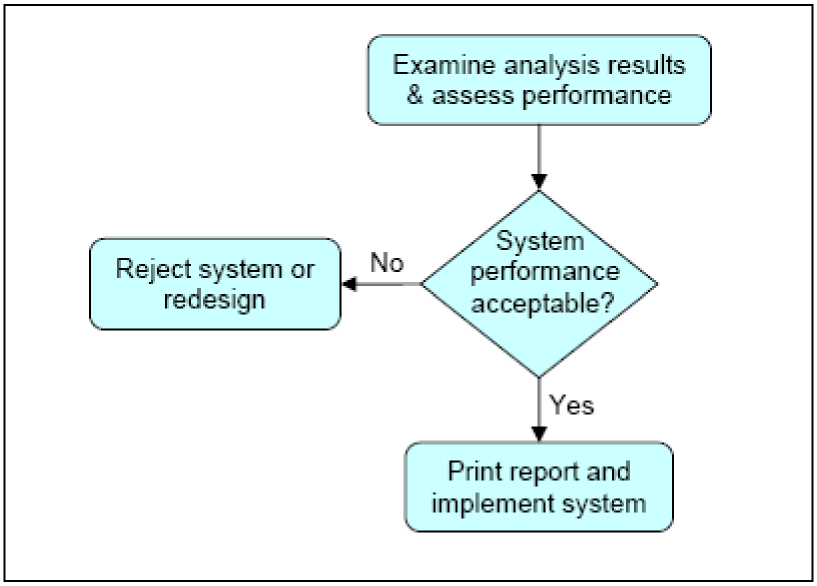


Figure 5.4 - Step 3 flowchart

5.3 Modeling for RWH and design of optimal storage for a Category 1 building

5.3.1 Modeling data

- *Rainfall Data*

Daily rainfall statistics were not available and so average monthly rainfall depths (mm/month) were used instead. The table below presents the average monthly rainfall depths obtained from Kanombe meteo-station.

Table 5.1: Average Rainfall depth

Month	Rainfall depth (mm/month)	Month	Rainfall depth (mm/month)
January	71.03	July	10.33
February	95.45	August	32.07
March	120.21	September	72.38
April	163.45	October	98.78
May	95.37	November	124.48
June	20.76	December	86.79

- *Proposed Catchment Area*

Catchment areas of buildings within this category are in the same range and therefore the catchment area of a representative building was obtained from the average of catchment areas of each building. The average roof area available for rainwater collection was estimated at 900 m^2.

The roof material consists of iron sheets and so an expected runoff coefficient of 0.90 will be used.

- *Rainwater Filter Coefficient*

A standard coarse debris filter is to be located before the main storage tank. These typically have a filter coefficient of 0.90 and so this is an acceptable value for the system under investigation.

- **Additional Inputs**

The system is intended to collect and store rainwater only and so there are no additional inputs to take into account.

- **Daily Demand for One Year**

It is anticipated that demand will only occur during working days and that any collected rainwater will be used for toilet (W.C.), urinal flushing and cleaning. Any shortfall in supply will be compensated for by mains top-up water.

The calculation of water demand to meet the above uses normally passes through counting the number of sanitary facilities within the building. In this category most buildings have inside toilets and urinals which use flushing system. Rainwater will be used through a network parallel to existing one that will distribute water to each sanitary facility.

Based on the average number of users and sanitary facilities within each of building we have estimated the daily water demand at 4.0 m^3/day during working days and 0.2 m^3/day on Saturdays.

- **Input Data into RainCycle Standard**

We now have all the data required to run the Optimise Tank Size analysis. Table 5.2 shows a summary of the data defined so far.

Table 5.2 – Summary of input data

Parameter	**Value**
Annual rainfall data	*See table 5.1*
Catchment surface area	900 m^2
Catchment runoff coefficient	0.90
Rainwater filter coefficient	0.90
Additional inputs	0 m^3/day
Daily water demand	4.0 m^3/day

5.3.2 Simulation and analysis of results

- ***Simulation of the System***

All data defined in previous paragraphs were entered in RainCycle Standard Software to run the simulation of the system.

Simulations will run until one of three conditions is met:

1. The maximum tank size to simulate as specified by the user has been reached.
2. 100% of demand has been met.
3. Percentage of demand met has peaked i.e. it does not increase with increasing tank size.

The last two criteria were included as there is no need to simulate beyond these points since no additional water savings will be observed.

In this case the simulation run until it reached a tank size of 33 m3, at which point the % of demand met has peaked at 54.2%. However, the assessment of the performance of the tanks showed that a tank of 30 m3 can meet the demand at 54.0% which is slightly less than the peak value and was therefore opted for further analysis of results.

- ***Analysis of results***

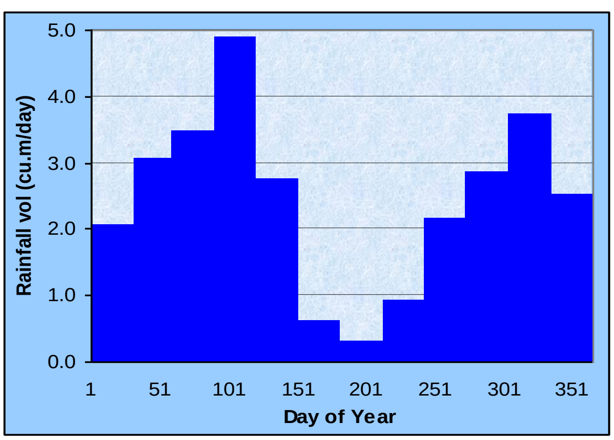
Among the proposed tank sizes, the storage tank volume of 30 m^3 was found to be performing better than others in terms of storage capacity. Below are some tables and charts that show the results of simulation.

Table 5.3: Catchment surface data

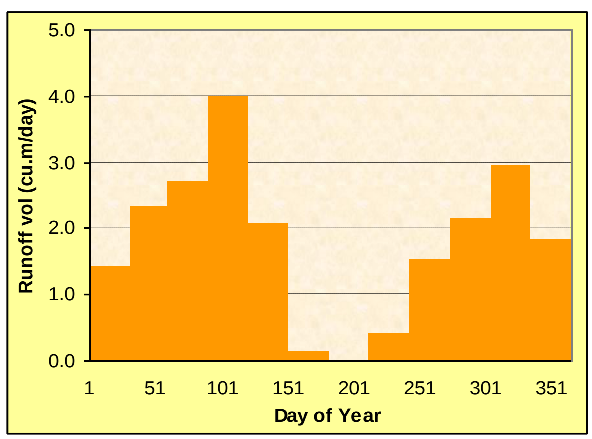
Surface area	900	m^2
Runoff coefficient	0.90	
First-flush volume	430	litres

Table 5.4: Summary of Rainfall/Runoff Results

Volume of rainfall falling on catchment surface	852	m^3/yr
Effective runoff volume	615	m^3/yr
Effective runoff volume as % of total	72	%
Rainfall losses	237	m^3/yr
Runoff losses as % of total	28	%



Volume of Rainfall on catchment/day



Effective runoff volume/day

Results of storage design are presented in tables and figures below.

Table 5.5: Storage tank data

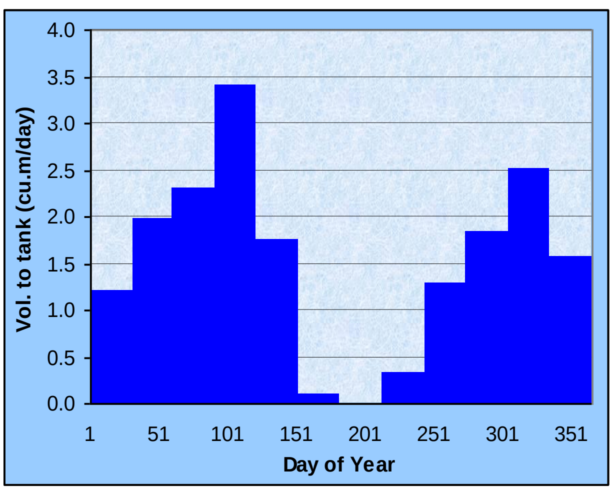
Storage tank volume	30.00 m^3
Mains top-up in storage tank?	No
No. of drain-down intervals	2 /yr

Table 5.6: Summary of storage tank results

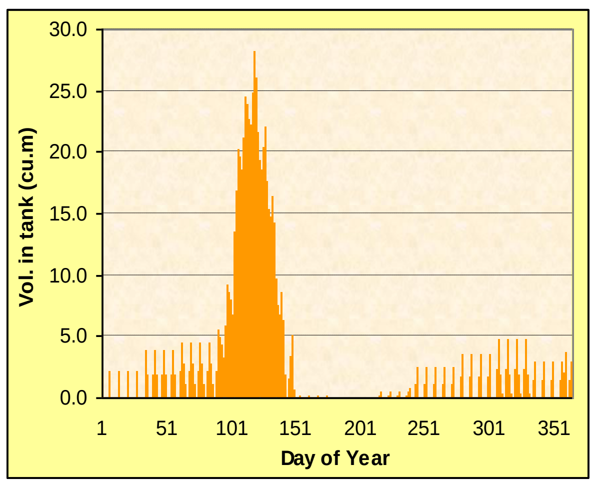
Volume of water entering tank			554 m^3/yr
Overflow	2 m^3/yr	As % of total	0 %
Withdrawal	552 m^3/yr	As % of total	100 %
Total number of days tank is empty			195 days/yr
Longest consecutive number of days tank is empty			40 days/yr

Results of storage reservoir design show that the proposed tank volume of 30 m^3 can hold 100% of volume of rainwater collected from the catchment.

Figures below show the proportions of supply and consumption per day by comparing the quantity of water that enters the tank and the quantity that remains in the tank at the end of the day.



Input to tank/day



Volume of water in tank/day

Table below summarizes the comparison of supply versus demand in terms of percentages.

Table 5.7: Summary of water demand results

Total yearly water demand				1,022	m^3/yr
Average daily water demand				2.8	m^3/day
Supplied	552	m^3/yr	As % of total	54	%
Shortfall	470	m^3/yr	As % of total	46	%

Results of the simulation for the catchment area show that the collected rainwater can satisfy 54% of the total yearly demand with an annual supply shortfall of 46% that can be supplemented by the mains water.

5.4 Modeling for RWH and design of optimal storage for a Category 2 building

5.4.1 Modeling data

- *Rainfall Data*

Daily rainfall statistics were not available and so average monthly rainfall depths (mm/month) were used instead. The table below presents the average monthly rainfall depths obtained from Kanombe meteo-station.

Table 5.8: Average Rainfall depth

Month	Rainfall depth (mm/month)	Month	Rainfall depth (mm/month)
January	71.03	July	10.33
February	95.45	August	32.07
March	120.21	September	72.38
April	163.45	October	98.78
May	95.37	November	124.48
June	20.76	December	86.79

- *Proposed Catchment Area*

Catchment areas of buildings within this category are in the same range and therefore the catchment area of a representative building was obtained from the average of catchment areas of each building. The average roof area available for rainwater collection was estimated at 2,300 m^2.

The roof material consists of iron sheets and so an expected runoff coefficient of 0.90 will be used.

- *Rainwater Filter Coefficient*

A standard coarse debris filter is to be located before the main storage tank. These typically have a filter coefficient of 0.90 and so this is an acceptable value for the system under investigation.

- **Additional Inputs**

The system is intended to collect and store rainwater only and so there are no additional inputs to take into account.

- **Daily Demand for One Year**

It is anticipated that demand will only occur during working days and that any collected rainwater will be used for toilet (W.C.), urinal flushing and cleaning. Any shortfall in supply will be compensated for by mains top-up water.

The calculation of water demand to meet the above uses normally passes through counting the number of sanitary facilities within the building. However, in this category some buildings have outside toilets and others have inside toilets with flushing system. Rainwater will be used through collection at tap stands installed on the tank for buildings with outside toilets and through a network parallel to existing one that will distribute water to each sanitary facility for buildings with inside toilets.

Based on the average number of users and sanitary facilities within each of building we have estimated the daily water demand at 12.5 m^3/day during working days and 0.1 m^3/day on Saturdays.

- **Input Data into RainCycle Standard**

We now have all the data required to run the Optimise Tank Size analysis. Table 5.9 shows a summary of the data defined so far.

Table 5.9 – Summary of input data

Parameter	Value
Annual rainfall data	*See table 5.8*
Catchment surface area	2,300 m^2
Catchment runoff coefficient	0.90
Rainwater filter coefficient	0.90
Additional inputs	0 m^3/day
Daily water demand	12.5 m^3/day

5.4.2 Simulation and analysis of results

- ***Simulation of the System***

All data defined in previous paragraphs were entered in RainCycle Standard Software to run the simulation of the system. Simulations will run until one of three conditions is met:

1. The maximum tank size to simulate as specified by the user has been reached.
2. 100% of demand has been met.
3. Percentage of demand met has peaked i.e. it does not increase with increasing tank size.

In this case the simulation run until it reached a tank size of 58 m³, at which point the % of demand met has peaked at 47.2%. However, the assessment of the performance of the tanks showed that a tank of 50 m³ can meet the demand at 47.0% which is slightly less than the peak value and was therefore opted for further analysis of results.

- *Analysis of results*

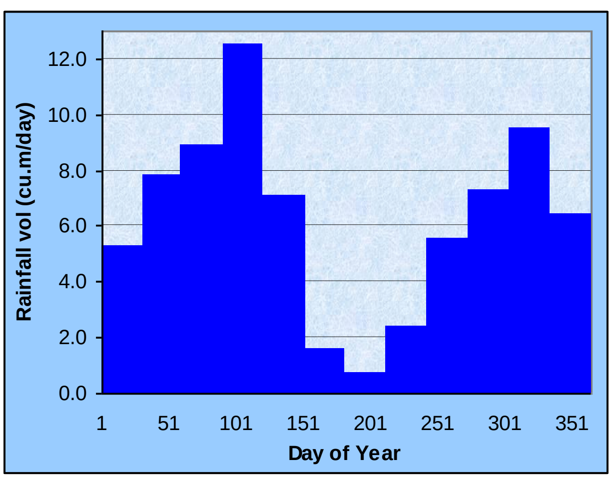
Among the proposed tank sizes, the storage tank volume of 50 m³ was found to be performing better than others in terms of storage capacity. Below are some tables and charts that show the results of simulation.

Table 5.10 – Catchment surface data

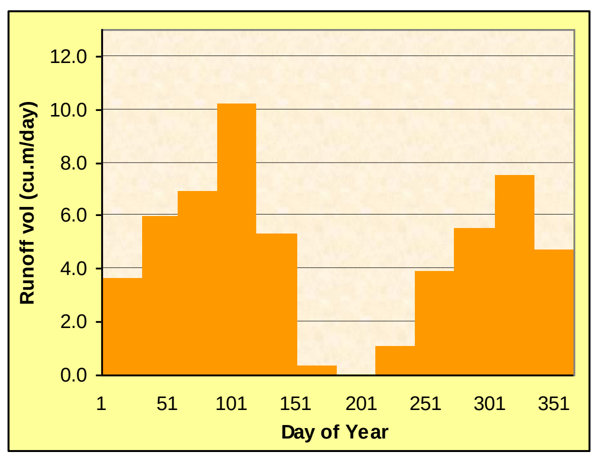
Surface area	2,300	m²
Runoff coefficient	0.90	
First-flush volume	1100	litres

Table 5.11 – Summary of rainfall/runoff results

Volume of rainfall falling on catchment surface	2,279	m³/yr
Effective runoff volume	1,663	m³/yr
Effective runoff volume as % of total	73	%
Rainfall losses	617	m³/yr
Runoff losses as % of total	27	%



Volume of Rainfall on catchment/day



Effective runoff volume/day

Results of storage design are presented in tables and figures below.

Table 5.12 – Storage tank data

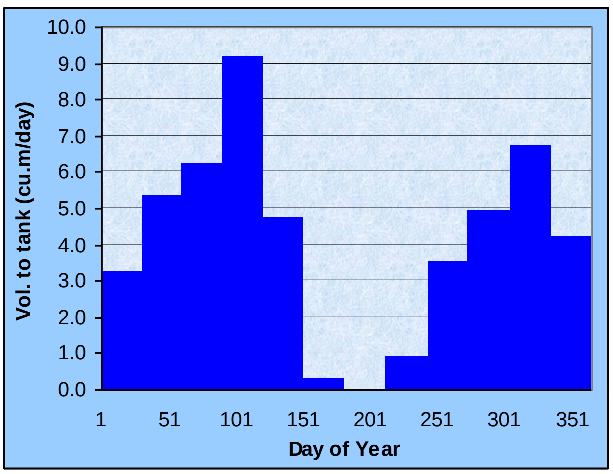
Storage tank volume	50.00	m³
Mains top-up in storage tank?	No	
No. of drain-down intervals	2	/yr

Table 5.13 – Summary of storage tank results

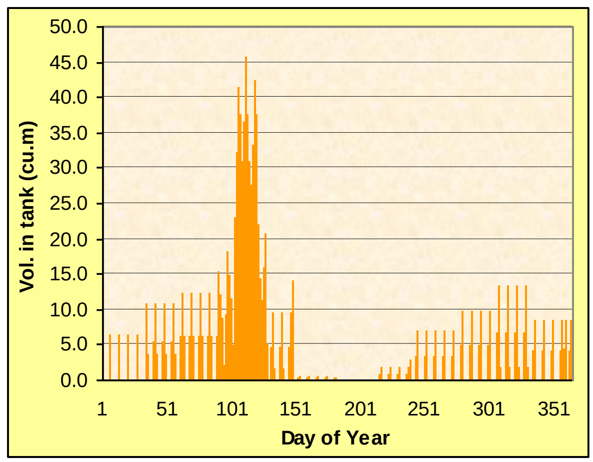
Volume of water entering tank			1,496	m³/yr
Overflow	7 m³/yr	As % of total	0	%
Withdrawal	1,490 m³/yr	As % of total	100	%
Total number of days tank is empty			208	days/yr
Longest consecutive number of days tank is empty			33	days/yr

Results of storage reservoir design show that the proposed tank volume of 50 m³ can hold almost 100% of volume of rainwater collected from the catchment.

Figures below show the proportions of supply and consumption per day by comparing the quantity of water that enters the tank and the quantity that remains in the tank at the end of the day.



Input to tank/day



Volume of water in tank/day

Table below summarizes the comparison of supply versus demand in terms of percentages.

Table 5.14 – Summary of water demand results

Total yearly water demand			3,168	m³/yr
Average daily water demand			8.7	m³/day
Supplied	1,490 m³/yr	As % of total	47	%
Shortfall	1,678 m³/yr	As % of total	53	%

Results of the simulation for the catchment area show that the collected rainwater can satisfy 47% of the total yearly demand with an annual supply shortfall of 53% that can be supplemented by the mains water.

5.5 Modeling for RWH and design of optimal storage for a Category 3 building

5.5.1 Modeling data

- *Rainfall Data*

Daily rainfall statistics were not available and so average monthly rainfall depths (mm/month) were used instead. The table below presents the average monthly rainfall depths obtained from Kanombe meteo-station.

Table 5.15: Average Rainfall depth

Month	Rainfall depth (mm/month)	Month	Rainfall depth (mm/month)
January	71.03	July	10.33
February	95.45	August	32.07
March	120.21	September	72.38
April	163.45	October	98.78
May	95.37	November	124.48
June	20.76	December	86.79

- *Proposed Catchment Area*

Catchment areas of buildings within this category are in the same range and therefore the catchment area of a representative building was obtained from the average of catchment areas of each building. The average roof area available for rainwater collection was estimated at 350 m^2.

The roof material consists of iron sheets and so an expected runoff coefficient of 0.90 will be used.

- *Rainwater Filter Coefficient*

A standard coarse debris filter is to be located before the main storage tank. These typically have a filter coefficient of 0.90 and so this is an acceptable value for the system under investigation.

- *Additional Inputs*

The system is intended to collect and store rainwater only and so there are no additional inputs to take into account.

- *Daily Demand for One Year*

It is anticipated that demand will only occur during working days and that any collected rainwater will be used for toilet (W.C.), urinal flushing and cleaning. Any shortfall in supply will be compensated for by mains top-up water.

The calculation of water demand to meet the above uses normally passes through counting the number of sanitary facilities within the building. However, in this category most buildings have outside toilets which have no flushing system. Rainwater will be used through collection at tap stands installed on the tank. We have estimated the daily water demand at 1.5 m^3/day during working days and 0.2 m^3/day on Saturdays.

- *Input Data into RainCycle Standard*

We now have all the data required to run the Optimise Tank Size analysis. Table 5.16 shows a summary of the data defined so far.

Table 5.16 – Summary of input data

Parameter	Value
Annual rainfall data	*See table 5.15*
Catchment surface area	350 m^2
Catchment runoff coefficient	0.90
Rainwater filter coefficient	0.90
Additional inputs	0 m^3/day
Daily water demand	1.5 m^3/day

5.5.2 Simulation and analysis of results

- *Simulation of the System*

All data defined in previous paragraphs were entered in RainCycle Standard Software to run the simulation of the system. Simulations will run until one of three conditions is met:

1. The maximum tank size to simulate as specified by the user has been reached.
2. 100% of demand has been met.
3. Percentage of demand met has peaked i.e. it does not increase with increasing tank size.

In this case the simulation run until it reaches a tank size of 16 m^3, at which point the % of demand met has peaked at 57.8%. However, the assessment of the performance of the tanks showed that a tank of 10 m^3 can meet the demand at 56.7% which is slightly less than the peak value and was therefore opted for further analysis of results.

- ***Analysis of results***

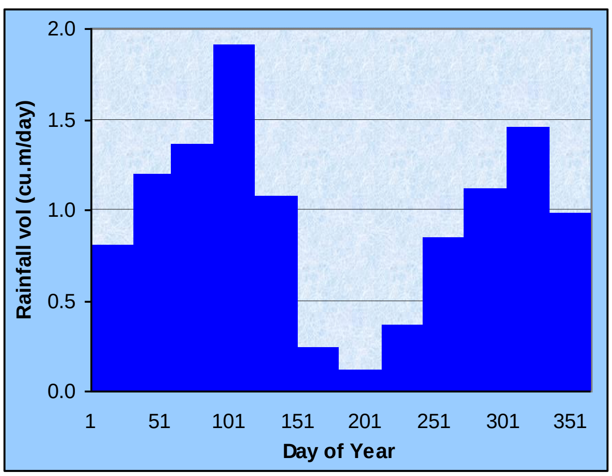
Among the proposed tank sizes, the storage tank volume of 10m^3 was found to be performing better than others in terms of storage capacity. Below are some tables and charts that show the results of simulation.

Table 5.17 – Catchment surface data

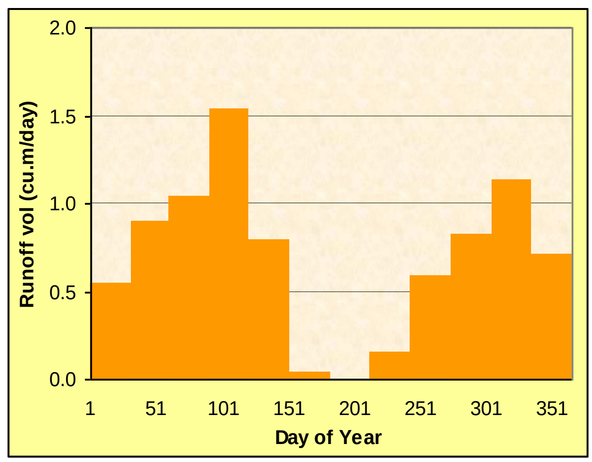
Surface area	350	m^2
Runoff coefficient	0.90	
First-flush volume	175	litres

Table 5.18 – Summary of rainfall/runoff results

Volume of rainfall falling on catchment surface	347	m^3/yr
Effective runoff volume	250	m^3/yr
Effective runoff volume as % of total	72	%
Rainfall losses	96	m^3/yr
Runoff losses as % of total	28	%



Volume of Rainfall on catchment/day



Effective runoff volume/day

Table 5.19 – Storage tank data

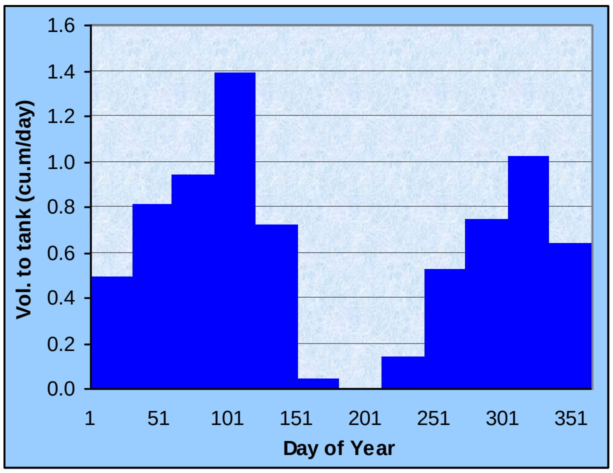
Storage tank volume	10	m^3
Mains top-up in storage tank?	No	
No. of drain-down intervals	2	/yr

Table 5.20 – Summary of storage tank results

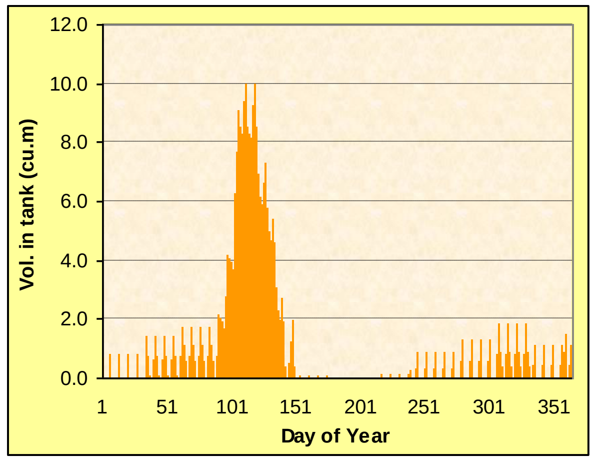
Volume of water entering tank					225	m^3/yr
Overflow	5	m^3/yr	As % of total		2	%
Withdrawal	221	m^3/yr	As % of total		98	%
Total number of days tank is empty					191	days/yr
Longest consecutive number of days tank is empty					41	days/yr

Results of storage reservoir design show that the proposed tank volume of 10 m^3 can hold 98% of volume of rainwater falling on the catchment area.

Figures below show the proportions of supply and consumption per day by comparing the quantity of water that reaches the tank and the one that remains in the tank at the end of the day.



Input to tank/day



Volume of water in tank/day

Table below summarizes the comparison of supply versus demand in terms of percentages.

Table 5.21 – Summary of water demand results

Total yearly water demand				390	m^3/yr
Average daily water demand				1.1	m^3/day
Supplied	221	m^3/yr	As % of total	57	%
Shortfall	169	m^3/yr	As % of total	43	%

Results of the simulation for the catchment area show that the collected rainwater can satisfy 57% of the total yearly demand with an annual supply shortfall of 43% that can be supplemented by the mains water.

5.6 Summary of results for storage reservoirs design

Results of simulations for sample buildings are presented in table below. They are summarized in terms of the percentage of water demand met by the proposed storage reservoir capacity which shows the overall performance of the proposed system.

Table 5.22: Summary of results for storage reservoirs design

Building	Reservoir capacity (m^3)	% of demand met	% of shortfall
CATEGORY 1	30	54	46
CATEGORY 2	50	47	53
CATEGORY 3	10	57	43

VI. STRUCTURAL DESIGN OF STORAGE RESERVOIRS AND PIPES

6.1 Choice of shape and construction materials for underground storage reservoir

The best tank shape is circular; rectangular tanks have a great number of disadvantages mainly the weakness in the joints. The economical materials for small to medium size tanks are a combination of reinforced concrete and stone masonry. An inside concrete layer with a small thickness is necessary and surrounded by a thick wall of stone masonry.

Horizontal reinforcement (in circles) is essential to withstand the stress on the circumference of a circular tank. At the top of the tank, the force is very weak, and reinforcement is hardly necessary; however, the space between the circular reinforcement bars should not be more than three times the thickness of the tank wall.

For the case of this project, the chosen storage capacities provide reservoirs in the range of small to medium capacity reservoirs and therefore we have opted for circular reservoirs in reinforced concrete inside layer and an outside stone masonry layer. In addition, considering the aesthetic and topography of the buildings we have proposed underground reservoirs.

6.2 Structural design of a circular water reservoir of 50 cubic meters

6.2.1 Choice of dimensions of the reservoir

The economic proportion of diameter to height of circular cylindrical tanks was found to be 4:1. For a tank of 50 cubic meters, the economic dimensions are chosen as follows:

Item	Dimension (m)
Water Depth	2.20
Interior Width	5.40
Thickness of Hardcore	0.30
Width of Apron	0.20
Wall Thickness	0.40
Freeboard	0.12
Sludge Depth	0.10

The structure has base and roof slabs made from reinforced concrete. The structure is plastered internally with three layers of waterproof mortar.

6.2.2 Analysis and design of the reservoir

The design has a steel access cover placed centrally over the valve chamber side. Good quality fittings should be used where possible. Where pipes pass through the walls, GI pipes should be used fitted with 'anti-passage' rings to the pipes to prevent the path of water filtration along the pipe. Calculations are based on the following design rules.

1. An ordinary 1:2:4 concrete mix is not waterproof therefore a richer 1:1.5:3 mixture (with a cement dosage of 380 kg/m^3) has been used for floor slab calculations. A standard 1:2:4 concrete mix with a cement dosage of 320 kg/m^3, has been used for the roof slab calculation.

2. Base slab thickness is determined using the empirical rule below, with a minimum value of 10 cm.

Slab Thickness = Shortest Span / 40

3. The base slab is designed for the weight of the structure and water stored pressing downwards and the reaction of the soil pressing upwards

Slab Loading = (Weight of Structure + Water)/ Slab Area

4. The base slab has been designed with sufficient strength to enable it to span over possible weak strength to enable it to span over possible weak patches of the ground. The bending moment is greatest at the center of the slab and has been calculated as follows:

Maximum Bending Moment = (Loading x Span) / 24

5. The required reinforcement to resist the maximum bending moment has been calculated assuming mild steel grade I ribbed bars with a tensile strength of 1,650kg/cm^2. The total area of reinforcement required for one meter's width of slab has been calculated by:

Area = Maximum Bending Moment/ (Max. Reinf. Tension x Lever Arm)

Where the lever arm can be found by the empirical rule:

Lever Arm = 7/8 x Concrete Wall Thickness

6. Base slab reinforcement sizes have been selected on the basis of providing the

smallest diameter practicable. Load spreading is provided by the lateral reinforcement members, which have the same area and spacing as the longitudinal reinforcement.

7. Roof slab thickness is determined using the empirical rule below, with a minimum value of 10 cm.

Slab Thickness = Shortest Span / 40

8. The roof slab is designed for the weight of the slab structure plus a local access loading of 200kg/m^2 (the weight of three people)

Loading = [(Slab W eight + (200kg/m^2 x Area)]/ Slab Area

9. In a simply supported slab resting on four walls, the bending moment is greatest at the center of the slab. The maximum bending moment (BM) has been calculated by:

Maximum BM = (Loading x Span^2) / 8

10. The required reinforcement to resist the maximum bending moment has been calculated assuming mild steel grade 1 ribbed bars with a maximum tensile strength of 1650kg/cm^2. The total area of reinforcement required for one meter's length of wall has been calculated by:

Total Area = Maximum BM/ (1650 kg/cm^2 x Lever Arm)

Where the lever arm can be found by the assuming mild steel grade I ribbed bars with a empirical rule:

Lever Arm = 7/8 x Concrete Slab Thickness

11. Roof reinforcement sizes have been selected on the basis of providing the smallest diameter practicable. Load spreading is provided by the lateral reinforcement members, which have the same area and spacing as the longitudinal reinforcement.

12. Internal plastering consists of three layers using waterproofing compound (should be well chosen) as follows:

- Layer 1: 6mm 1:4 – Splatterdash
- Layer 2: 10mm 1:3 – rough finish
- Layer 3: 10mm 1:2 – smooth float

6.2.2 Design of roof slab

The dosage of the roof slab is 320 kg/m^3 – 1:2:4 mix ratio.

Slab Thickness = Shortest Span / 40
= 3.2 m / 40
= 0.08 m (minimum 0.10 m)

Slab Loading = (Slab Weight + (200kg/m^2 x Area))/Slab Area
= [(3.22 m^3 x 2500 kg/m^3)
+ (200 kg/m^3 x 32.2 m^2)] / 32.2 m^2
= 450 kg/m^2

Therefore for a unit meter width of slab with a distributed loading of 450 kg/m, spanning 3.2 m

Maximum BM = (Loading x Span^2)/ 8
= [450 kg/m x (3.2 m)^2]/ 8
= 576.0 kg.m

Total Area = Maximum Bending Moment/(1650 kg/cm^2 x Lever Arm)

Where
Lever Arm = 7/8 x Concrete Slab Thickness
= 7/8 x 10 cm
= 8.75 cm

Rebar Area = 576 kg.m / (1650 x 0.0875 m)
(per m width) = 3.98 cm^2

Assume 8 mm reinforcement bars available with area 0.50 cm^2

Bars per m Width = 3.98 cm^2 / 0.50 cm^2
= 7.96 (8 bars)

Rebar Spacing = 1 m / 8 bars
= every 12.5 cm

Assume that load spreading (longitudinal) reinforcement will also consist of 8 mm reinforcement bars spaced every 12.5 cm.

6.2.3 Design of base slab

The dosage of the base slab is 380 kg/m^3 – 1:1.5:3 mix ratio.

Slab Thickness = Shortest Span / 40
= 6.6 / 40
= 0.165 m (minimum 0.15 m)
Slab Loading = (Weight of Structure + Water)/Slab Area

Where the total weight of the structure can be found by:

Total Weight = Floor + Roof + Walls + Water
= ((3.22 m^3 + 5.13 m^3 + 14.1 m^3) x 2,500 kg/m^3) + 50,000 kg
= 106,125 kg

Base Loading = 106,125 kg / 34.2 m^2
= 3,103 kg/m^2

Therefore, for a unit meter width of slab with a distributed loading of 3,103 kg/m, spanning 6.6 m

Maximum BM = (Loading x Span^2) / 24
= ((3,103 kg/m x (6.6 m)^2)/24
= 5,632 kg.m

Longit. Rebar (per m width) = Maximum BM/(Max. Reinf. Tension x Lever Arm)
Where
Lever Arm = 7/8 x Concrete Slab Thickness
= 7/8 x 18 cm
= 15.75 cm

Longit. Rebar (per m width) = 5,632 kg.m / (1650 x 0.1575 m)
= 21.7 cm^2
Assume 16 mm reinforcement bars available with area 2.01 cm^2

Longit. Rebar (per m width) = 21.7 cm^2/ 2.01 cm^2
= 10.79 (11 bars)
Longit. Rebar = 1 m / 11 bars
Spacing = every 10.0 cm

Lat. Bar Area (per m length) = Longitudinal Reinforcement Area
= 21.7 cm^2

Therefore lateral reinforcement will also consist of 10 x 16 mm reinforcement bars spaced every 10.0 cm.

Detailed plans of the reservoirs and reinforcement bars schedules are presented in annex 2.

The analysis and design for other sizes of storage reservoirs have been done in the same way as the previous one.

6.3 Design of piping system and its accessories

The piping system and its accessories in a RWH system can be made of the following elements:

- Collection and Distribution pipes;
- First-flush water diverters and Rain Filters used for water treatment;
- Overflow arrangement (including backflow prevention device);
- Pump and associated components;
- Header tank (for indirect and gravity fed systems);
- Mains top-up arrangement.

6.3.1 Design of rainwater collection and distribution pipes

6.3.1.1. Choice of pipe materials

The PVC pipes are preferable because most the existing rainwater collectors are in PVC and the other accessories to be used for pretreatment of collected water will be in PVC which will enable easy connection of those components. Distribution and service connection pipes shall be either in PVC or galvanized steel (GI).

6.3.1.2 Hydraulic design of collection pipes

Rainwater collection pipes take water from the roof and convey it to a storage device. The design of such pipes consists of finding the following parameters:

1. What it is the available head-loss ΔH (and consequently the pressure) in a pipe of diameter D, when it conveys flow Q?
2. What the flow Q that a pipe of diameter D can deliver if certain maximum head-loss ΔH_{max} (i.e. the minimum pressure p_{min}) is to be maintained?
3. What is the optimal diameter D of a pipe that has to deliver the required flow Q at a certain maximum head-loss ΔH_{max} (i.e. the minimum pressure p_{min})?

In all cases the flow Q is known from the available rainwater. The following table recommended dimensions of downspouts depending on the catchment area size.

Table 6.1 - Recommended Sizes for Downspouts

Type	Area of roof (cm^2)	Nominal Size (mm)	Actual size (mm)
Plain	45.61	76.20	76.20
	81.10	101.60	101.60
	126.64	127.00	127.00
Round	182.39	152.40	152.40
Corrugated	38.13	76.20	76.20
	71.03	101.60	101.60
	114.32	127.00	127.00
Round	167.55	152.40	152.40

6.4.2 Header tank

Indirect systems require the use of a header tank. This is normally located in the roof void of the building and should be at least 1m above the point of supply. High and low level switches are used to signal the storage tank pump when to activate and when to disengage. If mains top-up occurs in the header tank then this is usually controlled by a low level switch in conjunction with a solenoid or float valve.

Header tanks can be provided to allow gravity feed system for service connections. Water from underground reservoirs will be pumped to header tanks from which it will be distributed by gravity to service connections.

For each building classified in category 1 a header tank of 3.5 m^3 will be sufficient. This storage capacity can accommodate a big percentage of daily water demand for the building.

6.3.3 Storage device overflow arrangement

Modern rainwater tanks have an overflow arrangement in order to prevent localized flooding if the capacity of the tank is exceeded, and also to help avoid stagnation of stored water and remove floating debris. The overflow can be connected to a soakaway/infiltration device, storm drain or combined sewer system but not a foul sewer. It must include an anti-backflow device in order to prevent contaminated water entering the tank in the event of downstream surcharging. Overflows are predominantly unrestricted (no throttle) and water passes through them via gravity flow although pumped overflows are also available.

6.3.4 Solenoid valves

Solenoid valves are typically used to start/stop the mains top-up function. A float activated switch, located either in the header tank (for indirect and gravity fed systems) or primary storage tank (for direct systems), triggers the valve if the water volume falls below a predetermined level. This activates the mains top-up function, ensuring that a minimum amount of water is available at all times. Once the minimum water level has been restored, the float activated switch closes the valve, shutting off the flow of mains top-up water.

In case it is intended to automate the process of water distribution from header tanks, solenoid valves will be installed on header tanks to allow automatic activation of the pump that supplies water to them.

VII. COST ESTIMATION FOR PROPOSED RAINWATER COLLECTION SYSTEMS

7.1 Costs indication

Developing a budget for a rainwater harvesting system may be as simple as adding up the prices for each of the components and deciding what one can afford. The single largest expense is the storage tank, and the cost of the tank is based upon the size and the material. Table 7-1 shows a range of potential tank materials and costs per cubic meter of storage.

Table 7-1: Cost indication for Storage Tank

	Cost (RWF)	Standard Size	Comments
Fiberglass	220,000/ m^3	2–75 m^3	Can last for decades without deterioration; easily repaired; can be painted
Reinforced Concrete	350,000/m^3	Usually 30 m^3 or more (up to 4,000 m^3)	Risks of cracks and leaks but these are easily repaired; immobile; smell and taste of water sometimes affected but the tank can be retrofitted with a plastic liner
Metal	160,000/ m^3	1–10 m^3	Lightweight and easily transported; rusting and leaching of zinc can pose a problem but this can be mitigated with a potable-approved liner
Polyethylene	130,000/ m^3	1–20 m^3	
Brick/stone masonry	150,000/ m^3	5–30 m^3	
Mixed – RC/stone masonry	200,000/ m^3	10–100 m^3	

Gutters and downspouts (Table 7-2) are needed to collect the water and route it to the tank. Some method of discarding the first flush of rain from the roof is necessary to remove debris. The simplest method is a vertical PVC standpipe, which fills with the first flush of water from the roof, then routes the balance of water to the tank.

Table 7-2: Gutters cost

	Cost (RWF)	Comments
Metal	8,500/m	Easy to install and attach to metallic roof
Plastic	6,000/m	Leaking, warping and breaking are common problems
Iron sheet	4,500/m	Must be professionally installed

Table 7-3 shows the ranges for pump costs including pressure tanks. Demand activated pumps such as Grundfos may not require a pressure tank, and can often provide enough water to meet a home's demand for instantaneous flow. Careful thought should be given to the possibility of multiple simultaneous demands upon the system in determining the appropriate pump size.

Table 7-3: Pumps cost

	Cost (RWF)	Comments
Grundfos CH4 60 Water Supply System	1,640,000 – 1,720,000	Does not require a separate pressure tank
Shallow Well Jet Pump or Multi-Stage Centrifugal Pump	840,000 - 1,260,000	These require a separate pressure tank
Pressure Tank	280,000 - 345,000	Galvanized tanks are cheaper than bladder tanks but often become waterlogged, and this will wear out the pump more rapidly

7.2 Operating Costs

There are also operating costs that should be considered as the budget is prepared. As with any water treatment system, the cleaner the water needs to be, the greater the effort required to maintain the system.

Some of the operating costs and time expenditures necessary for system maintenance are regularly cleaning gutters and roof washers, checking the system for leaks by monitoring water levels, and paying close attention to water use rates to determine if an invisible leak has happened.

7.3 Cost estimation for installation of RWCS for a building of Category 1

The main components for installation of a rainwater collection system for a building of category 1 are:

1. A storage reservoir;
2. A pumping system and its accessories;
3. A header (rooftop) tank;
4. Gutters and downspouts;
5. Distribution pipes and their accessories.

In addition, there will be some cost for the construction and installation works, follow-up of activities as well as the cost for operation and maintenance of the system.

Based on costs indication in previous paragraph and current costs of construction activities and materials, the cost of installing a rainwater collection system for a building in category 1 has been estimated to a total amount of **Fifty Million Four Hundred Twenty Four Thousand Three Hundred and Fifty Rwandan Francs (50,424,350 RWF)**. Detailed bill of quantities is presented in the annex of this report.

The total number of public buildings in category 1 that have no rainwater collection systems and those with partial rainwater collection was estimated at 17 buildings from the inventory.

If we consider this number, the cost for installation of rainwater collection systems for buildings in category 1 is estimated at **857,213,950 RWF.**

7.4 Cost estimation for installation of RWCS for a building of Category 2

The main components for installation of a rainwater collection system for a building of category 2 are:

1. A storage reservoir;
2. A pumping system and its accessories;
3. Gutters and downspouts;
4. Distribution pipes and their accessories.

In addition, there will be some cost for the construction and installation works, follow-up of activities as well as the cost for operation and maintenance of the system.

Based on costs indication in previous paragraph and current costs of construction activities and materials, the cost of installing a rainwater collection system for a building in category 1 has been estimated to a total amount of **Sixty Three Million One Hundred Fifty Three Thousand Six Hundred Rwandan Francs (63,153,600 RWF)**. Detailed bill of quantities is presented in the annex of this report.

The total number of public buildings in category 2 that have no rainwater collection systems and those with partial rainwater collection was estimated at 380 buildings from the inventory.

If we consider this number, the cost for installation of rainwater collection systems for buildings in category 2 is estimated at **23,998,368,000 RWF.**

7.5 Cost estimation for installation of RWCS for a building of Category 3

The main components for installation of a rainwater collection system for a building of category 3 are:

1. A storage reservoir;
2. Gutters and downspouts;
3. Distribution pipes and their accessories.

In addition, there will be some cost for the construction and installation works, follow-up of activities as well as the cost for operation and maintenance of the system. This component will be summarized in miscellaneous expenses

Based on costs indication in previous paragraph and current costs of construction activities and materials, the cost of installing a rainwater collection system for a building in category 1 has been estimated to a total amount of **Nine Million Eight Hundred Eighty Six Thousand and Forty Rwandan Francs (9,886,040 RWF)**. Detailed bill of quantities is presented in the annex of this report.

The total number of public buildings in category 3 that have no rainwater collection systems and those with partial rainwater collection was estimated at 380 buildings from the inventory.

If we consider this number, the cost for installation of rainwater collection systems for buildings in category 3 is estimated at **3,756,695,200 RWF.**

7.6 Summary of costs for installation of RWCS per Province

The following tables summarize the cost for installation of rainwater collection systems (RWCS) on public buildings in Kigali city and other towns in Rwanda. The cost has been established based on the number of buildings with no rainwater collection systems and the buildings identified as having partial rainwater collection systems.

KIGALI CITY			
Category	**Number of buildings in need of RWCS**	**Rate (Rwf)**	**Total Amount (Rwf)**
1	14	50,424,350	705,940,900
2	122	63,153,600	7,704,739,200
3	68	9,886,040	672,250,720
TOTAL			**9,082,930,820**

EASTERN PROVINCE			
Category	**Number of buildings in need of RWCS**	**Rate (Rwf)**	**Total Amount (Rwf)**
1	1	50,424,350	50,424,350
2	55	63,153,600	3,473,448,000
3	48	9,886,040	474,529,920
TOTAL			**3,998,402,270**

WESTERN PROVINCE			
Category	**Number of buildings in need of RWCS**	**Rate (Rwf)**	**Total Amount (Rwf)**
1	0	50,424,350	0
2	92	63,153,600	5,810,131,200
3	64	9,886,040	632,706,560
TOTAL			**6,442,837,760**

NORTHERN PROVINCE			
Category	**Number of buildings in need of RWCS**	**Rate (Rwf)**	**Total Amount (Rwf)**
1	1	50,424,350	50,424,350
2	40	63,153,600	2,526,144,000
3	112	9,886,040	1,107,236,480
TOTAL			**3,683,804,830**

SOUTHERN PROVINCE			
Category	**Number of buildings in need of RWCS**	**Rate (Rwf)**	**Total Amount (Rwf)**
1	1	50,424,350	50,424,350
2	71	63,153,600	4,483,905,600
3	88	9,886,040	869,971,520
TOTAL			**5,404,301,470**
GRAND TOTAL FOR ALL BUILDINGS			**28,612,277,150**

Tables above show that MININFRA should be mobilized a total amount of at least 28 billion to set up rainwater collection systems on public buildings in Kigali City and other towns as inventoried in this feasibility study.

7.7 Summary of costs for installation of RWCS per Category

If we combine the results of costs estimation from the previous paragraphs we can make a summary of cost estimation for installation of rainwater collection systems for all categories defined in this study. Table below summarizes the results of cost estimation per category.

Category of building	Quantity	Rate (RWF)	Amount (RWF)
1	17	50,424,350	857,213,950
2	380	63,153,600	23,998,368,000
3	380	9,886,040	3,756,695,200
TOTAL			**28,612,277,150**

7.8 Strategic plan for implementation of construction of rainwater collection systems

The outputs of the feasibility study showed that most public buildings in Kigali City and other towns were classified in categories 2 and 3 according to criteria defined in the study. The installation of rainwater collection systems for categories 1 and 2 is a bit more complex and expensive than for category 3.

The Ministry of Infrastructure can start with construction of RWCS on buildings of category 1 in Kigali city because their total cost is too little compared to category 2 and they are at strategic locations which can help showcase the implemented technology. In other towns many public buildings were classified in category 2 and therefore MININFRA can start with category 2.

It is clear from the feasibility study that MININFRA will contribute much in terms of technical assistance and financial support in the construction of rainwater collection systems for buildings of categories 1 and 2.

The cost for installation of rainwater collection systems for buildings of category 3 seems to be affordable by local authority or owners of the buildings. They can implement the systems with their budget with the technical support of MININFRA whenever necessary.

VIII. RAINWATER QUALITY AND TREATMENT

Rainwater harvesting systems should be designed to ensure water maintains its purity while in storage. This is accomplished through the implementation of precision products that divert, collect, and store water.

Because of the lack of readily available information concerning rainwater quality, the general public is often doubtful of consuming and utilizing rainwater for potable and/or non potable use.

Rainwater qualities include:

- Naturally soft
- Slightly acidic (6.3 – 6.8)
- Contains no sodium
- Contains very few contaminants and bacteria
- Completely safe for non potable use in and around a building

Rainwater is considered uncontaminated until it falls on a roof and absorbs contaminates from both the roof and air, thus filtering is necessary before diverting rainwater to a storage tank or cistern.

8.1 Water quality standards

There are currently no water quality standards specifically for rainwater harvesting. We should be aware of water borne pathogens and possible water contaminants in untreated rainwater.

Contaminates of concern include:
- algae
- Chemical compounds (aerosols, disinfectants, etc.)
- Microorganisms from organic solids (bird excrement, etc.)
- Organic and inorganic solids (leaves, wood, moss, sand, dust, etc.)
- Radionuclide.

Although contaminants may exist in untreated rainwater, many are diverted through the fine filter prior to entering the storage tank (see Filters) and are present in minimal amounts that do not affect water quality for non potable use. During dry spells, debris may accumulate on the roof surface. The debris is washed off the surface upon rainfall and diverted through the first flush filtering process.

All roofing material should be monitored for organic build up such as branches, leaves, dead animals, and animal excrement. It is recommended that overhanging branches should be trimmed back to reduce the organic matter build up and thwart animal access.

8.2 First flush water diverters

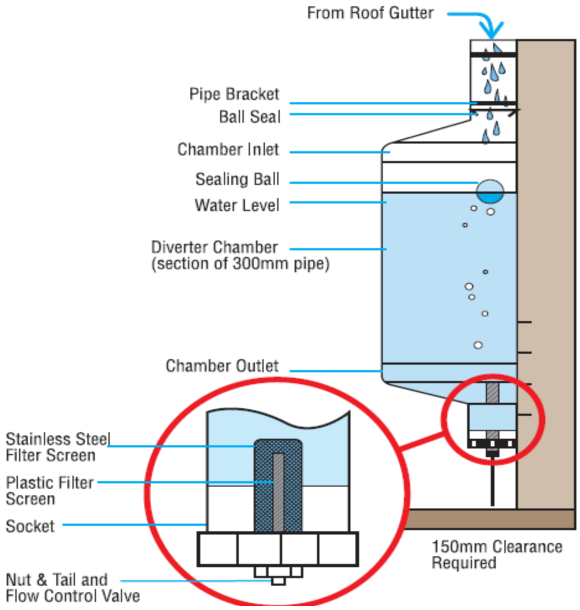
During dry periods roofs become contaminated with a variety of pollutants such as atmospheric particulates, bird droppings, leaves and other debris. When it rains, some of the contaminants are washed off the catchment surface and transported in the runoff flow. It is important to prevent heavy sediments and other roof pollutants from entering the rainwater tank. The amount of water diverted should be **a minimum of 20 litres** per 100 square metres of roof area (or 0.2L per m^2). In calculating the amount of water to divert, consideration can be given to (1) the **surface area of the roof**, and (2) the **amount of pollutants** on the roof and gutters. The following table gives the guidelines used to compute the volume of water to divert for the project's catchment areas.

Pollution factor for the roof	Water to divert
Minimum Pollution (Open field, no trees, no bird droppings, clean environment)	Divert 0.5L per m^2
Substantial pollution (Leaves and debris, bird droppings, various animal, e.g dead insects, skinks, ...)	Divert 2L per m^2

8.2.1 Choice and design of the first flush water diverter

Among the available types of first flush water diverters, the post wall first flush diverter are suitable to our project considering the type and location of rainwater collection pipes. The picture below shows the components of a post wall first flush diverter.

The design of a post wall Water Diverter consists mainly of choosing a sufficient length of the 300mm PVC pipe to form the diverter chamber. The length of pipe will depend on the amount of water to divert. The table below shows the length of pipe required to capture specific quantities of diverted water in the chamber. Either 90 or 100mm pipes can be connected to the inlet of the diverter chambers. The outlet only requires the use of 90mm pipe.

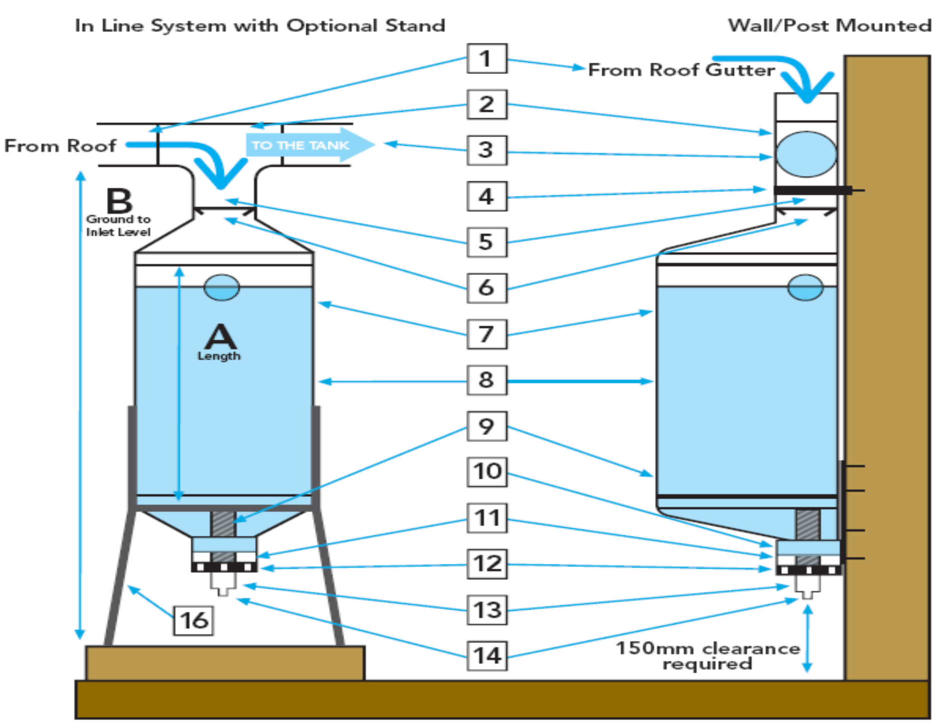


SIZES	PIPE	TOTAL
Litres	Length (mm)	Total Height Required (mm)
20	225	590
30	365	730
40	500	865
50	630	995
60	780	1145
70	905	1270
80	1050	1415
90	1180	1545
100	1310	1675
120	1610	1975
130	1735	2100
150	2005	2370

Considering the volumes of water to divert for each catchment area, the number and capacity of post wall first flush diverters have been estimated as follows.

8.2.2 Specification and installation of a post wall first flush water diverter

A simple configuration of a post wall first flush diverter can be made of the following components and be installed as shown on figure below.

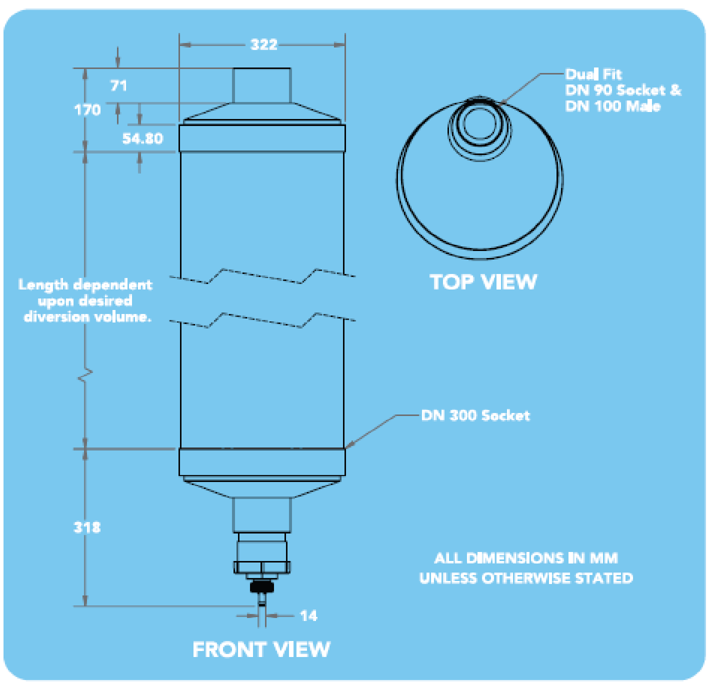


REFERENCE CHART					
1	In-feed from the roof	6	Ball seat	11	Chamber Outlet
2	Tee Junction	7	Sealing Ball	12	Screw Cap with O'Ring Seal
3	To the tank	8	Diverter Chamber	13	Flow Control Valve
4	Pipe Bracket	9	Filter Screen	14	Hose Connection
5	Chamber Inlet	10	Wall/Post Bracket	15	Optional Stand

Inlet End: The ball seat #6 is inserted into the top of the end cap as shown. For 90mm infeed –insert the ball seat #6 and attach the infeed pipe hard down on top of ball seat #6. For 100mm infeed – insert the ball seat #6 and glue the 90mm keeper ring (28mm long) hard down on top of the ball seat #6 to keep it firmly in place.

Outlet End: The outlet requires only 90mm pipe. Assemble as shown making sure to insert ball #7 before attaching cap #12. Select one of the four control valves #13 and fit into hose connector #14. Save the remaining valves for possible later use.

Stands: It is important to line up the center of the chamber outlet with the weld on the stand. Make sure that the stand is bolted down securely and that the pipe work connected to the top of the diverter chamber is appropriately secured so that the diverter is stable and the unit is not stressed by bad alignment.



Front view of a post wall first flush diverter

8.3 Rain Filters

It is recommended that rainwater be filtered before entry into the storage tank in order to remove debris such as leaves, grit, moss and soil. Filters should be easy to clean (or self-cleansing) and should not block easily. The *Triple Action* Filter System also filters out colour and odour that may taint the water supply, because the membrane used is impregnated with carbon. Carbon is used to reduce/remove colour and odour contaminants.

The goal of a filter is to not only to eliminate contaminants, but also to supply oxygen to water during the filtration process. An advanced filter does not restrict the diameter of the gutter and is positioned either vertically connected to the gutter system or horizontally connected to the downspouts.

Modern filters require extremely low maintenance and cleaning and can efficiently collect more than 90% of filtrated rainwater. To ensure the effectiveness of the filter, the appropriate filter should be paired with the appropriate roof area. Also, utilizing high quality filters ensures water is sufficiently filtered, oxygenated and directed to storage tanks. Filter meshes less than 0.5 mm work best.
Even with high rainfall events, filters should remain efficient in filtering water and diverting as much water as possible into the storage tank. Therefore, filters should be self-cleaning and self-drying between rainfall events. Filter fabric should dry between rainfall events to prevent algae and biofilm growth, which could block fabric pores. Also, fabrics should be made of stable materials that will not change shape and can withstand temperature changes, ice formation, and frost.

Stainless steel is considered the best filter fabric because it can withstand all weather conditions, even ice formation and frost, is self cleaning and self drying, maintains shape, and does not rust, thus reducing contamination likelihood. The vortex filters in Figure below include a removable stainless steel filter insert and the downspout filter in same Figure is constructed solely of stainless steel.

Vortex and downspout filters

In case of this project, the Triple action filtration system has been chosen. The chosen model and its specifications are presented below.

8.3.1 Rain Filters – Triple Action Filtration System

20" Filter Cartridge – Specifications (Model: WFRW04)

For use in the filtration of rainwater when the rainwater tank is connected for whole of house use, or internal use such as to washing machines, hot water systems and / or multiple toilets - colour, odour & sediment filtration

Rain Filters pleated carbon cartridges are designed for treatment of sediment, colour and odour within rainwater water supplies. The cartridges are constructed from a carbon impregnated non – cellulose media. Unlike cellulose cartridges Rain Filters cartridges are resistant to bacterial attack allowing them to be used for non chlorinated water applications.

They offer sediment filtration, as well as colour and odour reduction in the one cartridge. The unique pleated internal membrane provides additional surface area for higher dirt loading capacity, while maintaining minimal pressure drop. This combination of a pleated polyester membrane and carbon filtration produces an outstanding filter cartridge with extended service life.

FEATURES

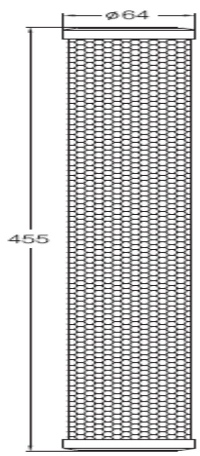
1. Contains a blend of premium activated carbons impregnated within the membrane to maximize the removal and reduction of colours and odours.
2. The larger surface area provides for greater sediment holding and longer filter life. Over seven (7) times more surface area than other carbon cartridges.
3. Will not release carbon fines.
4. Temperature rating at minimum 4.4o C to 51.7o C.

SPECIFICATIONS
MODEL: WFRW04
FLOW RATE: Suitable for flow rates up to 50 litres per minute
DIMENSIONS: 64mm diameter x 455mm height (cartridge)

CONSTRUCTION DETAILS
1. Low durometer, thermoplastic rubber gaskets to ensure effective sealing.
2. Injection moulded high impact plastic end caps for superior durability and appearance.
3. Inner polypropylene core for compressive strength.

4. Filter membrane constructed of pleated carbon impregnated polyester providing significantly more surface area than traditional cartridges.
5. Outer mesh netting for surface integrity.

SERVICE
The life of the filter cartridge is determined by three factors - water pressure, water quality and usage. Please ensure that your rainwater tank is properly maintained and 'pre-treatment devices' have been installed.



Rain Filters – Triple Action Filtration System
20" Filter Housing – Specifications (Model: WFRW02)

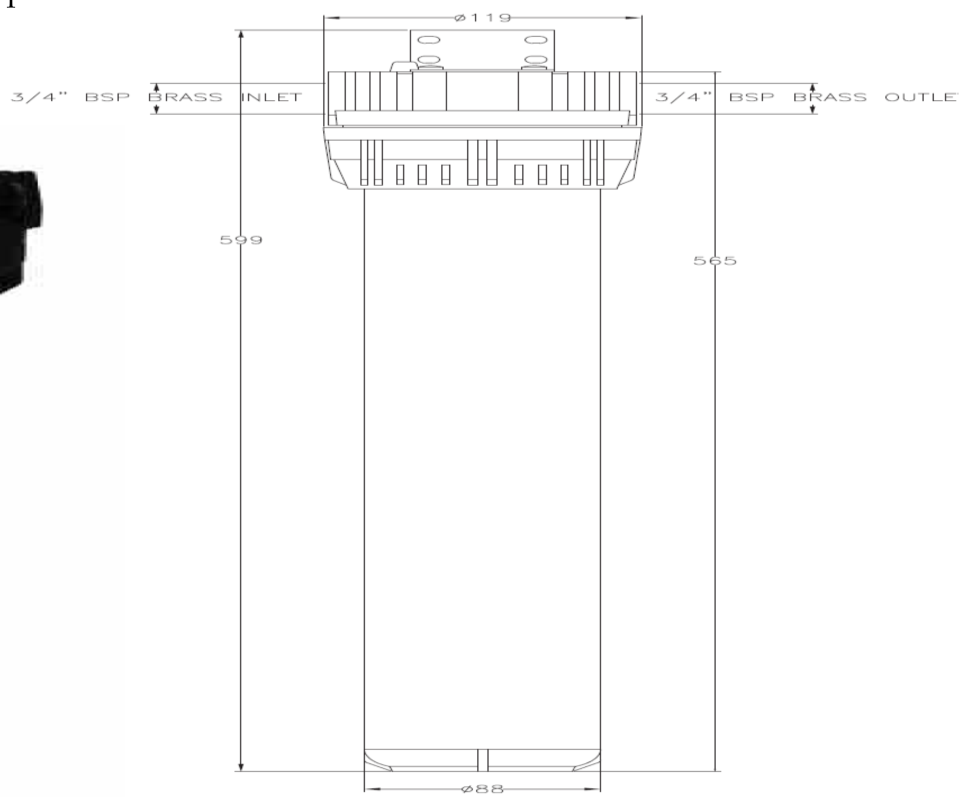
For use in the filtration of rainwater when the rainwater tank is connected for whole of house use, or internal use such as to washing machines, hot water systems and/or multiple toilets

- Heavy duty opaque housing.
- Brass pressure relief valve on top for easy opening of the filter housing.
- Completely corrosion resistant.
- 3 piece housing prolongs the life span of the o-ring.
- Top seated o-ring gasket.
- ¾" F BSP brass inserts for trouble free installation.
- Supplied with ¾" M BSP hex nipples for inlet/outlet.
- Complete with mounting bracket & screws, tightening wench.
- UV Stabilised Housing

SPECIFICATIONS
Head & Nut/Collar Construction: Filled Polypropylene with brass relief valve
Bowl Construction: Styrene Acrylonitrile (SAN) Plastic

O-ring: Nitrile Rubber (NBR)
Max. Operating Temperature: 50°C
Max. Operating Pressure: 125 psi
Inlet/Outlet Connections: ¾" F BSP brass.

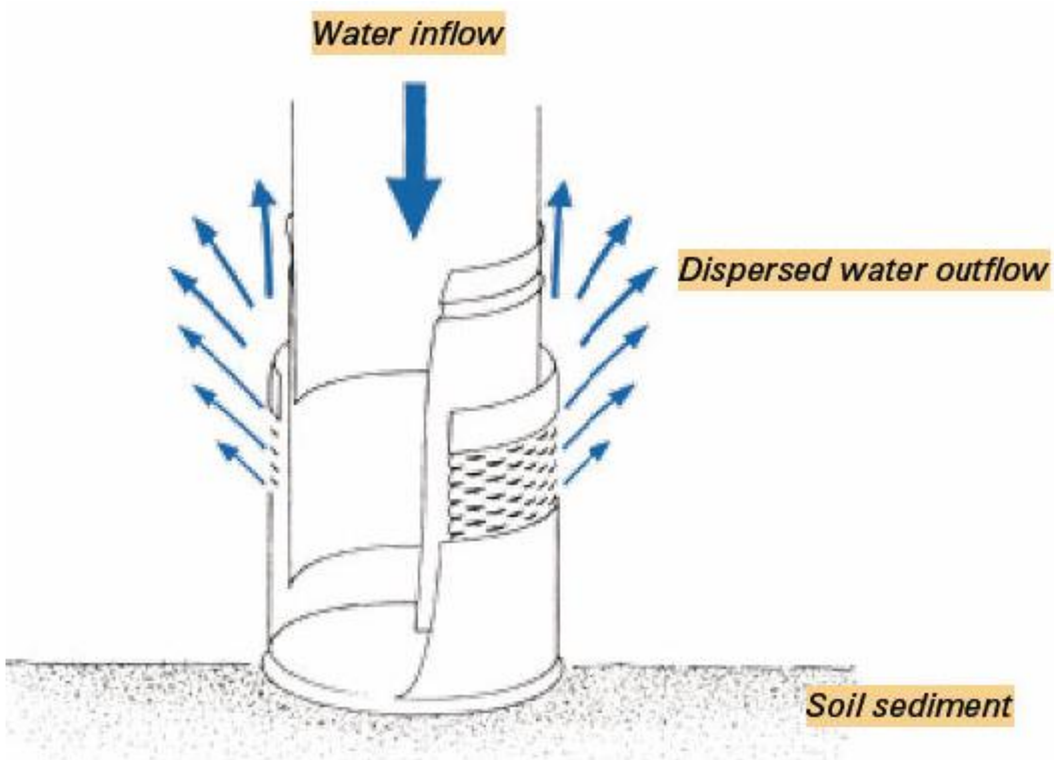
IMPORTANT NOTE:
If the filter housing is installed outside a suitable sunlight protective cover must be installed to prolong the life of the housing and filter cartridge, or alternatively it should be installed in a sheltered position.



These rain filters will be installed at the entrance of the tanks, i.e. before water enters the tanks, and at the entrance of the pumps i.e. before enters the header tanks and distribution pipes.

8.4 Calming inlets

Calming inlets, located at the bottom of storage tanks, smooth the entering water to prevent it from disturbing fine particulate matter on the bottom of the tank (see Fig. below). Water is directed upwards, reducing inflow speed and preventing water from whirling in the tank. The calming inlet also distributes fresh, filtered water while oxygenating the water to further ensure pure stored water. In round tanks, one calming inlet can evenly distribute the fresh rainwater. In larger square tanks, several calming inlets may be necessary to provide evenly distributed fresh rainwater.



Calming inlet

Soil sediment consists of fine particulate matter that settled to the tank bottom. This film is biologically active and converts organic materials to CO_2 and mineral substances. This natural process, similar to the aerobic cleaning processes in brooks, assists in cleaning the water and reduces the soil sediment layer. If the tank were cleaned the biologically stable biofilm would be destroyed.

However, this balance only occurs when water is fine filtered prior to entering the tank. Therefore, only fine sediment collects in the tank. If larger organic matter is present in the tank, oxygen is depleted and harmful anaerobic conditions occur. Therefore, it is important to ensure water passes through a filter <0.5 mm prior to storage.

To aspirate the water from the tank, a floating filter is located at the end of the pump's suction hose (Fig. below). It protects the soil sediment from destruction and protects the pump against particles. Floating filters are best when they are 0.2 mm particle size. Otherwise, a coarse meshed floating filter can be used. Filter fabric should be of excellent quality stainless steel, like the first flush filter.

Floating fine filter with pressure pump

8.5 Oxygenation

Oxygen in the stored water ensures collected rainwater remains high in quality. Oxygen depletion can lead to anaerobic conditions. In anaerobic conditions, surface biofilms form reducing water quality and creating an offensive odor. Appropriately designed rainwater harvesting systems incorporate products that oxygenate the water to maintain water quality.

Some filters are designed to oxygenate the water and provide continuous air flow to the storage tank (see Filters). Air vents in the tank also allow air movement into and out of the tank, thus saturating the water with oxygen. Some tanks are aerated through windmill aerators. When these windmills are placed alongside rainwater tanks and either wind or electricity can move the windmill, causing air bubbles to enter the tank, much like a fish tank. The bubbles provide aeration and prevent anaerobic conditions.

8.6 Cleaning and Maintenance

Appropriately designed rainwater harvesting systems require very little maintenance. However, like any household component, it should be checked periodically to ensure it is operating efficiently and appropriately.

Gutters: Gutters should be periodically flushed to clear them of organic matter and help eliminate any clogs. While some gutter guards are advertised as never clogging, they too should be monitored and checked periodically to ensure water is entering and flowing through the gutter.

Downspouts: Downspouts should be checked occasionally, especially where they connect to the gutter. Any debris should be removed to ensure the water flows through freely.

Filters: Modern filters do not require replacing and require little maintenance, unlike the old roofwasher design. The roofwasher on requires periodic cleaning and filters need replacing yearly, while the modern filter never needs replacing. However, the self-cleaning filter does require monitoring as buildup may occur, depending on the local environmental conditions. If the stainless steel filter needs cleaning, it can be washed in the dishwasher.

Tanks: If a first flush filter is not used, tanks will require yearly cleaning to remove organic debris buildup. If a first flush filter is used, tanks will not require cleaning as the biofilm on the bottom of the tank improves water quality by adding oxygen.

IX. ENVIRONMENTAL AND ECONOMICAL BENEFITS

In the water cycle, while there are several methods by which the earth looses water, there is only through rainfall does the water come back to the earth. At this stage the water is relatively clean and can be collected for use with minimal capital investment. Compared to the conventional systems of water supply for domestic consumption, agriculture, industrial and other uses that emphasize abstraction from surface streams, deep wells and even the seas, rainwater is much cheaper, as it requires minimum treatment and needs little if any reticulation systems.

It is paradoxical however, to allow rainwater to flow over the surface of the earth and cause environmental disasters such as the negative impacts of flooding, landslides and soil erosion while it is possible to harness it for use in households, agriculture, industrial as well as for livestock and environmental improvement.

9.1 How Rainwater Harvesting Addresses Environmental Issues

According to the Global Water Partnership, 'Integrated Water Resources Management is an approach that ensures the coordinated development of water, land and related resources to optimize economic and social welfare without compromising on the sustainability of environmental systems'. It can be seen that rainwater harvesting fits well in this scheme. A good example can be cited of a planting pit (or Trench) used to trap rainwater in organic matter to grow Napier grass for livestock. In this case, rainwater-harvesting structure is being applied to achieve soil conservation, forestation, provision of water and nutrients to the crops and provision of additional feed for livestock. This in turn implies increased food and/or income for the farmer, and effectively addresses livelihood and poverty issues

It is now well acknowledged that sustainable water management of the future is significantly different from the traditional water management paradigm that focused on meeting the demand for water by augmenting supply and disposing wastewater and stormwater to prevent the spread of disease. Sustainable urban water systems need to focus on achieving a 'closed loop' through initiatives such as rainwater harvesting and reuse. Such an approach not only reduces the amount of water imported into the urban area, it also treats stormwater runoff and sewage as resource and cuts down on their wasteful discharge into waterways.

9.2 Rainwater harvesting for Reuse and environmental sustainability

9.2.1 Rainwater reuse benefits

Harvesting rainwater has a long-term impact on the local water resources by reducing demands for surface and groundwater withdrawals. Also, harvesting rainwater protects the integrity of local waterways by reducing non point source pollution. Including rainwater harvesting in local and regional water supply plans offers an alternative and sustainable water source while protecting the local environment.

Rainwater harvesting offers alternatives to municipally supplied water for fire suppression. Harvested rainwater can be directed to interior sprinkler systems and used in the advent of a building fire.

Fire suppression can go beyond indoor sprinkler systems to protect buildings from forest fires. Stored water flows backward into the gutter system and overflows the gutters to form a shield of water. While forest fires are not as common in Virginia as they are in the arid west, rainwater could serve as protection for some homes located in heavily forested areas in the advent of a fire.

Another alternative is to collect rainwater for fire hydrants. Rooftop and street runoff can be directed to an underground tank connected to a fire hydrant. This prevents the reliance on potable water to fight fires and can reduce connection costs, especially in areas outside the main water distribution grid.

9.2.2 Rainwater harvesting Environmental positive impacts

When rain falls on a building, it lands on a rooftop, drains to the gutters and drainpipes, and then is diverted either across land or to storm drain pipes. This rooftop runoff ultimately reaches local waterways. When the rainwater is carried across landscapes, it picks up detrimental pollutants such as bacteria from animal excrement or decaying animals, chemicals, metals, nitrogen and phosphorus from fertilizers, oil, pesticides, sediment and trash. All of these collected surface pollutants contaminate waterways and affect native aquatic plants and animals.

Rainwater harvesting follows ecologically sound principles for water use as it reduces the impact on the land, promotes sustainable practices, reduces storm water runoff, reduces peak flow levels, reduces reliance on ground and surface water, allows for groundwater recharge, and promotes water conservation.

Through rainwater harvesting, individuals and businesses can divert rooftop runoff into an on-site storage tank or pond, thus preventing it from running across the landscape and further contributing to non point source pollution.

Installing rainwater harvesting systems in areas where non point source pollution from storm water runoff is a severe threat to stream integrity can significantly reduce pollution loads. Since storm water runoff can also lead to flooding, harvesting rainwater combats flooding by reducing peak flow from high rain events.
Rainwater is soft, which means less detergent is used and released into the environment. Also, rainwater harvesting systems with a connected vaporization system can raise site humidity and create a healthier microclimate. This is ideal for city areas dealing with air pollution. Likewise, utilizing rainwater as opposed to municipal and well water, benefits local streams, lakes, ponds and groundwater sources since less water will be pulled from these sources. Such benefits may not have a direct price tag, but their value is long lasting and considerable.

Installing and utilizing rainwater harvesting systems can have a trickle-down effect and cause other companies/individuals/organizations to be more environmentally conscious for environmental, economic and political reasons. Rainwater harvesting systems typically increase residential property value and offer current and future residents the opportunity to live an environmentally responsible lifestyle.

9.2.3 Economic benefits

The economic feasibility of harvesting rainwater is based on many factors, i.e. precipitation frequency, water consumption needs, prices of local water and wastewater treatment, and the cost of installation and maintenance. More importantly is the long term economic feasibility, which is based on the building's operational lifespan and system design. The combination of a high building lifespan of at least 40 years, high quality and sustainable prefabricated components, and minimum system servicing needs equates to rainwater harvesting being economically feasible and ecologically sensitive.

Utilizing inferior quality, less expensive, prefabricated components translates to higher service costs as these components must be replaced during the life of the building. Installing high-quality prefabricated components that last the life of the building is a sustainable building practice that is both economically and environmentally responsible.

Installing a rainwater harvesting system can help residents reduce their water supply costs. With rainwater harvesting systems, most of the cost is upfront cost, and systems ultimately pay for themselves within a few years, depending on the system and local water prices. This time could be reduced, depending on how quickly municipal water costs increase. Appropriately designed rainwater harvesting systems will have minimal maintenance costs associated with upkeep (see Maintenance and Cleaning) and will show the best long-term relationship between cost and financial benefit.

In some urban areas, rooftop runoff is directed to storm drains and then to water treatment facilities. These large pipes are expensive to install and travel many miles through urban areas. When a heavy rainfall occurs, the water treatment facilities are overwhelmed with stormwater, causing systems to overflow and even contaminate local waterways with untreated sewage.

X. CONCLUSION AND RECOMMENDATIONS

The population of Kigali City and other towns in Rwanda is expected to increase in the near future and this would augment the stress on their water consumption demand. In addition, most public buildings in Kigali city and other towns in Rwanda face a serious runoff problem that causes flooding of roads, streets and people's properties therefore creating some conflict situation between the authority and the population that should be solved. This feasibility study was therefore carried out as part of MININFRA to solve such problems and promote the rational utilization of water resources.

In this feasibility study a total of 796 public buildings were inventoried in Kigali City and other towns in Rwanda. Among the inventoried buildings, 23 buildings (2.9%) were classified in category 1, 390 buildings (49.0%) in category 2 and 383 buildings (48.1%) in category 3. As for existence of rainwater collection systems, if all categories are combined, 19 (2.4%) buildings were found to have operating RWCS, 191 (24.0%) buildings had partial RWCS while 586 (73.6%) buildings had no RWCS.

This feasibility study showed that most public buildings in Kigali City and other towns were classified in categories 2 and 3 according to criteria defined in the study and the installation of rainwater collection systems for categories 1 and 2 is a bit more complex and expensive than for category 3.

The cost estimation showed that a total budget of about 28 billion Rwandan Francs (28,000,000,000 RWF) should be mobilized if MININFRA is to set up the proposed systems for all inventoried public buildings without rainwater collection systems (RWCS) in Kigali City and other towns in Rwanda. It was found that in Kigali city RWCS for buildings of category 1 will require a budget of about 700 million Rwandan Francs while categories 2 and 3 will require respectively about 7.5 billion and 600 million Rwandan Francs.

It was recommended that MININFRA will contribute much in terms of technical assistance and financial support in the implementation of rainwater collection systems for buildings within categories 1 and 2. The cost for installation of rainwater collection systems for buildings within category 3 was found to be affordable by local authorities or owners of the buildings and it was suggested that they can implement the proposed systems with their budget with the technical support of MININFRA whenever necessary.

It has been found in this feasibility study that rainwater harvesting has not been fully utilized in Rwanda despite its proven uses for domestic, agricultural, commercial and environmental purposes. By implementing the outputs of this feasibility study the

Ministry of Infrastructure will contribute to achieving the objectives of policies on water and sanitation as embodied in the Rwanda Vision 2020.

ANNEXES

ANNEX 1: INVENTORY OF PUBLIC BUILDINGS IN KIGALI AND OTHER TOWNS IN RWANDA

ANNEX 2: BILL OF QUANTITIES FOR CONSTRUCTION OF RWCS ON SAMPLE BUILDINGS IN EACH CATEGORY

ANNEX 3: PLANS OF STORAGE TANKS