RESOURCE GUIDELINES FOR RAINWATER HARVESTING

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RESOURCE GUIDELINES FOR RAINWATER HARVESTING

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

South Africa has to prioritise from the mix of available water supply options to supply the huge water demands for development and economic growth. The country is actively pursuing water conservation and water demand management measures and the use of alternative water sources, such as desalination, groundwater, rainwater harvesting (RWH), and water reclaimed from acid mine drainage. Rainwater harvesting is an age-old proven practice; however, an enabling environment and government support is necessary in order to promote the implementation of RWH systems on a larger scale. Despite benefiting from the support of a number of national government departments, RWH is not being utilised to its full potential. The lack of clarity of the water-related legislation at local government level and the absence of a national umbrella body that coordinates the implementation of the practice are preventing the effective multisector involvement and promotion of RWH. Therefore, there should be a deliberate focus on RWH knowledge sharing and capacity building along with the creation of an enabling environment, and the development and enhancement of suitable frameworks, policies and legislation.

There are no regulations that specifically govern RWH in South Africa. However, the National Building Regulations (SANS 10400) which govern all building and construction work in South Africa and other consumer installation standards (SANS1200, SANS 10106, SANS 10106, SANS 10252 and SANS 10254) do affect aspects of RWH systems such as tank installations, internal plumbing, etc. While relevant acts make provision for the enforcement of such regulations, there is still a need to put in place the necessary resources for implementation and enforcement. Regulations should not be stringent to the extent of making it difficult for the average homeowner to set up a basic RWH system even though it is not "blatantly against the law for anyone and/or everyone". It should also not be too lax to fail to prevent the backflow of rainwater into the main water supply systems. Accordingly, existing regulations should apply for dual water supply systems but should be waived for stand-alone systems.

The most important question to pose is: "What will the water be used for?" This not only determines the RWH system design but also the degree the harvested water needs to be treated, as well as how its use should be regulated. In most cases, RWH is used for augmenting supply in areas receiving municipal water, but in areas with no supply, it is often either the sole or best water supply source available. National studies on the physico-chemical and microbial quality of the water harvested indicate that it is often below gazetted drinking water quality standards (SANS 241). The main source of contamination is the wash-off into the tank of airborne pathogens and organic matters from the catchment surface. Thus, some sort of pre and/or post water treatment is required. To maximise effectiveness, a multi-barrier approach where more than one method of treatment (such as sedimentation, filtration and disinfection) are used is recommended.

In addition to treatment options, there is need for guidance on RWH tank sizing. There is the misguided belief that back of the envelope calculations are sufficient to size RWH systems. There are several models that have been developed to determine the size of RWH systems. The lack of observed data with which to both run and to validate the models remains the main impediment. As a consequence, it is difficult to quantify, with a reasonable degree of confidence, water savings using rainwater tanks. In this document an attempt has been made to validate the models against observed data.

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ACRONYMS & ABBREVIATIONS

AMCOW	African Ministers' Council on Water
CFU	Colony-Forming Unit
CSIR	Council for Scientific and Industrial Research
DNA	Deoxyribonucleic Acid
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
E. coli	*Escherichia coli*
HPC	*Heterotrophic plate count*
HWT	Household Water Treatment
MF	Microfiltration
NBR	National Building Regulations
NF	Nanofiltration
NOM	Natural Organic Matter
NTU	Nephelometric Turbidity Units
NWRS	National Water Resources Strategy
PAC	Polyaluminium Chloride
PCR	Polymerase Chain Reaction
PVC	Polyvinylchloride
pH	potential of hydrogen
PVA	Polyvinyl alcohol
RWH	Rainwater Harvesting
SABS	South African Bureau of Standards
SANS	South African National Standards
SCS-CN	Soil Conservation Service – Curve Number
SOCO-DIS	solar collector disinfection
SODIS	Solar disinfection
spp	Species
TRHEC	Texas Rainwater Harvesting Evaluation Committee
TTC	Thermotolerant Coliform
UF	Ultrafiltration
UV	Ultraviolet
WHO	World Health Organisation
YRA	Yield Reliability Analysis

1 BACKGROUND

1.1 INTRODUCTION

The implementation of domestic rainwater harvesting is increasing in South Africa. The interest for the practice driven by the prevailing water scarcity situation due increased climate variability across the country. In addition, the escalating economic costs of supplying water via centralised supply systems coupled to the ever-increasing demand for water and decreasing quality of water bodies, has renewed interest in decentralised water supply infrastructures. Rainwater harvesting (RWH) is an unconventional water source that has been receiving a lot of attention over the past two decades. In the Sharm El-Sheikh declaration, the African Ministers' Council on Water (AMCOW), including their South African counterpart, committed to increase RWH share of total water supply to 10-15% by 2015. RWH presents many benefits for urban sustainability and is quickly emerging as a key strategy in order to cope with water scarcity in urban and rural South African settlements. As of 2010, rooftop RWH systems were already a source of drinking water in rural areas (Figure 1-1) especially in the Eastern Cape and KwaZulu-Natal (Mwenge Kahinda *et al.*, 2010). Although, rainwater harvesting is a well-recognized source of water, its nationwide adoption and implementation (particularly in urban settlements) has been at a much slower pace. This has been largely due to lack of specific user and program implementation guidelines. To develop a general or national guidance for rainwater harvesting, several factors must be considered.

Figure 1-1: Distribution of RWH tanks, used as primary water sources between 1996 and 2016, in the nine provinces of South Africa

While potable use is possible for harvested rainwater, necessary on-site treatment and perceived public health concerns will likely limit the quantity of rainwater used for potable demands. Irrigation and the non-potable use of water closets, urinals and heating, ventilating, and air conditioning, make-up the end uses that are generally the best match for harvested rainwater. A lesser amount of on-site treatment is required for these uses and, as seen from the use statistics (Figure 1-2), these uses constitute a significant portion of residential and commercial demand. Focusing harvested rainwater on irrigation and selected non-potable indoor uses can significantly lower demand while allowing a reasonably satisfactory comfort level amongst the public between municipal potable water and reused rainwater.

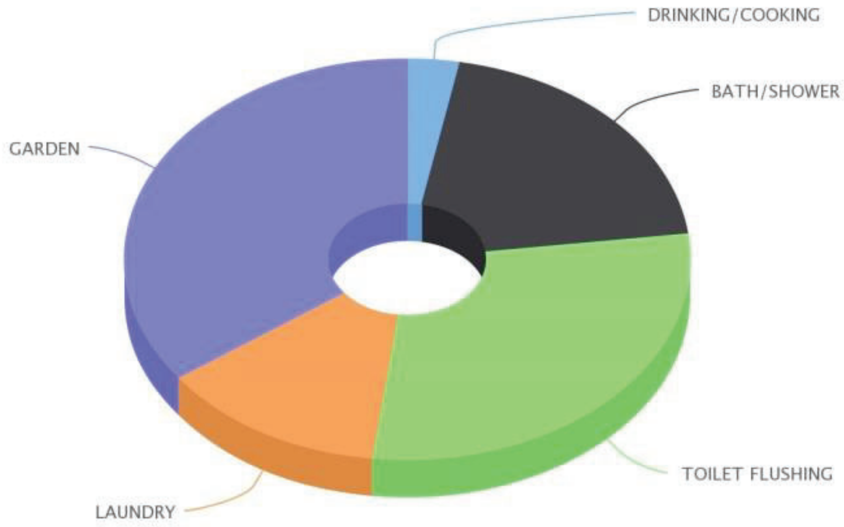

Figure 1-2: Typical water use in South African homes (DWAF, 2003)

There have been broad suggestions on a project to project basis as how to ensure optimum quality of harvested rainwater. The Department of Water Affairs and Forestry (DWAF) (now the Department of Water and Sanitation) released a document concerning the criteria guidelines required for the design of an RDP rural water supply (DWAF, 1997). Pertaining to rainwater harvesting, the following were suggested:

- Animals and people should be prevented from contaminating rainwater collection surfaces. House roofs are generally the preferred collection surfaces.
- Rainwater collection surfaces should be constructed from inert materials, should be well maintained and cleaned (particularly at the end of the dry season) to prevent contamination.
- A ‘first flush’ system should be incorporated into the rainwater collection system, to remove as much contamination as possible before the storage tank starts to fill.

National rainwater harvesting guidelines that give clear direction as to the routine water analysis and monitoring that needs to be undertaken to ensure constant quality of rainwater, do not currently exist in South Africa. This document is therefore a first attempt to address this need

1.2 LEGISLATIVE FRAMEWORK FOR RAINWATER HARVESTING

1.2.1 Overview

South Africa has changed its water legislation to usher in reforms in the water sector and ensure the sustainable use of increasingly scarce water resources. The South African water experience is unique since, until 1994, access to water by the vast majority of the population was restricted by the apartheid regime. While water related legislations that provide a proper enabling environment for the integrated management of water resources are in place, their implementation still proves to be a challenge. Apart from the governance aspects, South Africa is not well endowed with water resources. This situation is worsened by water pollution challenges, such as acid mine drainage from defunct and flooded underground mines, which severely threaten South Africa's scarce water resources (Naicker *et al.*, 2003; Hobbs and Cobbing, 2007; Oelofse, 2008).

The country's government has three distinctive, inter-related and inter-dependent spheres (national, provincial and local or municipal levels) that operate according to the constitution (Constitution Act 108 of 1996), laws and policies made by the national parliament. The functions of government are not only exercised at the national level but are also decentralised to levels closer to the people. Current South African water related legislations are a bit ambiguous on the adoption and implementation of RWH at local level (Mwenge Kahinda *et al.*, 2007; Mwenge Kahinda *et al.*, 2011). In effect, the current laws and regulations, as well as institutional arrangements are still lagging behind.

1.2.2 National Water Act (Act 36 of 1998) and Water Services Act (Act 108 of 1997)

The National Water Act (Act 36 of 1998) deals with the management and protection of water resources in the country. The Water Services Act (Act 108 of 1997) provides a framework for the provision of water supply and sanitation services to households in South Africa. At the time of writing this document the Department of Water and Sanitation (DWS) had embarked on a process of reviewing and possibly amalgamating these pieces of legislation. The Water Services Act is aligned to the National Water Act since its interpretation is subject to it. The Water Services Act transfers the responsibility for the provision and management of existing domestic water supply and sewerage disposal systems from national to local government. Moreover, all spheres of government have a duty, within their physical and financial capabilities, to work towards this objective. Section 9(1f) of the Water Services Act mandates the Minister of Water and Sanitation to prescribe compulsory national standards for the construction and functioning of water services works and consumer installations. Clause 14 of Regulation R509 (8 June 2001) was issued to give effect to this requirement and refers to compliance to SANS 10252-1: 2012 – Water supply installations for buildings and SANS 10252-2: 2016 – Drainage installations for buildings. The Water Services Act makes it illegal to install any plumbing component that does not comply with the relevant specifications listed in the latest versions of SANS 10106, 10252 and 10254 (Van Zyl *et al.*, 2008). However, it does not make mandatory for all components to bear the SABS mark.

In the 8 September 2017 Government Gazette Recently, the Department of Water and Sanitation (DWS) published draft National norms and standards for domestic water and sanitation services, which addresses issues of alternative water supply. However, there is still no clear guidance on how this can be implemented and enforced through bylaws. A bylaw gives effect to respective policies and is therefore the regulatory instrument through which a municipality exercises its authority. In theory, a bylaw must never conflict National or Provincial Legislation, where this happens national and provincial legislation supersede it. Two avenues are used to ensure alignment between bylaws of municipalities and legislation/regulation by the

Department of Water and Sanitation (the role of the Department of Water Affairs and Forestry, the custodian of the country's water resources, is one of a regulator):

- The Minister responsible for local government may also pass what are called "standard draft bylaws" to guide municipalities. Municipalities may then make their specific bylaws from any of the standard draft bylaws.
- The relevant national government departments provide what are called "model bylaws" to guide municipalities. In the case for water services, Section 21(4) of the Water Services Act makes provision for the Minister of Water and Sanitation to provide model bylaws to guide Water Services Authorities in drafting bylaws that provide for the installation, alteration, operation, protection and inspection of water services works and consumer installations (Section 21(1c) of the same Act).
- While these are comprehensive, municipalities use sections that suit their situation.

A bylaw is a legislation passed and enacted by a Municipal Council. Unlike a law, it is passed by a non-sovereign body, which derives its authority from another governing body. A municipal government gets its power to pass laws through a law of the state which specifies what things the city may regulate through bylaws. However, passing by-laws without clear plans for enforcement, serves no purpose and failure by a municipality to enforce its by-laws amounts to a failure to give effect to the obligations imposed upon a municipality by section 152 of the Constitution. Each municipality must compile a municipal code – a list of all its bylaws – that is available to members of the public upon request. The current legislation dictates that compliance and enforcement of such bylaws be administered by water inspectors under water services bylaws.

1.2.3 Municipal Systems Act (Act 32 of 2000)

The Municipal Systems Act (Act 32 of 2000) sets out legislation that enables municipalities to uplift their communities by ensuring access to essential services. Water forms part of the "right to basic municipal services" outlined in the Act.

1.2.4 Building Standards Act (Act 103 of 1977) and the National Building Regulations

In terms of design and construction, RWH infrastructure must be consistent with the National Building Regulations (NBR) SANS 10400. The NBR fall under the Building Standards Act (Act 103 of 1977), which governs all building and construction work in South Africa. Various updates have since been made. These regulations were originally produced as a set of functional guidelines for anybody building any type of structure. SANS 10400 establishes the level of performance (quantitative requirements) and deemed-to-satisfy provisions and the means by which the functional requirements established in the regulations may be satisfied. Although not intended to be prescriptive in terms of what people should build – they stipulate important do's and don'ts – many are, in fact, mandatory.

The NBR addresses the following aspects:

- Part A: General Principles and Requirements,
- Part B: Structural Design,
- Part C: Dimensions,
- Part D: Public Safety,
- Part E: Demolition Work,
- Part F: Site Operations,
- Part G: Excavations,

- Part G: Foundations,
- Part J: Floors,
- Part K: Walls,
- Part L: Roofs,
- Part M: Stairways,
- Part N: Glazing,
- Part O: Lighting and Ventilation,
- Part P: Drainage,
- Part Q: Non-water-borne Sanitary Disposal,
- Part R: Stormwater Disposal,
- Part S: Facilities for Disabled Persons,
- Part T: Fire Protection,
- Part U: Refuse Disposal,
- Part V: Space Heating,
- Part W: Fire Installation and
- Part XA : Energy Usage

Currently, there is no chapter of the National Building Regulations (SANS 10400) deals directly with water installations in buildings other than those pertaining to fire installations (SANS 10400 W). The other chapters only contain key element relevant to water installation in buildings and therefore, RWH. Moreover, consumer installations are regulated by SANS 10106, SANS 10252 and SANS 10254.

- SANS 10106 (2006) covers requirements for the safe installation of new and replacement domestic solar water heaters complete with all the relevant and applicable control units;

- SANS 10252-1 (2012) is a manual for the design of water systems inside buildings. It provides simple information to be applied by engineers;

- SANS 10252-2 (1993) establishes general principles for the design, installation and testing of sanitary drainage installations, and;

- SANS 10254 (2012) regulates electric storage water heating systems and all relevant plumbing fittings.

Compliance and enforcement processes of the National Building Regulations of South Africa are administered by the National Regulator for Compulsory Specifications (Twum-Darko and Mazibuko, 2015) though building control officers. Those are appointed by local authorities in terms of section 5 of the National Building Regulations and Building Standards Act (Act 103 of 1977) to make recommendations regarding any plans, specifications, documents and information submitted to such local authority in accordance with section 4 of the same Act. While all building plans must be approved by the building control officer, there is no requirement to submit water drawings as that falls under SANS 10106, 10252 and 10254. Both SANS 10252 and SANS 10254 fall under the Water Services Act (Act 108 of 1997) and therefore the Department of Water and Sanitation. Their compliance and enforcement are therefore not administered by building control officers but by water inspectors under water services bylaws.

Unlike the Building control officers, the qualification of the water inspector is not specified. The municipality may authorise any person in its employment to be a designated water inspector. The water inspector has the right, without access restriction, to enter with or without a written authorisation, any premise at any reasonable time. A legal framework can only be effective if it is enforced. As proposed by Van Zyl *et al.* (2008), every municipality should have a trained group of people who inspect water services and plumbing installations to ensure that these comply with both national and local legislation. This is currently not the case as municipalities do not have appointed water inspectors. SANS 10252 and SANS 10254 are not written in the format of SANS 10400 (Brink, 2017). Both need to be rewritten into SANS 10400 in order to be part and parcel of the building regulation set. This will *de facto* provide building control officers with the mandate and platform to enforce it. On one hand, it has been beneficial that South Africa had no regulations referring to RWH in the national building codes. This is because, over the past decades, local governments have been able to regulate RWH more freely. On the other hand, it has been a challenge to monitor compliance with and enforce contraventions of RWH bylaws that existed, due to the fact that most governments did not have the capacity to enforce bylaws. Nevertheless, it is evident that the enabling environment or the general legal framework of national, provincial and municipal policies, legislations and regulations; as well as the institutional arrangements of RWH, are lacking behind. The question that therefore needs to be asked is: *should RWH be regulated and to what extent should RWH be regulated?*

1.3 INSTITUTIONAL ARRANGEMENTS

Institutions include both formal and informal arrangements ranging from local to global level and may give rise to compliance or resistance. The lack of a national umbrella body to coordinate RWH continues to hamper its expansion and makes the collaboration between the various players very difficult (Mwenge Kahinda *et al.*, 2011; Mwenge Kahinda *et al.*, 2005). Institutions may comprise non-governmental organisations and government departments such as the Departments of Agriculture, Forestry and Fisheries, Water and Sanitation, and Rural Development and Land Reform. Figure 1-3 shows the institutional levels of policy making and implementation for RWH.

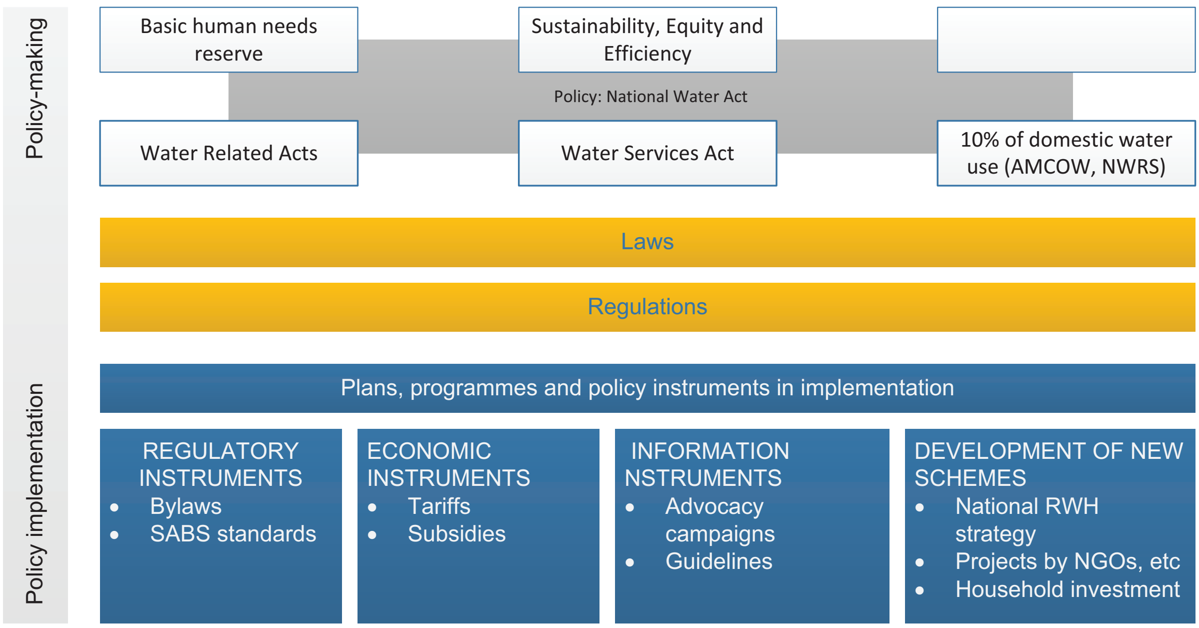

Figure 1-3: Institutional levels of policy-making and implementation of RWH (After WWAP, 2017)

The Department of Water and Sanitation supports a national rainwater harvesting programme, which has a narrow but important focus on the construction of above- and below ground rainwater storage tanks by rural households for food gardens and other productive water uses (de Lange, 2006). The intention as highlighted in Chapter 4 (four) of the NWRS 2 is to extend the programme to rainwater harvesting in both rural and urban households and office buildings. To some extent, clinics, schools and hospitals have now been included as beneficiaries of RWH (NT, 2015). Of late, the provision of RWH tanks is also driven through the Accelerated Community Infrastructure Programme. Several municipalities now use roof rainwater tanks for domestic purposes. These have been found to be particularly effective when used in conjunction with other water supply options. DWS considers RWH to be one of the practical water sources for schools (DWA, 2008). To this end, the potential of RWH to supply rural schools was recently investigated by Ndiritu *et al.* (2014) using the Yield Reliability Analysis (YRA) model. The YRA model (Ndiritu *et al.*, 2011) is a daily, continuous simulation model based on the volumetric reliability approach (Su *et al.*, 2009) which obtains relationships between rainwater supply from the catchment, storage size and the expected number of days the RWH system will meet demand (i.e. reliability).

As regards the initiatives undertaken by other national government departments: The Department of Rural Development and Land Reform (DRDLR) works with its national, provincial and local counterparts to facilitate the installation of RWH tanks (DGCIS, 2011); The Department of Agriculture Forestry and Fishery is more concerned with RWH for agricultural use, especially in-field and ex-field RWH – RWH is used extensively for vegetable gardening; The Department of Basic Education promotes, in line with DWS, the use of RWH as a water supply source in rural schools; The Department of Environmental Affairs, under its Climate Change Flagships directorate, identified a set of Near-term Priority Flagship Programmes, such as the Water Conservation and Demand Management Flagship Programme, for mitigating climate change and building climate resilience. The Water Conservation and Demand Management Flagship Programme, which identifies RWH, falls under the DWS's budget level programming (Molotsoane, 2016). Most departments appoint contractors for the supply and installation of RWH tanks. Although it might be argued that this practice boosts the local economy by promoting entrepreneurial enterprises, better coordination is required in order to avoid unnecessary duplication and to tease out best practices. The mainstreaming of RWH in the country's water resources requires an institutional innovation (Mwenge Kahinda *et al.*, 2011) that fosters collaboration between relevant government departments.

1.4 RAINWATER QUALITY AND USES

1.4.1 Overview

The ambiguities that currently exist with regard to what the harvested rainwater can be used for should easily be clarified by aligning the quality or 'fitness' of the harvested rainwater for a particular use or referring to the appropriate guidelines or standards specifying water quality requirements for specific uses.

1.4.2 Factors affecting rainwater quality

1.4.2.1 *Environmental conditions*

Environmental conditions are largely out of the hands of the designer and/or user of RWH systems. Environmental sources of contamination include anthropogenic sources such as air pollution caused by industries and major roadways. Natural sources of contamination include nearby trees and plants, which deposit leaves, pollen, etc., and animals (birds, squirrels), which deposit waste, etc., on the catchment surface (Figure 1-4).

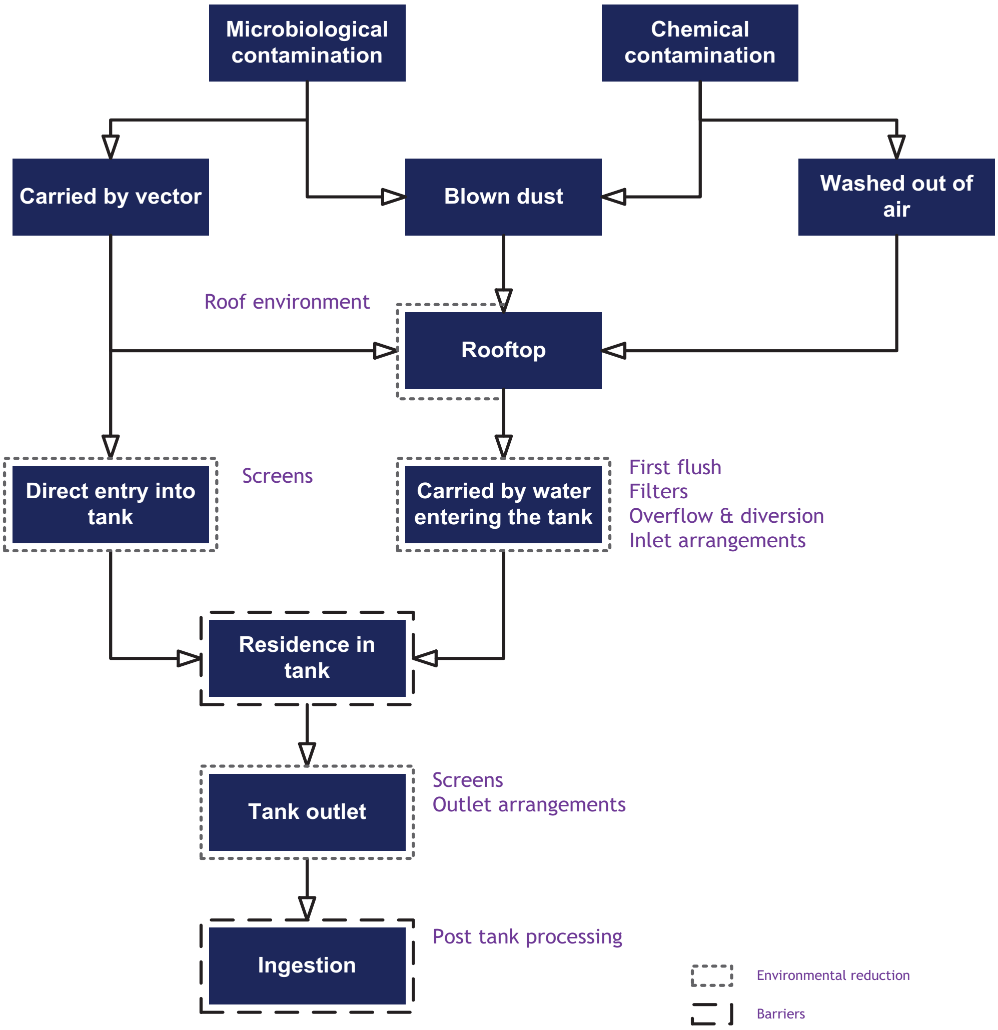

Figure 1-4: Contamination paths of rooftop RWH system

Rainwater is considered to be contaminant free except for pollutants that may be picked up by rain from the atmosphere. Air quality can also be affected by organic pollutants derived from fuel leakage of vehicles, petrochemical and plastic-chemical industries which may in turn contaminate the harvested rainwater (Huston *et al.*, 2012). The quality of harvested rainwater may also be affected through atmospheric pathways namely; scavenging of airborne microorganisms or bioaerosols by cloud or rain droplets. During dry periods, dust, faecal deposits, rodents and birds are the major sources of heavy pollution. After long dry periods caused by less rainfall the quality of harvested rainwater may be of serious health risks due to accumulation of these pollutants especially if the water is harvested from rooftops. Microbial contaminants such as *E. coli,* faecal coliforms, *Salmonella* spp. and *Giardia lamblia* may be detected during this time of harvesting. High concentrations of microorganisms may be observed during summer as compared to colder months. Location of the RWH system is an important aspect to consider when assessing the level of contamination in harvested rainwater. RWHs located in urban areas, may present higher contamination as rainwater might be already be contaminated before it reaches the catchment area due to poor air quality. This is regarded as the first stage of contamination which occurs when rainfall washes out and scavenges aerosols, gases and thin volatile particles from the urban atmosphere (Sánchez *et al.*, 2015). High levels of heavy metals have been isolated in harvested rainwater from urban areas as compared to rural areas (Azimi *et al.*, 2005).

1.4.2.2 *Catchment area*

Rooftop – Microbial quality of rooftop harvested rainwater is often compromised through bird droppings, poor collection and storage tank design while Chemical contaminants may dissolve from the atmosphere during precipitation and leach into the harvested rainwater, while roofing material may leach and disintegrate into the rainwater before storage. Contaminants can be introduced into runoff from the catchment surface in two ways (Figure 1-4), either by the washing-off of contaminants that have collected on the surface between rainfall events or through the leaching of chemicals and/or metals from the catchment material. Ground surface harvesting – has been identified as a potential threat to human and ecosystem health due to the high levels of chemical and biological contaminants that have been directly linked to disease outbreaks (Parker *et al.*, 2010). When rainwater drops on ground surfaces it picks up and transports different chemicals, pesticides, metals, petroleum products, sediment, human and animal faecal matter. A previous study on ground surface harvesting reported that surface water collected using conventional urban drainage techniques such as gutters, pipes, and channels was contaminated by sewage (Hatt *et al.*, 2006).

1.4.2.3 *RWH system construction material*

As with the catchment surface, chemicals and/or metals can leach from the rainwater storage tank material(s) or from the various components located in the tank (Figure 1-4). The rainwater storage tank can also have beneficial impacts on rainwater quality by providing a reservoir where suspended dirt and debris can settle to the bottom of the tank. Well-designed rainwater harvesting systems with clean catchments and storage tanks supported by good hygiene at point of use can offer drinking water with very low health risk, whereas a poorly designed and managed system can pose high health risks. Rainwater can be stored in either above or underground tanks. Above ground tanks are the most commonly used in South Africa and offer advantages such as: easy installation, inexpensive and they are easily accessible compared to underground tanks (Golay, 2011). Although underground tanks can also be easily installed, it is rather difficult to detect leaks and take corrective measures, in order to minimise possible contamination. Being in a colder and sunlight proof environment which reduces algae and bacteria growth, and they range from 700 to 10,000L (Golay, 2011).

Depending on the material used, it can either allow or inhibit the growth of biofilms. Very few studies have reported on bacterial composition and distribution, its development and role within RWH systems (Webb *et al.*, 2003). Research has shown that the presence of biofilm creates certain negative effects such as biofouling in filters, and biocorrosion and biocontamination in drinking water distribution networks (White *et al.*, 1999; Flemming *et al.*, 2002; LeChevallier and Au, 2004; Coetser and Cloete, 2005). In other studies, it has been suggested that biofilm may have a function of self-cleaning of the tank and regulation of the microbial quality in rainwater (Kim and Han, 2011; Kim and Han, 2016).

1.4.3 Rainwater contaminants

1.4.3.1 *General debris*

Debris in harvested rainwater refers to contaminants that can be physically seen. These would include insects, bird and animal droppings as well as dust and leaves. Not only does debris have an effect on the aesthetic quality of rainwater but they (especially dust, leaves, and animal and bird droppings) also transport microorganisms (bacteria, parasites and viruses). The surfaces of leaves and dust might also be contaminated with potentially harmful chemicals.

1.4.3.2 *Microbiological contaminants*

Unlike other rainwater contaminants, microbiological contaminants in rainwater present a greater and health risk to the user because they can cause diseases rapidly. For infants, elderly and individuals with compromised immune systems, waterborne illness acquired from contaminated rainwater can pose a serious and sometimes deadly health risk (Ahmed *et al.*, 2012). Pathogens (disease causing organisms) do not usually alter the taste, smell or look of water and therefore neither their presence nor absence can be determined with the naked eye. The occurrence of microbial contamination in rainwater occurs when it is harvested and subsequently stored. Further deterioration of stored harvested rainwater may occur at household level due to unhygienic practices (Ashbolt and kirk, 2006). There are two types of microbial contaminants that occur in rainwater, pathogenic organisms and non-pathogenic (do not cause disease) organisms. Non-pathogenic organisms are usually found in higher numbers and include *Escherichia coli*, which is used as a general indicator of water quality. Even though non-pathogenic organisms do no not cause disease, they affect the general aesthetic quality of the water and might hamper the efficiency with which the rainwater harvesting system works.

Pathogen contamination is likely to occur when faecal matter from human, animal or bird droppings enters the rainwater collection and storage system (Lee *et al.*, 2012). Some of the pathogens that have been detected in rainwater include the following bacteria: Pseudomonas sp., *Shigella* sp., *Salmonella* sp., *Vibrio* sp. and *Campylobacter* sp (Ahmed *et al.*, 2011). The protozoa, *Cryptosporidium* sp. and *Giardia* sp. have also been detected in rainwater. If storage tanks are not covered adequately, they present a breeding ground for mosquitoes which can then transmit the dengue virus and the malaria parasite (*Plasmodium* sp.). Algal growth in the tank will also occur readily if sunlight is able to reach the tank.

1.4.3.3 *Chemical contaminants*

Similar to microbiological contaminants, most chemicals in rainwater originate from the collection, treatment and distribution system. The sources of chemical pollution include atmospheric deposition and the materials that make up the catchment area. Studies have shown a higher level of chemical contamination to be present in harvested rainwater during the dry season as compared to during the wet season when there is an increase in rainfall events (Ahmed *et al.*, 2008 and Despins *et al.*, 2009). The concentrations of chemical contaminants usually remain constant in rainwater and therefore periodic testing is usually sufficient to monitor chemical levels. This is in contrast with microbiological contaminants where continuous and prolonged monitoring is required to ensure microbial free rainwater. The main chemical contaminants in water include metals, minerals, inorganic chemicals and volatile and synthetic organics.

1.4.4 Uses for the harvested rainwater

The fitness for use for harvested rainwater should be assessed against the appropriate South African Water Quality Guidelines (SAWQGs), and SANS 241 if intended for drinking purposes. SAWQGs, developed by the Department of Water and Sanitation, clearly articulate the quality of water required for each of the different use categories, e.g. domestic, recreational, agricultural and industrial (DWAF, 1996). Currently, the SAWQG are under revision, it is envisaged that the revised guidelines follow a risk-based approach in determining either fitness for use or water quality requirements for specific uses. Table 1-1 presents some water quality terms presented in the domestic guideline.

Table 1-1: Definition of water quality terms (DWAF, 1996)

TERM	DEFINITION
Water quality	The physical, chemical, biological and aesthetic properties of water which determine its fitness for a variety of uses and for protecting the health and integrity of aquatic ecosystems. Many of these properties are controlled or influenced by constituents which are either dissolved or suspended in water.
Water quality guideline	A water quality guideline is essentially a user needs specification of the quality of water required for a particular use. Guidelines are developed as an important information resource primarily for water quality managers but can be used by members of the public who are interested in various aspects of water quality and its management. Guidelines are reviewed periodically and if need be updated to include relevant new information that has been obtained locally or internationally.
Water quality criteria	Are scientific and technical information provided for a particular water quality constituent in the form of numerical data and or narrative descriptions of its effects on the fitness of water for a particular use or on the health of aquatic ecosystems.
Constituent	Any of the properties of water and/or the substances suspended or dissolved in it.

1.4.4.1 *Using rainwater for drinking purposes*

General drinking water guidelines apply if the harvested water is to be used for drinking. It is critical that the water does not contain any harmful microbiological contaminants after undergoing treatment. This implies that in order for one to use rainwater for drinking purposes, there should be zero amounts of total coliform, faecal coliform, viruses and protozoan cysts (*Giardia* sp. and *Cryptospordium* sp.) (Table 1-2). The turbidity of water is in an indicator of the amount of organic and inorganic material, plankton, clay and silt in a particular water sample. A high turbidity level of a particular water sample is often linked with a greater chance of microbial contamination.

Table 1-2: SANS 241:2015 Drinking water quality guidelines for potable use (SANS 241:2015)

Determinants	Limit
Microbial determinants	
E.coli or Faecal coliforms count/100 ml	0
Total coliforms count/100 ml	<10
Hetero trophic plate count count/1 ml	<1000
Cryptosporidium species count/10 ml	0
Giardia species count/10 ml	0
Physico-chemical determinants	
Total dissolved solids mg/L	<1200
Turbidity	<5
Colour pt-Co	<15
Conductivity @25°C mS/m	<170
pH	>5 and <9.7

It is critical that rainwater that will be used for drinking purposes within the public water distribution system meets the same criteria as that of other sources of water used in the water distribution system (Table 1-2). Chapter 6 provides guidance on the variety of treatment technologies that can be used to treat the collected water to the required standard. It is important that each rainwater water treatment system is designed according to the surface from which the rain will be harvested.

1.4.4.2 *Non-potable use of rainwater*

Non-potable uses of rainwater include flushing toilets, car washes and also laundry. Guidelines for water quality requirements for non-potable water are not as stringent as compared to that of potable water. However, where the risk of exposure to harmful contaminants is higher, the acceptable or no health effect levels are normally defined. In South Africa, the minimum water quality requirements for different water uses, including non-potable, are stated in the SAWQGs.

1.5 SCOPE AND PURPOSE OF THIS GUIDELINE

Scope	The South African rainwater harvesting resource guidelines is a manual that provides guidance for the design, installation and management of domestic rainwater harvesting systems.
Purpose	The South African rainwater harvesting guidelines will serve as a primary source of information and decision-support to all stakeholders. The guidelines contain similar information to what is available in the international literature and a number of guidelines; however, the information here is tailor-made to south African conditions. Specific elements for regulation and enforcement will be passed in the relevant legislations.
Users of the Guidelines	The South African rainwater harvesting guidelines are being developed as the primary information resource for stakeholders such as homeowners, engineers, architects, contractors, developers, regulators, as well as members from municipal, provincial and national levels of government.
Ongoing Review	The South African rainwater harvesting guidelines will be periodically reviewed. The purpose of the reviews is to incorporate into the guidelines, all relevant new information from international and local sources as they become available.

In order to promote an informed implementation of RWH, there is a need of address six components that make up a RWH system (Figure 1-5):

i. Catchment surface, environment and atmospheric conditions;
ii. Gutters and downspouts through which water moves from the catchment into the tank;
iii. First flush diverters, leaf screens and roof washers which remove large pieces of debris and dust before the harvested rainwater goes into the tank;
iv. Storage tank(s);
v. Controls and pumps which determine the level of water in the tank, minimise air gaps and prevent backflow;
vi. Filtration, treatment and disinfection: This depends on the end use of the water. For potable use, filtration, treatment and disinfection need to be used. For non-potable use, filtration and treatment may be sufficient.

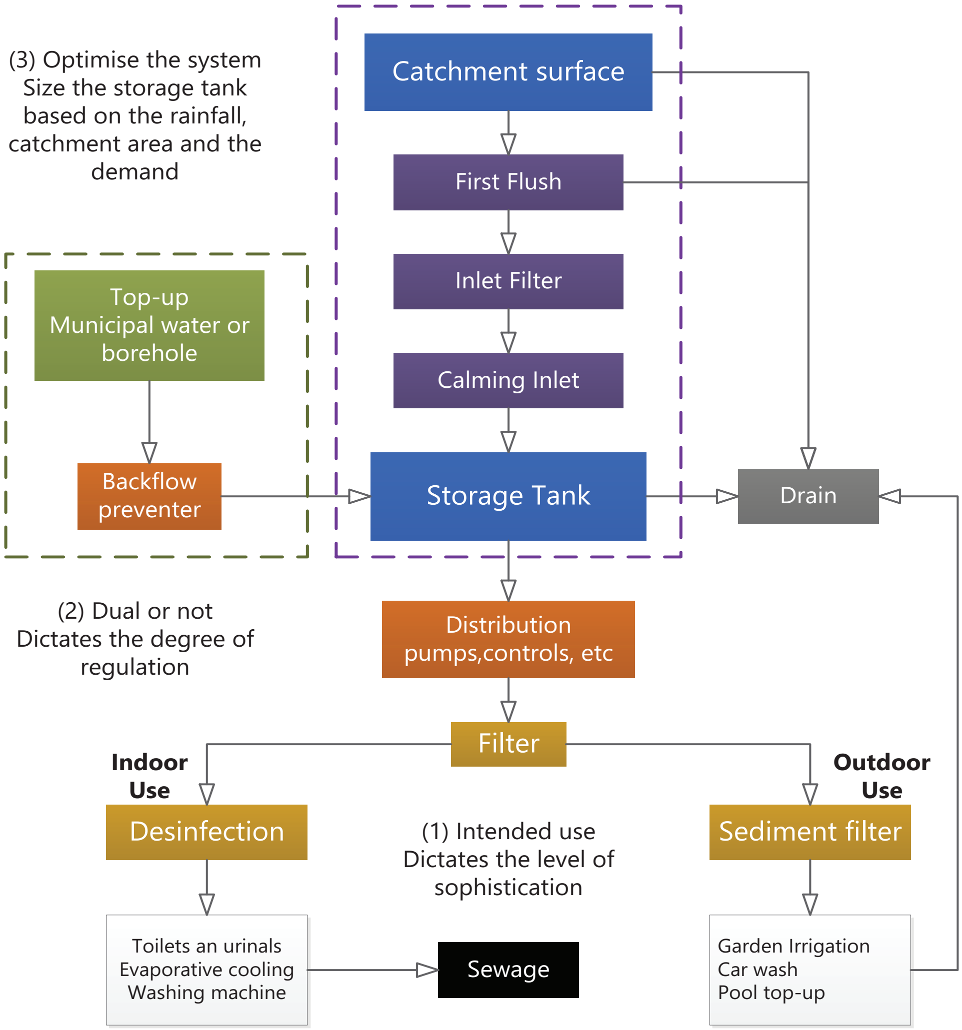

Figure 1-5: Rainwater Harvesting Flow Chart (Van Giesen and Carpenter, 2009)

2 GUIDANCE ON CATCHMENT & CONVEYANCE

2.1 INTRODUCTION

A key component of any rainwater harvesting system is collecting rainwater from a catchment surface and conveying it to a tank for storage and future use. The catchment area has a significant impact on both the design and water savings potential of RWH systems. In general, it is recommended that the size of the catchment area used for an RWH system be as large as possible to maximise water savings. RWH systems most often utilise the roof of a house or building for collecting rainwater. It is possible to collect rainwater from other surfaces such as lawns and parking lots but, these catchments are not addressed in this manual due to concerns surrounding the quality of rainwater collected from these surfaces. This second chapter provides guidance on the collection of runoffs from roof surfaces, or roof catchments. Once rainwater has been collected from the catchment surface, it must be conveyed to the storage tank by means of a 'conveyance network.' The most common method of conveying rainwater is through the use of gravity flow, whereby rainwater is transported to the storage tank without the use of pumps or other means of assistance. For most RWH systems collecting rainwater from a roof catchment, the size of the catchment area is usually predetermined by the size of the existing house or building. In such cases, one means of collecting additional rainwater is to utilise multiple roof catchments and convey rainwater to one central or 'communal' storage tank. Alternatively, it may sometimes not be feasible or beneficial to collect rainwater from the entire catchment area due to rainwater quality concerns, location/placement of rainwater storage tank or for other reasons. These and other issues are discussed further in the Design and installation guidelines.

2.2 APPLICABLE STANDARDS AND GUIDELINES FOR CATCHMENT AND CONVEYANCE

The applicable standards found in the South African national standards are listed in Table 2-1.

Table 2-1: Standards and codes applicable to catchment and conveyance network

Applicable codes, standards and guidelines	Selected provisions and design and installation implications
SANS 10400-L:2011 The application of the National Building Regulations Part L: Roofs	4.3.2 Gutters and downpipes
SANS 10400-R:1990 The application of the National Building Regulations Part R: Stormwater disposal	RR3 Valleys and gutters
SANS 10252-1:2012 Water supply and drainage for buildings Part 1: Water supply installations for buildings.	5 Materials, pipes, fittings, components and fixtures 5.1 General 5.2 Pipes and pipe fittings 6.7 Pipes 7.6 Pipe sizing 8.5 Joints 8.6 Laying of pipes

2.3 RAINWATER HARVESTING CATCHMENT

2.3.1 Catchment material

The roofing material is the outermost layer on the roof of a building, sometimes self-supporting, but generally supported by an underlying structure. A building's roofing material provides shelter from the natural elements. The outer layer of a roof shows great variation dependent upon availability of material, and the nature of the supporting structure. Those types of roofing material which are commercially available range from natural products such as thatch and slate to commercially produced products such as tiles and polycarbonate sheeting.

The most common roofing material can be categorised as:

- Thatch – roofing made of dry vegetation such as straw, water reed, sedge (*Cladium mariscus*), rushes, or heather. This type of roof is common in both urban and rural South Africa.
- Shingle or roofing slate – the generic term for a roofing material that is in many overlapping sections, regardless of the nature of the material are made of various materials such as wood, slate, flagstone, fibre cement (in the past, the fibre in the cement material was asbestos which has been banned for health reason), metal, plastic, and composite material such as asphalt shingles. Ceramic roof tiles, which still dominate in Europe and some parts of Asia, are still usually called tiles.
- Membrane roofing – a type of roofing system for buildings and tanks. It is used on flat or nearly flat roofs to prevent leaks and move water off the roof. Membrane roofs are most commonly made from synthetic rubber, thermoplastic (PVC or similar material), or modified bitumen. Membrane roofs are most commonly used in commercial application, though they are becoming increasingly more common in residential application.
- Metal roofing – a type of roofing system made from metal pieces or tiles. Metals used for roofing are: lead; tin and aluminium; copper; galvanized steel; blend zinc, aluminium and silicon-coated steel; Stainless steel, etc.
- Concrete or fibre cement, usually reinforced with fibres of some sort. Concrete tiles are made from sand of various grading and cement Fibre cement is a composite building and construction material, used mainly in roofing and also façade products because of its strength and durability.
- Structural concrete roofing – are usually used for flat roof constructions of large buildings. The three main categories of structure concrete roof are: precast/prestressed, cast-in-place and shell.

The type of catchment material used by an RWH affects:

- the proportion of rainfall collected during a rainfall event, defined as the ‘collection efficiency’ from the roof catchment and;
- the quality of harvested rainwater. The quality of rainwater runoff from a catchment surface can be affected in two ways. Dirt and debris can collect on the roof surface from direct atmospheric deposition, from overhanging foliage or bird and rodent droppings. Alternatively, the roof material itself can contribute both particulate matter and dissolved chemicals to runoff water.

In South Africa most houses are mostly covered with ceramic tiles, concrete tiles, corrugated iron and thatch. Structural concrete mostly covers administrative buildings.

2.3.2 Estimating the volume of rainwater collected from a catchment

2.3.2.1 *Runoff coefficient*

Theoretically, a 1 litre of runoff can theoretically be collected from each millimetre of rainfall falling on a 1 m^2 surface area. In reality, some losses occur following contact with the catchment surface. These losses vary depending on the type of catchment material and the geometry of the roof and should be considered when estimating the amount of rainwater that can be collected and utilised by the RWH system.

These losses can be characterised by: (1) an initial loss factor (in mm of rainfall) due to the absorbency of the catchment material, and continuous losses (in percentage of rainfall) from wind and leaks; (2) the runoff coefficient – a dimensionless value that estimates the portion of rainfall that becomes runoff, also taking into account losses due to spillage, leakage, catchment surface wetting and evaporation (Singh, 1992).

Thus, the actual volume of water harvested by the catchment area is given by:

$$V_h = r_c \times CA \times P \qquad \text{Equation 2.1}$$

Where: V_h = Volume harvested by the roof [m^3]; r_c = runoff coefficient; CA = Catchment Area [m^2] and P = Precipitation [m]

2.3.2.2 *Volume of water collected from rooftop catchments*

The size of the catchment area or roof determines how much rainwater can be harvested. The area is based on the “footprint” of the roof (Figure 2-1), which is basically the sum of the surface area of the building and the surface area of the roof’s overhang. Differences in roof shapes do not change a building’s catchment area.

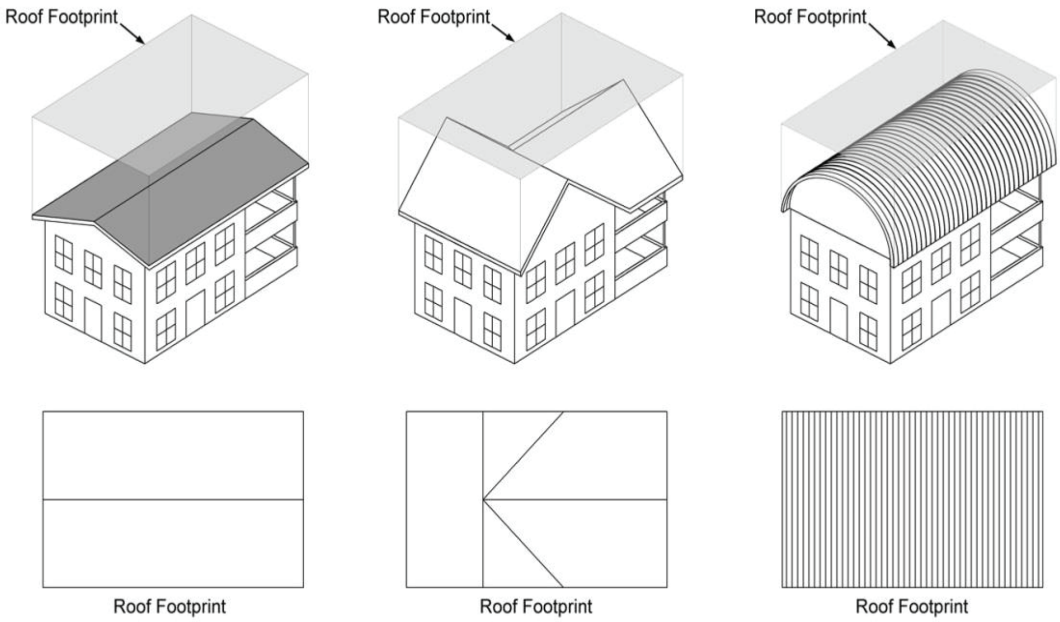

Figure 2-1: Roof footprint of a building

Nevertheless, the slope of the roof determines how quickly water will runoff during and after a rainfall event. A steep roof will shed runoff quickly and more easily clean the roof of contamination. On roof with gentle slopes, runoff moves more slowly, raising the potential for contamination to remain on the catchment surface. There is a vast array of roof shapes (Figure 2-2) and they tend to vary greatly from region to region. The main factors which influence the shape of roofs are the climate, the materials available for roof structure and the outer covering. Roof shapes vary from almost flat to steeply pitched. They can be arched or domed; a single flat sheet or a complex arrangement of slopes, gables and hips; or truncated (Figure 2-2).

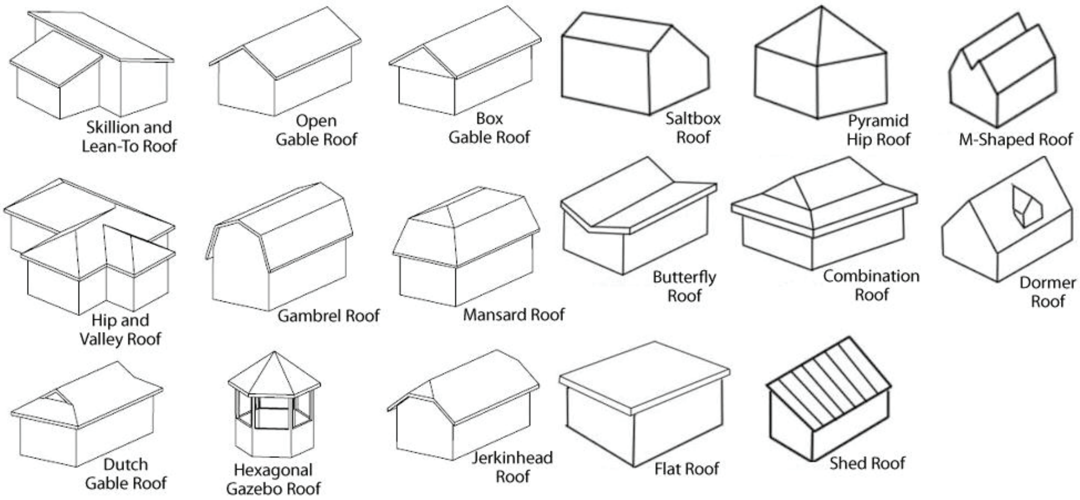

Figure 2-2: Various roof shapes

Theoretically, for every square metre of roof catchment area, 1 litre of rainwater can be captured per millimetre of rainfall (Figure 2-3).

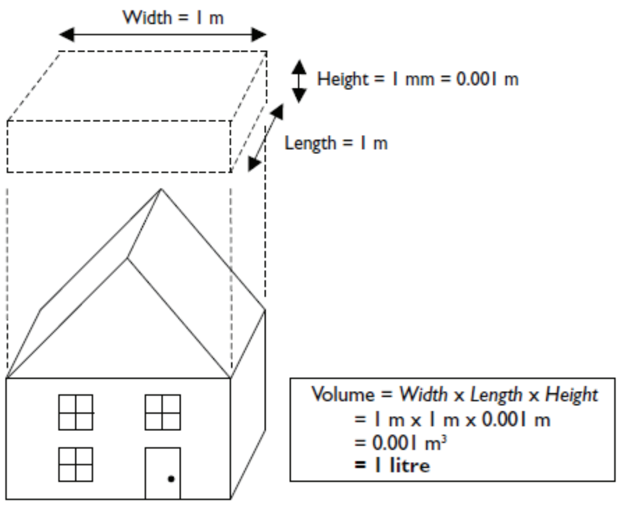

Figure 2-3: Theoretical volume of rainwater collected from a roof catchment

The theoretical volume of water collected from the roof is therefore given by:

$$Vt = CA \times P \qquad \text{Equation 2.2}$$

Where: V_t = theoretical volume [m^3]; CA = Catchment Area [m^2], P = Precipitation [m]

To calculate the catchment area or footprint:

$$CA = L \times W \qquad \text{Equation 2.3}$$

Where: CA = Catchment Area [m^2], L = length [m] and W = Width [m]

The volume of water collected is directly proportional to the catchment area (Figure 2-3). Hence, the larger the catchment area, the greater the quantities of rainwater collected per millimetre of rainfall.

2.3.2.3 *Volume of water collected from impervious areas*

Rainwater that falls on impervious surfaces such as sidewalks, driveways, parking lots, streets, etc., can also be channelled to an underground tank.

(a) The curve number method

The method was developed by the United States Department of Agriculture Soil Conservation Service (now Natural Resources Conservation Service), from an empirical analysis of runoff from small catchments and hillslope plots (NRCS, 1986). The major disadvantages of the method are sensitivity of the method to Curve Number (CN) values, fixing the initial abstraction ratio, and lack of clear guidance on how to vary Antecedent Moisture Conditions. The method is used widely and is accepted in numerous hydrologic studies and models such as the SWAT model (Neitsch *et al.*, 2002). The SCS-CN method is based on the following basic form calculating runoff from rainfall depth,

$$\begin{cases} Q = \dfrac{(P - I_a)^2}{(P - I_a) + S} & for\ P > I_a \\ Q = 0 & for\ \ P \leq I_a \end{cases} \qquad \text{Equation 2.4}$$

Where: Q = Runoff [mm]; P = Rainfall [mm]; Ia = the initial abstraction and S = potential maximum retention.

$$I_a = \lambda S \qquad \text{Equation 2.5}$$

Where: I_a = the initial abstraction; λ = dimensionless faction; S = Potential maximum retention

Initial abstraction (I_a) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. It has generally been assumed that $I_a = 0.2S$ (NRCS USDA, 1986), although more recent research has found that $I_a = 0.05S$ (Woodward *et al.*, 2003) may be a more appropriate relationship in urbanised watersheds where the CN is updated to reflect developed conditions.

$$Q = \frac{(P - \lambda S)^2}{P + (1 - \lambda)S} \qquad \text{Equation 2.6}$$

S is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by:

$$S = \frac{25400}{CN} - 25$$ Equation 2.7

Where: CN = curve number

Lower numbers indicate low runoff potential while larger numbers indicate increasing runoff potential.

(b) Runoff coefficient method

The runoff coefficient (C) is a dimensionless coefficient relating the amount of runoff to the amount of precipitation received. It is a larger value for areas with low infiltration and high runoff (pavement, steep gradient), and lower for permeable, well vegetated areas (forest, flat land).

$$Q = P \times r_c$$ Equation 2.8

Where: Q = Runoff [mm]; P = Rainfall [mm] and; r_c = runoff coefficient.

Whenever the catchment area consists of several different types of surfaces, the total runoff generated is the sum of individual runoffs generated.

$$Q = \sum_{i=1}^{n} P \times r_{ci}$$ Equation 2.9

2.4 CONVEYANCE SYSTEM COMPONENTS

Rainfall collected by the catchment is transferred to the rainwater storage tank through the conveyance network (Figure 2-4). Rooftop rainwater harvesting conveyance systems consists of two basic elements: (1) gutter(s) that collect water from the roof and (2) downspout(s) that channel the water collected by the gutters into the storage tank.

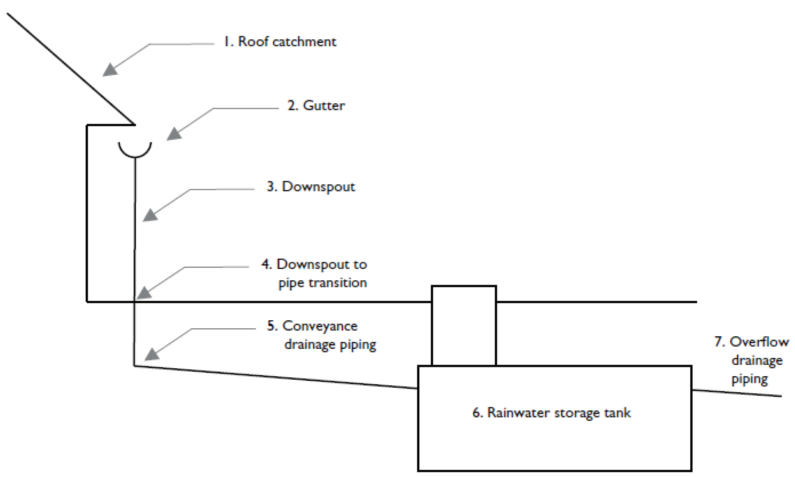

Figure 2-4: A typical conveyance network for an above ground rainwater storage tank

2.4.1 Gutters

A rain gutter, eaves channel, dripster, guttering or rain catcher, is a narrow channel, or trough, forming the component of a roof system which collects and diverts rainwater away from the roof edge. Gutters come in several sizes and shapes called profiles. The most common type of gutter used today is the open gutter, which often comes in standard lengths and profile, and also as continuous roll-formed seamless gutters. They are made of aluminium, Zinc, vinyl or copper. Guttering systems are often designed to maximise the amount of water that can be harvested. These systems can also be critical to the introduction of contamination into stored rainwater. Some of the designs of guttering systems that minimise contamination include the use of a primary filter such as coarse screen or fine screen. Leaf screens and gutter guards meet the minimal requirements for pre-filtration of small systems, although direct water filtration is preferred. All pre-filtration devices should be low-maintenance or maintenance-free. The purpose of pre-filtration is to significantly cut down on maintenance by preventing organic build-up in the tank, thereby decreasing microbial food sources. If rainwater is not pre-filtered, a large amount of organic matter in the form of leaves and dirt can enter the storage tank. When aerobic bacteria begin to consume the organic matter, they use up all the dissolved oxygen. This sets up anaerobic conditions that allow anaerobic bacteria to predominate, and thus results in odour.

2.4.1.1 *Leaf screen*

A leaf screen is a type of coarse screen that is able to prevent larger particulate matter from entering the tank. For rainwater harvesting systems installed in areas with dense vegetation it should be a requirement to have one of these types of screens. The fine screen such as a strainer bucket, sits between the delivery pipe and the tank preventing small insects and possibly rodents from having access to the storage tank. The sizes of these filters can be regulated depending on what type of particulate matter needs to be removed. Leaf screens are installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the storage tanks. Built-up debris can also harbour bacteria and enhance their growth within gutters or downspouts (TWDB, 2005).

2.4.1.2 *Gutter guard or screen*

Gutter screens can be installed on the gutter (Figure 2-5) to filter debris before they enter the gutter. One advantage of gutter screening is the large filtering surface area which can reduce maintenance of the filter surface. Some higher quality gutter screening is nearly self-cleaning and requires very little maintenance. The micro-mesh screen can filter debris in the 80-100 micron size which is beneficial for potable or indoor fixture systems which require superior filtration.

Figure 2-5: Smart Screen Gutter

2.4.2 Downspouts

A downspout, waterspout, downpipe, drain spout, roof drain pipe or leader, is a pipe draining rainwater from a rain gutter. Downspouts are usually vertical and usually extend down to ground level. The water is directed away from the building's foundation, to protect the foundations from water damage. The water is usually piped to a sewer, let into the ground through seepage or in this case, collected into a rainwater storage tank. In order to keep sediment, leaves and other debris from entering the RWH system, a downspout filter (leaf catcher) or first flush diverter device is are placed either at the top of the downspout where it meets the gutter, or somewhere along the length of the downspout.

2.4.2.1 *Downspout filters (leaf catchers)*

Downspout filters (Figure 2-6) generally only provide coarse filtration of 3175-1587 microns and should only be used for rain barrel systems. A few models can filter to 280 microns and make good pre-filters for irrigation systems and indoor non-potable uses.

Figure 2-6: Leaf catchers

2.4.2.2 *First flush diverter*

The first litres of rainwater which are harvested should be drained off through the use of first flush diverters. This reduces the contamination that can arise from a dirty roof or catchment surface area. The first flush of water need not be wasted and can be diverted to an area with vegetation and plant life that would require watering with the exclusion of small gardens and anything grown for ingestion. There are various types of first flush diverters that can be used with the simplest ones being made out of a PVC standpipe. Various factors need to be taken into consideration when determining how much water must be diverted initially. These factors include the duration between rainfall events, the slope and smoothness of the catchment area as well as the intensity of the rainfall event. In general, first flush diverters should be able to divert at least 38 ℓ of water per 92 m^2 of roof area.

First flush diverters direct the initial pulse of rainfall away from the storage tank (Figure 2-7). While leaf screens effectively remove larger debris such as leaves, twigs, and blooms from harvested rainwater. First flush diverters can be used to remove smaller contaminants such as dust, pollen, and bird and rodent faeces. Simple first flush diverters require active management, by draining the first flush water volume to a pervious area following each rainstorm. First flush diverters may be the preferred pre-treatment method if the water is to be used for indoor purposes.

Figure 2-7: First flush diverters

Size the first-flush chamber based on the desired amount of runoff (typical diversion height is 0.5-1.5 mm) to divert from the storage tank, using the following formulas:

$V_{df} = d_h \times CA$ Equation 2.10

Where: V_{df} = Diversion Volume [m^3]; d_h = diversion height [m]; CA = Catchment Area [m^2]

$$h_f = 4\frac{d_v \times 1000}{\pi \times \emptyset}$$ Equation 2.11

Where: d_v = Diversion Volume [m^3]; h_f = Height of first-flush chamber [m]; Ø = Pipe diameter [m]

2.5 DESIGN AND INSTALLATION OF CATCHMENT AREA AND CONVEYANCE NETWORK

1. Selection of the catchment area

a. only roof surfaces are recommended;

b. Ensure that your rooftop is suitable for RWH. Corrugated iron or metal rooftops are best for harvesting rainwater, followed by tiled and concrete rooftops. Thatched roofs, green roofs or any roof painted with paint releasing chemicals are not suitable for practical rainwater harvesting.

c. sections of the roof with overhanging foliage or trim where possible should be avoided as much as possible.

2. Catchment area

a. Determine catchment area using Equation 2.3

b. If sections of one roof catchment or multiple catchment surfaces are used, the catchment area can be determined by summing the multiple smaller areas.

3. To maximize the volume of rainwater collected by the RWH system

a. the catchment surface should be as large as possible;

b. when a roof catchment material can be selected and installed in conjunction with the RWH system, material with runoff coefficient close to 1, such as steel, should be selected convey rainwater using appropriately sized and sloped components, including gutters, downspouts, and/or conveyance drainage piping;

c. where possible, combined the surface area of several multiple roof catchments and connect them to a central rainwater storage tank.

4. Gutters and downspouts

a. Gutter and downspout materials

i. Aluminium or galvanised steel are recommended.

ii. Copper, wood, vinyl and plastic gutter and downspout materials are not recommended.

b. Gutter slope

i. Slope gutters in the direction of the location of the rainwater storage tank.

ii. Ensure a minimum slope of 0.5-2% (the greater the slope the better) is maintained throughout the gutter length.

c. Gutter size (SANS 10400-R)

i. Any valley or gutter shall have a cross-sectional area of not less than that given in Table 2-2, for the rainfall region in question.

Table 2-2: Roof valley and gutter sizes

Rainfall region	Internal cross-sectional area of valley or gutter per m^2 of roof plan area served
Summer	140 mm^2
Year round	115 mm^2
Winter	80 mm^2

Such requirements in respect of any downpipe shall be deemed to be satisfied where the internal cross-sectional area of such downpipe is not less than 100 mm^2 per 1 m^2 of roof plan area served by such downpipe: Provided that such internal cross-sectional area is not less than 4,400 mm^2

ii. Areas experiencing intense storm events need wider gutters than areas with less intense rain events. The gutters should be sized so that they adequately move rainwater runoff from a 100-year storm event. A 100-year storm event has a 1% chance of occurring every year and produces rainfall with great intensities.

d. Location and spacing of downspouts

i. Ultimately, the locations of downspouts depend on the configuration, architectural features and appearance of the building. Whenever applicable, locate them near the storage tank.

ii. Each downspout should drain a maximum of 15 m of gutter. However, the very design of the building might prevent the installation of more gutters

iii. Avoid locations where water must flow around a corner to reach a downspout.

e. Downspout size

i. In general, downspouts come in standard profiles and sizes. These should be suitable for most typical residential roof drainage areas and gutter lengths.

ii. The gutter and downspout size required is highly dependent on the amount of gutter and the spacing of the downspouts. Adding additional downspouts will require gutter and downspout volume result in smaller gutter/downspouts.

5. Plan the layout of the conveyance network:

a. Determine the location of the tank (refer to Chapter 3. GUIDANCE ON THE RAINWATER STORAGE TANK for details).

b. Route downspout(s) and/or conveyance drainage piping into the tank.

6. Tank connection

Rainwater conveyance drainage piping should enter the tank at a height no lower than the overflow drainage piping, or, ideally, 50 mm above the bottom of the overflow drainage pipes entering the tank.

7. Water quality aspects

Improving the roof runoff quality of rainwater minimises the contamination levels that could be subsequently observed in stored rainwater. Removal of vegetation from around the catchment area and the installation of leaf guards, prevent large debris from entering the storage tank. Birds, rodents and small animals should also be deterred from wandering around the RWH catchment area thereby introducing microorganisms into the runoff rainwater, primarily through their faecal droppings. The material the roof or catchment area is made of has an influence on the quality of the water harvested. A metal roof made out of powder coated steel is a smooth surface which allows efficient water runoff from the roof and furthermore, it is highly resistant to corrosion. Slate is also ideal as a catchment surface but more expensive than metal. Irrespective of the type of roofing material used, water quality testing of the runoff must be conducted in order to determine typical values of microbial and chemical quality.

2.6 MAINTENANCE OF CATCHMENT AND CONVEYANCE NETWORK

1. The catchment surface should be inspected twice a year

a. Identify any sources of contamination, including accumulated dirt and debris, presence of overhanging tree branches or other foliage, and/or signs of animal activity (for example, bird droppings); and

b. If contaminants are present, these should be removed by cleaning the catchment surface by hosing or sweeping and, if applicable, trimming overhanging tree branches/foliage.

2. The gutters and downspouts should be inspected twice a year.

a. Gutters must be maintained regularly to remove leaves and other debris to keep them from clogging. Gutters that are filled with debris can overflow and soak the foundation, damage the roof structure. Effective gutter guards that keep debris out but allow water to enter are a good alternative to regular cleaning. Gutter protection devices include: strainers, snap-in metal and plastic gutter guards, filtered gutter guards, stainless steel gutter guards, hinged gutter guards, plastic and metal total gutter covers and gutter brushes.

b. Regardless of the gutter guard protection used, all gutter systems should be examined for cleaning and repair twice every year.

c. Another option is to use a closed gutter to ensure that debris and leaves do not enter the gutter. The continuous hanger is a way to protect gutters from clogging and damage while reducing required cleaning to a minimum.

d. repair and/or replace damaged components to ensure proper rainwater flow and prevent entry of birds, rodents or insects into the RWH system.

3 GUIDANCE ON THE RAINWATER STORAGE TANK

3.1 INTRODUCTION

The storage container (cistern, tank) is often the most visible or recognisable component of a RWH system where the captured rainwater is diverted to and stored for later use. Thus, the main purpose of the storage tank is to store water that is safe to use while preventing its access to children or animals. There are several topics related to storage containers and you should go through each before making a decision on purchasing one. There are a number of different RWH systems available with a range of features, depending on the manufacturer. These systems can be grouped into three basic types of RWH systems: (1) water collected in storage tank(s) and pumped directly to points of use; (2) water collected in storage tank(s) and fed by gravity to points of use; and (3) water collected in storage tank(s), pumped to an elevated cistern and fed by gravity to the points of use. All those systems listed above have a reservoir that is used to store rainwater harvested from roof catchments referred to as a rainwater storage tank.

3.2 APPLICABLE STANDARDS AND GUIDELINES FOR RAINWATER STORAGE TANKS

The applicable standards found in the South African national standards are listed in Table 3-1.

Table 3-1: Standards and codes applicable to rainwater storage tanks

APPLICABLE CODES, STANDARDS AND GUIDELINES	SELECTED PROVISIONS AND DESIGN AND INSTALLATION IMPLICATIONS
SANS 10252-1:2012 Water supply and drainage for buildings Part 1: Water supply installations for buildings.	5.4.6 Storage tanks 6.5 Storage tanks (6.5.1 and 6.5.2) 9.3.2 Storage tanks
SANS 10100-1:2000 Structural use of concrete Part 1: Design	Concrete reservoir
SANS 1200 G:1982 Concrete (structural)	Testing of concrete reservoirs

3.3 GUIDANCE ON THE SELECTION OF STORAGE TANKS

3.3.1 Overview

The storage tank is another critical point in the RWH system where rainwater quality can be compromised. Table 3-2 gives a brief summary of the different types of storage tanks available and the pros and cons of their use to meet the quality requirements for potable and non-potable harvested rainwater. Although there are a variety of options when it comes to choosing a storage tank, there are certain characteristics that all tanks must have in order to optimise the quality of rainwater. All tanks must have lids and be covered at all times and preferably with vents, which hamper mosquito breeding.

Table 3-2: Description of storage tank materials (Van Giesen and Carpenter, 2009)

MATERIALS	FEATURES	CAUTION
Plastics		
Barrels 55 gal-150 gal	Commercially available Inexpensive	Use only new cans
Fiberglass	Commercially available; Alterable and moveable	Must be sited with smooth solid level footing
Polyethylene/polypropylene	Commercially available; Alterable and moveable	May be UV-degradable, can be painted or tinted if not inhibited
Metals		
Steel Drums (55 gallons)	Commercially available; Alterable and movable	Verify prior to use for toxics; Prone to corrosion and rust
Galvanized steel tanks	Commercially available; Alterable and moveable	Possible corrosion and rust; Should be lined for indoor use
Concrete and Masonry		
Ferrocement	Durable and immoveable Potential to crack and fail	
Stone, concrete block	Durable and immoveable Difficult to maintain	
Monolithic/Poured-in-place	Durable and immoveable	Potential to crack and fail
Wood		
Treated pine, fir, cypress	Attractive, durable, can be disassembled and moved	Expensive

To block sunlight thereby preventing algal growth, tanks must be opaque. If the tank is not opaque at the time of purchase it should be painted later on. With continual use of the tank, sediment build up and biofilm formation might occur in the tank. It is necessary to have easy access to the tank in order to clean and perform the necessary maintenance thereby maintaining the quality of stored rainwater. Location of the tank can have negative impacts on the quality of stored water, especially if the tank is stored underground. Tanks that are stored underground should be located 15 meters away from animal breeding grounds and any wastewater treatment related activity (Georgia, 2009). The inlet of the tank should incorporate a mesh cover and a strainer to keep leaves from entering the tank and to prevent access of mosquitoes and other insects (Figure 3-1). The overflow should also be covered with an insect proof cover such as plastic insect mesh wired around the pipe.

Figure 3-1: Insect Screen

3.3.2 Aboveground tanks

Storage containers are available in several materials (corrugated steel, concrete, wooden, fiberglass, Polyethylene and Polypropylene) each with pros and cons. There is therefore a need to weight their costs and benefits.

3.3.2.1 *Corrugated Steel and Enclosed Metal*

Corrugated steel tanks are often used because of their availability, price, and aesthetic value. They can range in sizes from a few hundred gallons to tens of thousands of gallons. The large corrugated steel tanks are usually the support structure for a vinyl bladder on the inside which actually stores the water. Because of their size, these tanks are usually assembled on-site. An enclosed metal tank is typically prefabricated and assembled off-site. The tank is sealed on the inside with a potable water approved liner or sealant. They are often more expensive than the corrugated tanks because they need to be shipped as a whole unit.

3.3.2.2 *Concrete tanks*

Concrete tanks are durable, strong, and heavy. They can be installed above ground or below ground. There are two common types of concrete storage containers: ferro-concrete and monolithic-pour concrete. Ferro-concrete is a relatively new approach where a special concrete mixture is sprayed on directly applied on a metal frame. This type of approach is common in developing nations. Monolithic-pour concrete tanks are either poured in place or prefabricated and assembled on site. An advantage to concrete is that they can raise the pH of the stored water (rainwater is naturally acidic, so it actually neutralises it)

3.3.2.3 *Wooden*

Although redwood tanks were once popular, they have become more expensive and less available. If located in a dry climate, the wood will dry and shrink, allowing water to leak out. To prevent leaking, the tank must be kept full, or lined.

3.3.2.4 *Fiberglass*

Fiberglass tanks are very versatile as they can be installed above or below ground. They are rigid and fairly lightweight and can be easily repaired. Because their individual strands are very fine and sharp, you should take be careful with parts that have been cut.

3.3.2.5 *Polyethylene and Polypropylene (Plastic)*

Plastic tanks are the most common material used for residential RWH systems in South Africa (Figure 3-2). This is because they are lightweight, come in many sizes and colours, and can are affordable. Polyethylene is flexible plastic and polypropylene is a rigid plastic. Both can be translucent or opaque. An opaque, solid colour is better for reducing the chances of algae growth. The selection of one of these materials for a rainwater storage tank will largely depend on local availability, as well as on cost, storage requirements, site accessibility and/or engineering specifications. In recent installations, above-ground tanks are often plastic. Another consideration is the potential for chemicals to leach from the tank into the stored rainwater; however, this is primarily a concern if rainwater must be of very high quality for one or more of the connected fixtures. In most cases, installation and operational specifications can be sought from manufacturers.

Figure 3-2: An example of a 2000 litre capacity RainCell 3 Cell Tank

3.3.3 Underground tanks

Most tanks are above ground, however if the user does not wish to either see the tank or lose precious backyard space, there is the option of burying the water tank underground. They are constructed from a variety of materials: polyethylene, Steel, Fiberglass or Concrete. Plastic underground rainwater tanks are a type of rainwater tank that are designed to be installed underground (Figure 3-3) while still operating effectively. These tanks are made from UV stabilised polyethylene (food grade) and are specifically designed and manufactured for strength, with factors such as large ribs added to the water tank walls. Modern polyethylene water storage tanks that are designed to be installed underground can be positioned underneath driveways, allowing a car to be driven over the top of the tank.

Figure 3-3: Example of an underground Jojo storage tank

Concrete underground tanks tend to be more expensive to install than polyethylene water tanks as more excavation is required. Those tanks are also at little risk of rusting, corroding, or damage from tree roots. Because concrete tanks are stronger, they are ideal for placing under driveways, courtyards, sheds, or other areas where they have to take heavy loads. Concrete underground rainwater tanks are either precast or poured on site to the client specifications.

3.4 TANK CAPACITY

3.4.1 Overview

As a rule of thumb, the larger the tank, the greater the volume of rainwater that can be collected and stored during rainfall events (collection efficiency). However, this is true only up to a certain point – after which other factors, such as local rainfall patterns, roof catchment area and rainwater demand, will limit the amount of rainfall that can be collected and utilised by the system. Thus, for any RWH system with a given roof catchment area, rainwater demands and local rainfall patterns, the storage capacity of the tank can be described as either:

1. Too small – Much of the collected rainwater overflows during rainfall events. Significant improvements in collection efficiency can be achieved with minor incremental increases in storage volume.
2. Optimum – Rainwater tanks in this range provide the best balance between collection efficiency of the RWH system and minimising its size and cost.
3. Too large – Rainwater tanks in this range rarely fill to capacity. A smaller tank can be used without a significant drop in the collection efficiency of the RWH system. An oversized rainwater storage tank, however, may be desirable if stormwater management is a strong driver for installing an RWH system.

3.4.2 Tank sizing

The correct sizing of a RWH tank is important in order to avoid extra costs incurred when the tank is over sized and for avoiding low efficiency when it is under sized [16]. The effectiveness of a RWH system depends on factors such as the catchment size, rainfall variability, temporal and spatial variation the water demand and the tank size. Tank sizes have an important role since they dictate the maximum amount of water that gets stored. However, there must be other attributes that must be considered. The effectiveness of a RWH system depends on factors such as the catchment area, temporal and spatial rainfall variability, the water demand and the tank size, the demand from the system, etc.

- Catchment area – The size and nature of the catchment area determines the amount of rainfall that can be harvested (Liaw and Tsai, 2004). The runoff coefficient is defined a dimensionless value that estimates the portion of rainfall that becomes runoff, taking into account losses due to spillage, leakage, catchment surface wetting and evaporation (Singh, 1992). According to (Liaw and Tsai, 2004) the performance of a RWH system is sensitive to the runoff coefficient value only for small tank sizes.

- Rainfall variability – The efficiency of a RWH system is largely affected by the distribution patterns of rainfall (Su *et al.*, 2009). The optimum size of RWH is likely to differ in South Africa's five rainfall regions; all year, winter, early summer, mid-summer, late summer and very late summer regions (Schulze *et al.*, 2007).

- Water demand – It is the actual volume of water extracted from the tank for various uses at a given time. When optimising RWH system, scholars usually use a single figure to express the potable water demand (Su *et al.*, 2009; Imteaz *et al.*, 2011 and Ndiritu *et al.*, 2011). This is not a reflection of the actual water demand which varies throughout the year. Moreover, no good correlation has been established between the tank capacity of a RWH system and the fixed daily potable water demand (Ghisi, 2010). Therefore, a rainwater tank must never be sized according to potable water demand only.

- Reliability – The Reliability is the probability that a system can meet the expected demand (McMahon and Adeloye, 2005). It can be divided into two types; time-based reliability and volumetric reliability. The former is the probability that a reservoir will be able to meet a certain demand on a specific time interval; while the latter is the ratio of the amount of water supplied to the total water demand during the simulation period. The reliability of the rainwater tank is very important for domestic water conservation as it indicates the ability of the tank to satisfy the demand of the household on a given day.

- Temporal resolution – Time intervals affect the quality of the simulation results. The use of monthly rainfall data to calculate the storage of a RWH tank results in an underestimation of the required storage capacity (Fewkes and Butler, 2000; Van der Zaag, 2000; and Mwenge Kahinda and Taigbenu, 2010) because it overlooks the temporal distribution of rainfall (Chiu and Liaw, 2007 and Mukheibir and Sparks, 2003). Hourly or daily time series are said to provide a more accurate simulation of system performance than monthly time intervals (Fewkes and Butler, 2000). However daily time steps have found more preference in sizing RWH tanks (Fewkes and Butler, 2000; Mwenge Kahinda and Taigbenu, 2010; and Ndiritu *et al.*, 2011) because sub-daily time series data are generally unavailable (Ndiritu *et al.*, 2011).

- Release rule and reliability – The Reliability is the probability that a system can meet the expected demand (McMahon and Adeoye, 2005). It can be divided into two types; time-based reliability and volumetric reliability. The former is the probability that a reservoir will be able to meet a certain demand on a specific time interval; while the latter is the ratio of the amount of water supplied to the total water demand during the simulation period. The reliability of the rainwater tank is very important for domestic water conservation as it indicates the ability of the tank to satisfy the demand of the household on a given day.

- Interval used in simulation – Time intervals affect the quality of the simulation results. The use of monthly rainfall data to calculate the storage of a RWH tank results in an underestimation of the required storage capacity (Fewkes and Butler, 2000; Van der Zaag, 2000; and Mwenge Kahinda *et al.*, 2010) because it overlooks the temporal distribution of rainfall (Chiu and Liaw, 2008; Mwenge Kahinda *et al.*, 2010). Hourly or daily time series are said to provide a more accurate simulation of system performance than monthly time intervals (Fewkes and Butler, 2000). However daily time steps have found more preference in sizing RWH tanks (Fewkes and Butler, 2000; Mwenge Kahinda *et al.,* 2010; Ndiritu *et al.,* 2011a) because sub-daily time series data is generally unavailable (Ndiritu *et al.,* 2011a).

- Tank sizes – The storage tank is the most expensive component of a RWH system (Van der Zaag, 2000; Sturm *et al.,* 2009). The storage capacity of the tank dictates the maximum amount of water that can be stored. Most RWH systems in the country are installed using a rule of thumb law which does not involve proper sizing; as a result, the RWH tanks installed are either oversized or undersized tank (Mwenge Kahinda *et al.*, 2010).

Storage tank optimisation is an important but often overlooked design step of RWH systems. Before the most cost-effective proportion of the area of a roof to be used for harvesting the water that will be stored in a tank can be determined, the relationship between roof area and storage capacity must be outlined along with the major parameters such as: release rule and reliability, interval used in simulation, record length of rainfall data, and runoff coefficient (Liaw and Tsai, 2004). The release rule can either be Yield before spillage (YBS) or Yield after spillage (YAS). In the YBS rule, the water is abstracted for use before the inflow. This leads to an underestimation of the required storage volume. The opposite applies with the YAS rule, which is more conservative and therefore usually preferred (Raimondi and Becciu, 2014). Several methods are used to size the tanks of RWH systems; the main methods include Simplified methods, critical period, probability matrix methods, statistical methods and Procedures based on stochastic data generation.

3.4.2.1 *Simplified Methods*

The simplified method, used for preliminary design, is based on user defined relationships *(*Ward *et al.,* 2010*)*. Though they are used with relative ease, their results are not reliable due to poor modelling of rainfall and/or water storing processes (Raimondi and Becciu, 2014). The supply side approach assumes that the required tank is large enough to store the maximum amount of rainwater in the wet season. Limitations of the method are that it ignores the water demand which lead to inaccuracies when sizing the system. The method does not account for the seasonal variation in rainfall. The tank design is only based on the water needs and the period of water shortage. The demand side approach assumes that the storage requirement is equal to the largest demand to be supplied by the tank. The method does not take into account water demand and uses only the water availability for the design of the storage tank (Ward *et al.,* 2010). The main limitation is the assumption that there will be enough rains to fill the tank before the dry period commences.

3.4.2.2 *Critical Period Method*

The critical period method is based on the continuity equation wherein the required storage is equal to the maximum difference between the outflow and inflow of the reservoir during a critical period (McMahon and Adeloye, 2005). The term critical period refers to the period from a full reservoir condition to emptiness (McMahon and Adeloye, 2005). It identifies and uses sequence of flows where demand exceeds supply to determine the storage capacity (Fewkes and Butler, 2000). The Critical period methods base the reservoir capacity on a single worst critical period or a synthesized one (Ndiritu *et al.*, 2011).

3.4.2.3 *Behavioural analysis*

The continuous simulation method (behavioural analysis) uses a simple mass balance equation. This approach is popular because it can be applied with simple mathematical tools as spreadsheet applications and incorporates seasonal changes with relative ease (Raimondi and Becciu, 2014). The limitations of the model are that: depending on the length of the annual inflow data, storage size for high reliabilities cannot be estimated (McMahon *et al.,* 2007). and Considering stochastically generated annual streamflows, Pretto *et al.* (1997) found that biases occur in the mean and higher order quantiles of storage estimates before the estimated storage size converges to a stationary value after a long sequence (typically 1000 years or more). Behavioural models simulate the operation of the reservoir with respect to time by routing the simulated mass flows through an algorithm which describes the operation of the reservoir (Fewkes and Butler, 2000).The input data which is in time series format is used for the simulation of the mass flows through the model and will be based upon a time interval of either a minute, hour, day or month (Fewkes and Butler, 2000), they have found more preference (McMahon and Adeloye, 2005; Ndiritu *et al.,* 2011a, Raimondi and Becciu, 2014), because they represent the storage behaviour more realistically than other methods and it can be adapted with ease to model complex configuration and operating rules (McMahon and Adeloye, 2005).

The operation of the system is usually simulated over a given period of time using a time step of a minute, hour or month (Fewkes and Butler, 2000). Several models that can be used for the design and modelling of the storage tank have been developed (Fewkes and Butler, 2000; Su *et al.*, 2009; Ndiritu *et al.,* 2011). The difference in the models is the release rule which may be YAS or YBS as explained above. Fewkes and Butler (2000) investigated the accuracy of behavioural models using different time steps with the YAS and YBS release rule for both small and large storages. Each model run was one year, the results of this preliminary analysis indicated that a YAS model using either hourly or daily input time series could be used to predict system performance. Some models have been incorporated into software packages while others operate in excel. There are two releases rules mainly involved in behavioural models namely yield after spillage (YAS) or yield before spillage (YBS) algorithm. The two release rules were originally developed by Jenkins *et al.* (1978), but later further development was done by Fewkes (2000).

The yield after spillage operating rule:

$$\mathrm{Y_t} = \min \begin{cases} \mathrm{D_t} \\ \mathrm{V_{t-1}} \end{cases} \qquad \text{Equation 3.1}$$

$$\mathrm{Q_t} = \min \begin{cases} \mathrm{V_{t-1}} + \mathrm{Q_t} - \mathrm{Y_t} \\ \mathrm{S} - \mathrm{Q_t} \end{cases} \qquad \text{Equation 3.2}$$

The yield before spillage operating rule is:

$$\mathrm{Y_t} = \min \begin{cases} \mathrm{D_t} \\ \mathrm{V_{t-1}} + \mathrm{Q_t} \end{cases} \qquad \text{Equation 3.3}$$

$$\mathrm{Q_t} = \min \begin{cases} \mathrm{V_{t-1}} + \mathrm{Q_t} - \mathrm{Y_t} \\ \mathrm{S} \end{cases} \qquad \text{Equation 3.4}$$

Where: R_t= Rainfall [m] during interval, t; Q_t= Rainwater run off [m^3] during time interval, t; M_t= Mains supply make-up [m^3] during time interval, t; O_t= Overflow from store [m^3] during time interval, t; V_t= Volume in store [m^3] during time interval, t; Y_t= Yield from store [m^3] during time interval, t; D_t= Demand [m^3] during time interval, t; S= Store Capacity [m^3]and; A= Roof Area [m^2]

In the YBS rule, the water is supposed to be abstracted for use before the inflow at each time step and which leads to underestimation of the storage volume that is needed, the opposite is the case with the YAS, which is more conservative and then is usually preferred(Raimondi and Becciu, 2014). Fewkes and Butler (2000) and found that a YAS model using either hourly or daily input time series could be used to predict system performance. Mitchel (2007) used a 6-min time step over a 50-year simulation period and concluded that the selection of either the YAS or YBS operating rule has negligible impact on the estimation of yield and volumetric reliability. There are however other algorithms rather than YAS and YBS; Ghisi (2010) estimated rainwater tank sizing and potential for potable water savings using an algorithm of the Neptune computer programme which is neither YAS nor YBS.

3.4.2.4 *Mass Curve Method*

The mass curve methods use a mass balance of the worst drought recorded, thereby assuming that a more severe drought will not occur in the future (Ndiritu *et al.,* 2014). The method further assumes that the tank is initially full at the beginning of the flow record and hence will be full at the start of the critical period (McMahon and Adeloye, 2005). Restriction control curves that are a function of storage content cannot be handled by the method (McMahon and Adeloye, 2005) and no estimate of the expected reliability is provided (Ndiritu *et al.,* 2014). Moreover, the algorithm does not account for storage losses.

3.4.2.5 *Procedures based on stochastic data generation*

Storage estimates are made based on stochastic or synthetic streamflow data in conjunction with one of the Critical period method (McMahon and Adeloye, 2005). One of the methods based on this procedure is the Behavioural analysis method discussed in section 3.4.2.3.

3.4.2.6 *Probability Matrix Methods*

The probability matrix method is based on analytical derivation of probability distribution functions of design parameters, probabilistic modelling of the storage process is possible without the need of continuous simulations (Raimondi and Becciu, 2014). The method considers a maximum of two isolated rainfall events rather than the entire time series, and it assumes that the tank is full at the end of the first rainfall event (Raimondi and Becciu, 2014). The limitation in this method is that each year of the record is simulated separately thereby ignoring serial correlation of the hydrological variables involved (Ndiritu *et al.*, 2011a).

3.4.3 Examples of models for calculating tank storage capacity/sizing

A number of scholars have developed RWH models through the years, e.g. Jenkins and Pearson (1978) developed the yield before spillage (YAS) and yield before spillage (YBS) release rules ; Dixon (1999) developed a daily time step model that simulates tank size, water quality, quantity and cost of the RWH system ; Van der Zaag (2000) developed a spreadsheet based model which calculates storage capacity when daily water use and roof area are known; Roebuck and Ashley (2007) developed an excel based mass balance transfer model that predicts future financial and hydraulic performance of RWH systems; Ndiritu *et al.* (2011) developed a daily time-step simulation of household water supply and a frequency analysis of the resulting number of days that the household gets supply for every year of the analysis; Raimondi and Becciu (2014) developed a model which uses analytical probabilistic approaches to the modelling of rainwater tanks.

As previously alluded, the storage tank greatly affects the initial capital cost and the volume of the rainwater collected because it is the most expensive component of a RWH system. Proper tank sizing is therefore important in order to avoid extra costs incurred when the tank is over sized and for avoiding low efficiency when it is under sized (Ghisi, 2010). It is a daunting task to review all existing RWH models. Thus, while a number of models presented in the literature are listed (Table 3-3), only those that were accessed are discussed in more details.

Table 3-3: Existing RWH models, their developers, spatial and temporal resolutions as well as their availability

Model	Developer	Spatial resolution	Temporal resolution	Validation	Availability
Yield Reliability Analysis	Ndiritu *et al.,* 2011a	Household	Daily	No	Free
Domestic Rainwater Harvesting	Dixon *et al.,* 1999	Household	Hourly	No	Free
Household Water Cycle	Liu *et al*., 2013	Household	Minutes	Yes	Lost code
Aquacycle	Mitchel, 2005	Household, Cluster and Catchment.	Daily	Yes	Free
Probabilistic Modelling	Raimondi and Becciu, 2014	Household	Daily	No	Requested
Rainfall storage Drain	Kim and Han, 2001	Household	Daily	No	Requested
Roof	Zaag P, 2000	Household	Daily	No	Free
SamSamWater Rainwater Harvesting Tool (SRWT)	SamSamWater	Household	Daily	No	Free
REWAPUT	Vaes and Berlamont, 2001	Household	Daily	No	Requested
RWIN	Herrmann and Schmida, 2000	Household and multi-story building	Minutes	No	Requested
RWH model	Zhou *et al.,* 2010	Household	Daily	No	Requested
The Urban Water Optioneering Tool	Markopolos *et al.,* 2009	Household	Daily	No	Requested
RainCycle (RC)	Asheley and Roebuck, 2007	Household	Daily	Yes	Free
Water Saving Efficiency Model	Vialle *et al.,* 2011	Household	Daily	Yes	Requested
Rainwater Analysis and simulation Model	David and Sample, 2014	Household	Daily	No	Not stated
Water Balance Simulation Model	Hajan and Rahman, 2014	Household	Daily	No	Requested

3.4.3.1 *Roof*

Roof is a spreadsheet-based water balance model that calculates storage capacity when daily water use and roof area are known, the model requires a complete series of daily rainfall data for at least three consecutive years. Roof uses the following water balance equation:

$$\frac{dV}{dt} = Q_r + Q_t - Q_{abs} - Q_0 \qquad \text{Equation 3.5}$$

Where: V = volume of water stored in the tank [m^3], Q = roof runoff into the tank [m^3 d^{-1}], Q_T = additional inflow into the tank [m^3 d^{-1}], Q_{abs} = water abstracted from the tank [m^3 d^{-1}], Q_o = Overflow from the tank [m^3 d^{-1}] and t = time [day].

With roof runoff equal to:

$$Q_r = P \times A_r \times c_r \qquad \text{Equation 3.6}$$

Where: P = precipitation (m d^{-1}), Ar = roof area (m^2) and cr = roof runoff coefficient.

The model produces a storage capacity graph which provides guidance in selecting the best tank size for a given geographical area. The relative storage capacity graph consists of the 'Relative Water Consumption' (RWC) expressed in mm water layer per day on the horizontal axis, and the 'Relative Storage Capacity' (RSC) expressed in mm water layer on the vertical axis. The model is based on the following equations:

$$RWC = \frac{Q}{A} \qquad \text{Equation 3.7}$$

$$RSC = \frac{S}{A} \qquad \text{Equation 3.8}$$

Where: RWC = Relative Water Consumption [mm d^{-1}], RSC = Relative Storage Capacity [mm], Q = daily water consumption [10^{-3} m^3d^{-1}], A= roof area [m^2], S= storage capacity [10^{-3} m^3], A= roof area [m^2]

The storage capacity graph represents a combination of the RWC and RSC for a given satisfaction level. The satisfaction level refers to the days where the daily water demand will be fully satisfied and it is expressed in percentage, a 30% satisfaction level means that daily water demand will be fully satisfied for 30% of all the days. For a given combination of daily water demand and roof area the RWC value is known, therefore the RSC value can be obtained from the graph by multiplying the obtained RSC value by the roof area, thereby obtaining the storage capacity in the certain situation. The roof model was used on a study by (Mwenge Kahinda *et al.*, 2010) where the optimum tanks size for the area studied was found to be 0.5 m^3.

3.4.3.2 *The SamSamWater Rainwater Harvesting Tool*

SamSamWater Rainwater harvesting tool is a global online RWH tool used for determining the optimum size of a rainwater harvesting system. The tool requires inputs of the location, roof size, roof type and water demand of the household. The rainfall data set used in the tool is based on the CRU CL 2.0 dataset which is adopted from (New *et al.*, 2002). The tool provides outputs of monthly rainfall for an average year, water availability and water demand throughout the year, water level in the tank throughout the year. The value of the volume of water harvested at a certain month is represented in equation 3.9.

$$V_h = A \times r_c \times R_{avg} \qquad \text{Equation 3.9}$$

Where: V_h = Volume harvested by the roof [m^3]; r_c = runoff coefficient, and R^{avg} is the average rainfall [m]

These outputs are then used to conclude the size of the tank that would be suitable for the specific location.

3.4.3.3 *Yield Reliability Analysis model*

The Yield Reliability Analysis (YRA) is a daily continuous simulation model developed by (Ndiritu *et al.*, 2011a), the model is based on an approach towards volumetric reliability by (Su *et al.*, 2009) who applied daily continuous simulation modelling to obtain relationships between storage size, deficit and its exceedance probability, which allows for the selection of a confidence level associated with a specific yield and tank size. Ndiritu *et al.* (2011a) used the above-mentioned approach by Su *et al.* (2009) determining exceedance probabilities using the frequency analysis of the number of days of supply each year using a plotting position formula. The model calculates the number of days in a year that a household water demand is met by a RWH (rainwater harvesting) system, ROR (run-off-river), and the combination of the two. An optimal tank volume is described as the minimum tank size giving the highest number of days of supply for the specific roof area. The yield reliability analysis model has been used in 3 case studies to date:

- The yield-reliability analysis of rural domestic water supply from combined rainwater harvesting and runoff river abstraction in Nzhelele village, Limpopo province (Ndiritu *et al.*, 2011a)
- Incorporating hydrological reliability in rural rainwater harvesting and run-of-river supply (Ndiritu *et al.*, 2011b)
- Probabilistic assessment of the rainwater harvesting potential of schools in South Africa (Ndiritu *et al.*, 2014)

3.4.3.4 *Raincycle*

Raincycle is a Microsoft Office Excel based mass balance transfer model that predicts future financial and hydraulic performance of RWH systems (Roebuck and Ashley, 2007). The model is applicable for RWH systems in domestic, commercial, public or industrial buildings and, makes use of the YAS spillage algorithm as described by (Jenkins and Pearson, 1978). The model accounts for the change in water demand throughout working days, weekends and holidays. The models can provide daily simulations of the proposed design for up to 100 years of operation. The main result of the model is expressed as the percentage of demand fulfilled by harvested water. The model was validated by comparing the hydraulic outputs of the model with the methodology described by Fewkes and Warm (2001).

3.4.4 Evaluation criteria of RWH models

To evaluate RWH models, a set of evaluation criteria has been developed, after Cunderlik (2003) who developed evaluation criteria for hydrologic models. The selection of an existing model to be used in this project depends therefore on a range of criteria rather than the personal preferences of the project team. A number of criteria are informative while, other are ranked and included in the evaluation process. Criteria are ranked from either 1 to 3 or 1 to 2 with: rank 1 – Bad, 2 – Average and 3 – Good. A summary of the comparison between the four models is presented in Table 3-4

where:

- Temporal scale refers to the time step of the input data and used in the model [sub-hourly (+/-), hourly (+/-), daily (+/-), monthly (+/-), annually, flexible]. Rank: [1-3]; models with flexible time step that include the daily time step receive the highest rank 3, models working at the daily time step get 2, and models with time steps higher than the daily time step get 1.
- Length of rainfall input data refers to the length of the rainfall time series used to run the model [1 year; 10 years; > 10 years]. Rank: [1-3]; 3 for models with long time series (> 10 years), 2 for models with time series longer than 5 years but sorter or equal to 10 years, and 3 for model with short time series (1 year).
- Length of water demand input data refers to the volume of water extracted from the tank [Flexible, time series, fixed value]. Rank: [1-3]; 3 for model with flexible demand (both fixed and time series), 2 for time series of water demand and, 1 for fixed water demand.
- Process modelled refers to all processes that are modelled (reliability, optimum tank size), Rank: [1-6] (1-3 for each process); 6 if both processes are modelled, 4 if only one process is modelled, and 1 if none of the processes are modelled.

Table 3-4: Comparison of selected RWH models using criteria developed by Cunderlik, 2003

Model/Criterion	Roof	Yield Reliability Analysis	Raincycle	SamSamWater
Temporal scale	Day	Day	Day	Month
Length of rainfall input	>3 years	10	1 year	Satellite data
Water demand	Fixed	Fixed	Time series	Fixed
Processes	Yes	Yes	Yes	Yes
Cost	Public domain Requires Ms Office	Public domain requires a basic PC	Public domain Requires Ms Office	Public domain Phone application
Data requirements	High	High	High	Low
Expertise	Medium	High	Medium	Low
Technical support	Yes	Yes	No	Limited
Documentation	Bad	Medium	Good	Bad
Ease of use	Medium	Difficult	Medium	Easy
Operating system	Windows 7	Windows 7	Windows XP	Phone application
Validation	No	No	No	No
Advantages	Excel based Code accessible	Excel based	Excel based Whole Life Costing	Minimum data input Customised for the globe
Disadvantages		No user interface for the version provided Code not accessible	Code not accessible Uses only one year of rainfall. Code not accessible Requires an old operating system	Uses average monthly rainfall data
References	Van der Zaag, 2000	Ndiritu *et al.*, 2011a; Ndiritu *et al.*, 2011b; Ndiritu *et al.*, 2014	Roebuck and Ashley, 2007	None
Total score	**29**	**27**	**24**	**25**

- Cost refers to the price of the model in ZAR Rands and the cost of the required system to run it. Rank [1-3], 3 for public domain models with free or cheap platform, 2 for public domain models running on expensive platforms, 1 for models which cost money.
- Data requirements refers to the input data (beside the roof area, the rainfall time series and the water demand) that the model requires in order to run. Rank [1-3]; 1 – high, 2 – medium, 3 – low.
- Expertise refers to the scientific skills required to use the model adequately [low, medium, high]; 3 – low, 2 – medium, 1 – high.
- Technical support; support available for setting up the model, calibration and use. Rank: [1-3], 3 – if full support is available, 2 – if limited support is available, 1 – if there is no support.
- Documentation refers to the available documents of a model, such as reference manuals, user's guides, web pages, etc. [good, medium, bad]. Rank: [1-3]; 3 – good, 2 – medium. 1 – bad.
- Ease of Use refers to the user friendliness of the computer-based model, taking into consideration Graphical User Interface (GUI), input-output (I/O) operations, and visualization options [easy, medium, and difficult]. 3 – easy, 2 – medium, 1 – difficult.
- Operating system refers to the operating system required for the effective use of the model [Linux, UNIX, MAC, Windows CE, 95, 98, 2000, XP, 7, 8]. Rank: [1-3]; 3 for Windows based applications since

Windows 7, 2 – for DOS applications and windows operating systems before Windows 7, and 1 – for other operating systems.

- Validation – indication of whether or not the model results can be validated against observed data, Rank [1-3], 3 – validated. 1 – not validated.
- Advantages and disadvantages summarise the merits and demerits of a given model. Rank: [-].
- References – list the key reference(s) to the model in the literature. Rank: [-].
- The total score gives the sum of all ranked criteria.

3.4.5 Modelling using the shortlisted RWH models

The Roof, SamSamWater rainwater harvesting tool, Yield reliability analysis and the Raincycle model were used to estimate the optimum tank sizes of households across the country using existing daily rainfall time series1989 to 1998 with the exception of SamSamWater rainwater harvesting tool which has its own rainfall data set. Four sites where selected for this analysis namely: Pretoria University, Cape Town fire service station, Stellenbosch and Durban botanical Garden. The following parameters were used for various sites across the country: roof area of 150 m^3, daily demand of 50 litres per capita per day (an average of 4 inhabitants per household), a runoff coefficient of 0.8. The results of the modelling exercise provided a variety of optimum tank sizes for the range of models used (Figure 3-4). While there was no agreement between most model outputs, the Raincycle and YRA models were in agreement in some areas. The SamSamWater rainwater harvesting tool underestimated the optimum tank sizes because it uses monthly rainfall data. A number of models have been developed optimise RWH systems and quantify their water savings. There are however no guidelines to verify which model is more relevant for which reasons, given that they are not validated against observed data. Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate predictions (Refsgaard, 1997). A model is said to be validated if its accuracy and predictive capability in the validation period/area have been proven to lie within the predefined acceptable limits. It is therefore a necessary step that is almost totally overlooked by the developers of the RWH models discussed above.

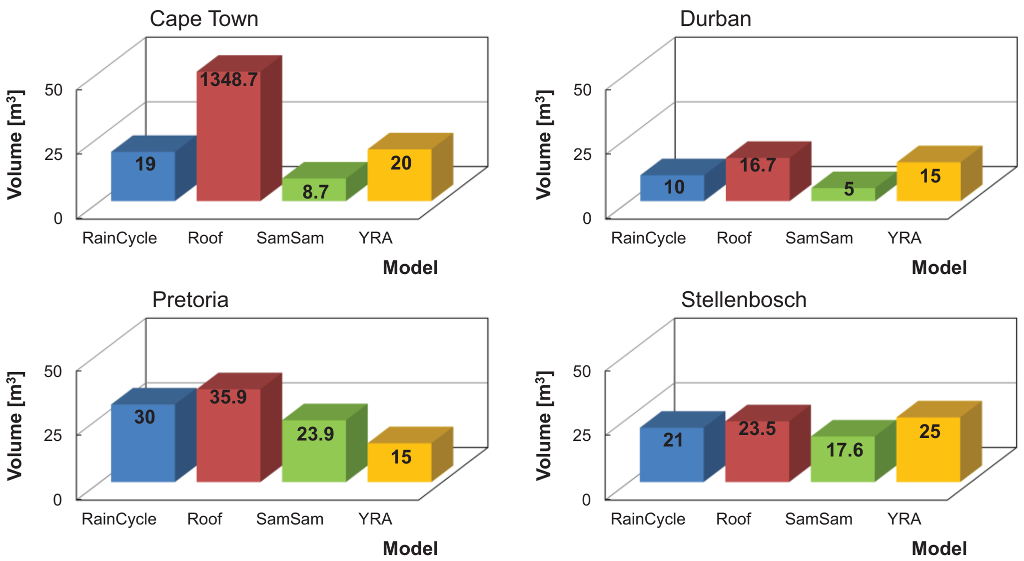

Figure 3-4: Modelling results of the Roof, YRA, SamSam and RainCycle in Cape Town, Durban, Pretoria and Stellenbosch.

3.5 DESIGN AND INSTALLATION OF RAINWATER STORAGE TANK

1. Determine the rainwater storage tank capacity

a. To determine the appropriate rainwater storage tank capacity, two methods are available.

i. RWH models – A number of RWH models have been developed to calculate the optimal storage tank capacity given site-specific details, including rainfall time series, catchment area and material, and rainwater demands (often a constant demand).

ii. Rainwater storage tank sizing tables – Tables of optimal rainwater tank capacities generated for the various rainfall zones of the country.

b. When selecting a tank size, consideration must be given to the unused volume at the bottom and top of the tank (dead storage), which reduces the effective storage volume.

c. Sizing the tank is often done without reference to the RWH model or the rainwater storage tank sizing tables.

i. Consider the unused volume (typically referred to as the 'dead storage') when selecting tank size.

ii. If unknown, assume 10 to 20% of tank capacity will be dead storage; and

iii. the collection losses from pre-storage treatment devices (refer to Chapter 5. Rainwater quality and treatment for details).

2. The type of material used for the rainwater tank are a function of the:

a. placement;

b. storage volume requirements;

c. connected rainwater fixtures and desired quality

3. Determine the location of the rainwater storage tank

a. Ensure the location allows for:

i. proper drainage of rainwater through the conveyance network (refer to Chapter 2 GUIDANCE ON CATCHMENT & CONVEYANCE for details);

ii. proper drainage of make-up water through top-up drainage piping (refer to Chapter 5 DUAL WATER SUPPLY SYSTEMS AND BACKFLOW PREVENTION for details); and

iii. proper drainage of rainwater from the storage tank into an appropriate stormwater discharge location (refer to Chapter 4 OVERFLOW PROVISIONS for details).

b. Identify the area(s) where the tank can be located.

i. Ensure the location is permitted by applicable National/Provincial/ Local codes and regulations and relevant by-laws. Consult relevant authorities for details.

ii. Ensure the location has sufficient space for access above and around the tanks for inspection and maintenance.

iii. Rainwater tanks are generally gravity fed with the rainwater from the collection surface, thus they must be located below the harvesting surface area. If however this is not possible a small intermediate storage tank with a pump can be used to collect the water and then pump it at high volume to the rainwater storage tanks.

iv. Minimise exposure of above ground tanks to direct sunlight by covering them or installing them under a roof or trees. It prevents excessive water temperature fluctuations and extends the life of the tank.

4. Tank access and openings

a. Tanks shall be provided with an access opening.

b. Access openings shall be a minimum of 450 mm to facilitate installation, inspection and maintenance of components in the rainwater storage tank.

c. Access openings shall have drip-proof, non-corrosive covers.

d. Openings that are larger than 100 mm shall have lockable covers.

5. Installation of the rainwater storage tanks

a. Consult the tank manufacturer's installation instructions regarding recommended ground work or structure where the tank will be placed

6. Installation of components in the rainwater storage tank

a. Components installed in the tank might include:

i. A pump or pump intake

ii. water level sensors and/or other types of control equipment; and

iii. electrical wiring for the pump and control equipment

b. Entry into the rainwater storage tank for the purpose of installing components within the tank is not recommended.

c. If entry into the rainwater storage tank is required, it shall be performed in accordance with the South African Safety, Health, Environment and Quality due to the significant dangers involved when working in a confined space.

d. Reduce and/or eliminate the need to perform work inside the storage tank:

i. Wherever possible, install internal components using the access port, without entering the tank; or

ii. Have RWH components installed by tank manufacturer, using personnel trained to work in confined spaces.

e. Install components so that they are accessible for inspection and maintenance, without entry into tank.

f. Components installed in the tank should be suited to a wet environment.

3.6 MAINTENANCE OF THE RAINWATER STORAGE TANK

1. A rainwater storage tank should be inspected at least twice a year for the following:

a. Leaks – leaks can be identified visually by examining the area surrounding the tanks, or through poor system performance or soil moisture (if applicable).

b. Accumulation of debris

i. Sediment may accumulate on the bottom of the tank and, depending on the treatment provided, appear at the point of use. In such cases, the location (height) of the pump intake (if one is installed) may need adjustment. Adjust the location of the pump intake so that it is located 100-150 mm above the bottom of the tank.

ii. If sediment is still detected at the point of use, pre-storage and/or post-storage treatment devices may need to be installed (or cleaned/maintained) to improve rainwater quality (refer to Chapter 6 GUIDANCE ON POST HARVESTING TREATMENT OF RAINWATER for details).

iii. It may be necessary to remove the accumulated sediment at the bottom of the tank. Place a pump capable of handling large debris and/or solids (for example, a suitable sump pump or effluent pump) at the bottom of the tank to pump out the sediment layer. (Note: removal of sediment and/or tank cleaning is not generally recommended on an annual basis, as this can destroy beneficial ‘biofilms’ in the tank. These biofilms may contribute to improved stored rainwater quality.)

c. Fault with pump or other control equipment

d. While inspecting, cleaning or repairing the tank, follow all necessary safety precautions provided by the tank manufacturer.

2. Minimizing sediment transport through RWH systems

Use of roof washers and roof-water filters, minimise the input of particulate matter to the tank. However, these devices will not completely eliminate input of fine particulates or the formation of a sediment layer on the bottom of a tank. Therefore, certain steps need to be taken to prevent this sediment from being transported through the distribution system and possibly reaching the tap.

4 OVERFLOW PROVISIONS

4.1 INTRODUCTION

On occasion, the volume of rainwater collected from the roof catchment will exceed the storage capacity of the rainwater storage tank, causing the tank to overflow. If overflow handling provisions are not in place, excess rainwater will back up rainwater conveyance and top-up drainage piping, until it reaches a point from which it can most easily discharge/overflow. This may be at the downspout-to-conveyance drainage pipe transition, or at less ideal locations like the access opening of the tank, or at the air gap of a top-up system. Overflows at these points may damage the rainwater tank itself or do water damage to a building's exterior or interior. All tanks, whether underground or above ground require some form of overflow. For underground tanks, the overflow is typically piped underground, carrying overflow water to a lower elevation. Above ground tanks can have the overflow above or below ground. Both overflow systems should be designed utilising only gravity to carry the water away from the tank location. The size of an overflow pipe is determined by the size of the inlet pipe. The overflow pipe size must be at least as large as the inlet to ensure maximum flow discharge. The water carried out through the overflow typically will not require any type of filtration unless discharge regulations mandate. Due to the consequences of not properly handling excessive volumes of rainwater, it is important that the RWH system include sufficient overflow provisions. The design of overflow systems involves deciding where excess volumes of rain can be appropriately discharged, and how to convey these overflow volumes from the storage tank to the point of discharge.

4.2 APPLICABLE STANDARDS AND GUIDELINES FOR OVERFLOW DISCHARGE

The applicable standards found in the South African national standards are listed in Table 4-1.

Table 4-1: Standards and codes applicable to catchment and conveyance network

APPLICABLE CODES, STANDARDS AND GUIDELINES	SELECTED PROVISIONS AND DESIGN AND INSTALLATION IMPLICATIONS
SANS 10400-R:1990 The application of the National Building Regulations Part R: Stormwater disposal	RR4 Access to stormwater drains RR5 Connection to stormwater sewer RR6 Use of street surface drainage system
SANS 10400-P:2010 The application of the National Building Regulations Part P: Drainage	4.10 Discharges from swimming baths, swimming pools, fountains or reservoirs 4.14 Sizing of discharge pipes 4.15 Sizing of drains
SANS 10252-2:1993 Water supply and drainage for buildings Part 2: Drainage installations for buildings	6.3.1 Hydraulic load 6.3.2 Sizing of drains

4.3 OVERFLOW DISCHARGE LOCATIONS

The purpose of the overflow system is to handle excessive rainwater flows, directing them away from the rainwater storage tank to a suitable location. Table 4-2 shows some of the pros and cons of overflow discharge locations/methods. Overflow volumes can be directed to grade, a storm sewer, or even an onsite soakaway pit. In each case, rainwater can be conveyed via gravity flow or by pumping. For RWH systems with aboveground tank, two methods apply:

- Discharge to grade via gravity flow – This method applies when rainwater overflows can be directed to grade via gravity flow
- Discharge to storm sewer via gravity flow – This method applies when rainwater overflows can be discharged into a storm sewer via gravity flow, although the tank cannot be directly connected to the sewer.

Table 4-2: Comparison of the advantages and disadvantages associated with overflow discharge locations/methods

OVERFLOW DISCHARGE LOCATIONS/METHODS	ADVANTAGES	DISADVANTAGES
Discharge to grade via gravity flow	• Simplest method to design, install and operate. • Low probability of rainwater backing up the overflow drainage piping.	• If discharge location not prepared properly, may cause soil erosion at site. • May pose a nuisance/safety issue if discharging large volumes from big catchment surfaces. • Overflow drainage piping may freeze if large sections are above the frost penetration depth; ice may build up at the point of discharge if not designed properly.
Discharge to storm sewer via gravity flow	• Ideal for below-ground tanks as storm sewers are also located below grade. • Storm sewers are specifically designed to collect roof runoff and direct it to an appropriate location off-site.	• Design must prevent backflow from storm sewer into rainwater tank. • Stormwater discharges can have negative environmental impacts on receiving water bodies.

4.3.1 Overflow to bioretention

Bioretention system store stormwater runoff and pass it through a filter bed of engineered soil media composed of sand, soil, and organic matter. Filtered runoff may be collected and returned to the conveyance system or allowed to infiltrate into the soil. Design variants include: traditional bioretention, streetscape bioretention, engineered tree pits, stormwater planters and residential rain gardens. Bioretention systems are typically not designed to provide stormwater detention of larger storms (e.g. 2-year, 15-year), but they may be in some circumstances. Bioretention practices shall generally be combined with a separate facility to provide those controls.

4.3.2 Overflow to infiltration practices

Infiltration practices capture and temporarily store the design storm volume before allowing it to infiltrate into the soil over a two-day period. Design variants include:

- Infiltration trench;
- Infiltration basin.

Infiltration practices use temporary surface or underground storage to allow incoming stormwater runoff to exfiltrate into underlying soils. Runoff first passes through multiple pre-treatment mechanisms to trap sediment and organic matter before it reaches the practice. As the stormwater penetrates the underlying soil, chemical and physical adsorption processes remove pollutants. Infiltration practices are suitable for use in residential and other urban areas where field measured soil infiltration rates are sufficient. To prevent possible groundwater contamination, infiltration must not be utilised at sites designated as stormwater hotspots.

4.3.3 Overflow to grass channels or dry swales

4.3.3.1 *Grass channels*

Grass channels can provide a modest amount of runoff filtering and volume attenuation within the stormwater conveyance system resulting in the delivery of less runoff and pollutants than a traditional system of curb and gutter, storm drain inlets, and pipes. The performance of grass channels will vary depending on the underlying soil permeability. Grass channels, however, are not capable of providing the same stormwater functions as dry swales as they lack the storage volume associated with the engineered soil media. Their retention performance can be boosted when compost amendments are added to the bottom of the swale. Grass channels are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system, where development density, topography, and soils permit.

4.3.3.2 *Dry swales*

Dry swales, also known as bioswales, are essentially bioretention cells that are shallower, configured as linear channels, and covered with turf or other surface material (other than mulch and ornamental plants). The dry swale is a soil filter system that temporarily stores and then filters the desired design storm volume. Dry swales rely on a premixed soil media filter below the channel that is similar to that used for bioretention. If soils are extremely permeable, runoff infiltrates into underlying soils. In most cases, however, the runoff treated by the soil media flows into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale, beneath the filter media. Dry swales may appear as simple grass channels with the same shape and turf cover, while others may have more elaborate landscaping. Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees.

4.4 SELECTING THE APPROPRIATE OVERFLOW DISCHARGE LOCATION

Selection of an overflow discharge location must not only include a comparison of the advantages and disadvantages discussed above, but also a number of other factors, which include:

- stormwater management requirements – In some cases, overflow from the rainwater tank may need to be handled in accordance with special stormwater management requirements. These requirements may be imposed by a municipality or various conservation authorities for buildings located in an environmentally sensitive area, or in an area where the existing storm sewer infrastructure does not have sufficient capacity to accept additional stormwater flows, or for a variety of other reasons.
- applicable provincial/national regulations and municipal bylaws – Even if there are no special stormwater management requirements, provincial regulations and municipal bylaws may still restrict the locations where rainwater overflows can be discharged.
- Tank location – The location of the storage tank can also have an impact on the overflow discharge location selected. Overflow handling is simplest with above ground tanks, since overflows can typically be discharged to grade.
- site conditions – Site conditions, such as topography, space availability and accessibility, and the existence of other buried services, also affect the selection of an overflow discharge location.

4.5 RAINWATER QUALITY

To prevent contaminants from entering into the tank, the overflow drainage piping design should be similar to the conveyance network (that is, it should be structurally sound with no points of entry other than those required for water flow). When connecting to the storm sewer, either an air break, or a special type of check valve, called a “backwater valve” must be installed on the overflow drainage piping. During intense rainfall events, rainwater can potentially back up in the storm sewer, causing contaminated water to back up into the rainwater storage tank. Backwater valves act like backflow preventers, preventing the water from the storm sewer from entering the rainwater storage tank.

4.6 DESIGN AND INSTALLATION OF OVERFLOW

1. Determine the overflow discharge location and method.

a. Overflow discharge locations include: grade, storm sewer or soakaway pit.

b. Overflow discharge methods include: gravity flow or pump-assisted flow.

c. Overflow by pump-assisted flow is not recommended.

d. Consult the applicable National/Provincial/ Local codes and regulations, municipal by-laws and local authorities regarding the permitted overflow discharge locations.

e. Evaluate the feasibility of the overflow discharge locations.

i. Overflow to grade

- The overflow discharge location must be at a lower elevation than the flood level rim of the tank for gravity flow to be feasible.

ii. Overflow to storm sewer

- A storm sewer connection must be present at the site.
- The overflow discharge location must be at a lower elevation than the flood level rim of the tank for gravity flow to be feasible.

iii. Overflow to soakaway pit

- The percolation rate of site soil must be sufficient to permit infiltration of rainwater overflows discharged into the soakaway pit

2. Plan the layout of the overflow system.

a. Plan route of overflow drainage piping from the tank to the overflow discharge location

b. Contacting the municipality and service providers to ensure that there are no buried service lines (gas, electricity, water, stormwater, wastewater, phone or cable lines) in the area where digging will take place to accommodate buried overflow drainage piping.

3. Overflow pipes

a. Overflow drainage pipes

i. Pipe material

- Pipe selected must be approved by applicable National/Provincial/ Local codes and industry standards.

ii. Pipe size and slope

- Overflow drainage piping shall be sized to ensure that the capacity of overflow drainage pipes is no less than the capacity of the rainwater conveyance drainage pipes.
- Ensure a minimum slope of 0.5-2% (the greater the slope the better) is maintained throughout the pipe length.

iii. Tank connection

- Overflow drainage piping shall exit the tank at a height no lower than the rainwater conveyance drainage piping, or, ideally, at a height 50 mm [2 in.] below the bottom of the conveyance drainage pipes entering the tank.

iv. Consult applicable provincial/local codes and regulations pertaining to the installation of drainage piping.

4. **Discharging overflow to grade**

   a. Overflow must be discharged at a location where rainwater will not pond or collect around building foundations.

   b. Erosion prevention measures should be taken.

   c. A screen should be installed where the pipe terminates to prevent the entry of birds, rodents and insects.

5. **Discharging overflow to storm sewer**

   a. Overflow drainage piping cannot be directly connected to a storm sewer, unless approved by local authorities.

   b. A direct connection may be permitted if a backwater valve is installed on the overflow drainage pipe. Consult local authorities for approval.

   c. An indirect connection can be made by:

      i. overflowing to an interceptor tank, which then overflows into the storm sewer;

      ii. overflowing to a soakaway pit, which then overflows into the storm sewer;

      iii. overland flow to a sewer grate; or

      iv. using an air gap in the case of above-ground tanks.

6. **Discharging overflows to a soakaway pit**

   a. Consult applicable provincial/district and local guidelines regarding the design and installation of soakaway pits.

   b. If there is limited space for a soakaway pit or if the soil has low permeability, it is recommended that the soakaway pit have its own overflow, discharging overflows to grade or into a storm sewer.

7. **Incorporating an RWH system as part of a stormwater management system**

   a. Consult relevant authorities regarding how to incorporate an RWH system into other stormwater management systems.

4.7 MAINTENANCE OF OVERFLOW

1. **If the overflow drainage piping discharges above grade, it should be inspected annually.**

   a. The point at which the overflow discharges should be examined for signs of erosion. A splash pad or several small rocks can be placed at the discharge point to protect the area from future damage.

b. The coarse screen at the end of the overflow drainage pipe should be inspected for dirt and debris and, if necessary, cleaned and/or replaced.

c. If removing the coarse screen for cleaning or replacement, the inside of the overflow drainage pipe should be inspected for objects or debris that may cause clogging.

2. **If the overflow drainage piping discharges below grade, inspection and/or repair is necessary only when signs of a blocked or poorly performing overflow-handling system are observed, such as:**

   a. water damage to the rainwater tank, tank lid or access hatch, or components located inside the tank above the maximum water level;

   b. water leaking from the tank lid or access hatch;

   c. water backing up rainwater inlet lines and top-up drainage piping; or

   d. water leaking from downspout-to-conveyance drainage pipe transitions, or from top-up system air gap.

3. **If any of the above signs are observed, the components of the overflow system should be inspected and repaired.**

   a. Inspect coarse screens located on the overflow drainage pipe for debris that would impede water flow, and clean, repair or replace the coarse screen as necessary.

   b. Inspect all overflow drainage pipes using a pipe scope for signs of blockages or pipe damage. All debris/blockages must be removed from the overflow drainage piping, and all damaged sections of pipe must be replaced.

   c. If the overflow drainage piping discharges into a soakaway pit, the pit may be clogged with dirt and debris and may not be providing sufficient infiltration capacity. It may be necessary to repair and/or expand the pit to accommodate overflow volumes.

   d. If there are no obvious problems with the overflow system, it may be necessary to simulate an overflow event (or observe one during a rainfall event). Monitor the system visually or by pipe scope to determine what is causing the problem.

4. **While inspecting, cleaning or repairing components of the overflow system, follow all necessary safety precautions as per the South African Safety, Health, Environment and Quality, if entry into the rainwater storage tank is required.**

5 DUAL WATER SUPPLY SYSTEMS AND BACKFLOW PREVENTION

5.1 INTRODUCTION

The option of “dual-supply” systems is an option worth exploring in situations where there is a need to augment municipal/public supply. In such systems, the public supply can be supplemented with other sources such as rainwater, with the appropriate backflow prevention. In four of the five South African rainfall regions (winter, early summer, mid-summer, late summer and very late summer regions), rainfall occurs seasonally, requiring a large storage capacity to hold enough water collected during rain events to last through the dry spells. Therefore, harvested rainwater can be a supplemental water source in urban and peri-urban areas where customers are already connected to the public water supply infrastructure. There are two general dual systems options available:

- Top-up – The rainwater storage tank can be partially filled, either manually or automatically, with make-up supplies of water from municipal (potable) or private water sources
- Bypass – The rainwater supply from the pressure system can be shut off, either manually or automatically, and water from municipal or private sources can be directed through the rainwater pressure piping. This option will not be further explored, because a non-potable water system should not be connected to a potable water system.

A RWH can be topped-up manually or automatically, each option has advantages and disadvantages discussed in Table 5-1.

Table 5-1: Advantages and disadvantages associated with top-up methods

TOP-UP METHOD	ADVANTAGES	DISADVANTAGES
Manual	• Simplest method to design and install due to reduced control equipment requirements • Lowest cost alternative	• May result in service interruptions (for example, no water for flushing toilets) if tank not topped up prior to going dry • Requires homeowner to monitor volume of stored rainwater in tank and top up pre-emptively if low
Automatic	• Reduces the number of service interruptions by automatically filling tank before it runs dry • Make-up system operates without the need for monitoring or intervention by the homeowner	• Improper design or installation of control equipment may cause insufficient or excessive top-up volumes to be dispensed by the make-up system • Service interruption during power failure

5.2 APPLICABLE STANDARDS AND GUIDELINES FOR DUAL SYSTEMS AND BACKFLOW PREVENTER

The applicable standards found in the South African national standards are listed in Table 5-2.

Table 5-2: Standards and codes applicable to dual systems and backflow preventers

APPLICABLE CODES, STANDARDS AND GUIDELINES	SELECTED PROVISIONS AND DESIGN AND INSTALLATION IMPLICATIONS
SANS 10252-1:2012 Water supply and drainage for buildings Part 1: Water supply installations for buildings.	5.4.1 Backflow preventers 5.4.12 Gate valves, ball valves and butterfly valves 6.3 Backflow prevention 7.2 Design pressures and flows 7.4.2 Connections 7.4.3 Prevention of backflow 8.4.2 Backflow prevention devices

5.3 CONTROL EQUIPMENT

5.3.1 Types of control equipment

Control equipment used in make-up rainwater harvesting systems consist of water level sensor and valves (shut-off and solenoid (Table 5-3). The level sensor is placed inside the tank to sense water level. Basic sensors only indicate the water level while, the more sophisticated systems can control (turn on or off) warning lights, solenoid valves and/or pumps, based on water level

Table 5-3: Control equipment for make-up water systems

CONTROL EQUIPMENT	DESCRIPTION	DEVICES/OPTIONS AVAILABLE
Water level sensor	• A device inside the tank is used to sense water level • Can control (turn on or off) warning lights, solenoid valves and/or pumps, based on water level	• Float switch • Ultrasonic level sensor • Liquid level switch (Float switch is typically used for residential applications).
Shut-off valve	• A device that is manually opened (or closed) to permit (or prevent) the flow of water • Integrated into the RWH pressure system to manage waterflow and isolate components of the makeup system (for example, solenoid valves and backflow preventers)	• Types: ball valves, gate valves Shut-off valves selected must be approved for handling water under pressure.
Solenoid valve (automated shutoff valve)	• A valve that activates (opens or closes) • automatically when turned on • Connected to water level sensor to activate make-up water system	• Come in a variety of configurations The solenoid valves selected must be approved for handling water under pressure

Shut-off valve – A valve manually opened (or closed) to allow (or prevent) the flow of water. Integrated into the RWH pressure system to manage waterflow and isolate components of the makeup system (for example, solenoid valves and backflow preventers)

Solenoid valve – Automated shut-off valve that activates (opens or closes) automatically when turned on. When connected to water level sensor, it provides seamless mains back-up in the event of no rainwater or electrical interruptions, for consumer convenience and comfort.

When selecting control equipment for the make-up system, the issues listed in Table 5-3 must be considered.

5.3.2 Sizing control equipment

All control equipment must be appropriately sized. Of particular concern for top-up-based systems is the sizing of the top-up drainage piping. This pipe must be sized according to gravity flow, not pressurized flow, to prevent water backing up the pipe. In addition, all valves and backflow preventers must also be sized to be the same diameter as the pipes to which they are connected.

5.3.3 Power requirements

Most control components of a dual-system require an electrical supply to operate. When designing the electrical system for the RWH system, the following must be taken into consideration:

- The electricity supply source: National grid, solar power, dual source (grid and solar power);
- the operating voltage of the pump (generally 220 V), solenoid valve and other relevant components;
- the power requirements of the pump (in watts), solenoid valve and other relevant components;
- power rating for float switches and electrical wiring; and
- all equipment must be certified and installed in accordance with the relevant South African electrical Code.

Many water level sensors (such as float switches) must be rated to handle the power of the device they are controlling. For instance, if a float switch controls a solenoid valve or a pump, it must be rated to handle the power needed to operate the valve or the pump.

Float switches and solenoid valves act like typical light switches; however, they differ in that these actions can take place whether power is connected or not. To differentiate between these two operating conditions, the terms “normally open” (N/O) and “normally closed” (N/C) are used.

5.4 CROSS-CONNECTIONS AND BACKFLOW PREVENTION

Whenever rainwater and mains water are interconnected, the mains water must be isolated from the rainwater system by a suitable backflow prevention device or a visible air gap. To ensure that backflow does not take place, backflow prevention devices (also called “backflow preventers”) are required to be installed in conjunction with any domestic rainwater harvesting system.

5.4.1 Cross-connections

Traditionally, a cross Connection is any actual or physical connection between a potable water supply and any source of non-potable liquid. When talking about rainwater harvesting, a cross-connection is defined as any actual or potential connection between municipal water supply and harvested rainwater. Risks of cross connection are traditionally minimised through:

- Sealed and pressurised pipe systems to prevent non-drinking water from entering the water supply.
- Backflow prevention devices fitted to high-risk newly developed or redeveloped properties. These devices prevent the reverse flow of water from a potentially contaminated source into the drinking water supply.
- Monitoring compliance with plumbing regulations, designed to prevent and minimise backflow contamination.

5.4.2 Backflow prevention

A backflow event occurs when there is a physical connection between the potable water system and the rainwater distribution system. When such a connection is present, rainwater may unintentionally be drawn into the potable water supply of the house or drawn into the entire water supply of a municipality causing contamination of the potable water system. Backflow prevention measures should be applied on two distinct levels:

- Zone protection – Backflow prevention device is installed at the point of an actual cross-connection to protect residents of the building from backflow.
- Premise isolation – Backflow prevention device is installed on the potable water piping entering a building in case zone protection fails or in case of a future unintentional or clandestine cross-connection. Serves to protect users of the municipal system from backflow.

In addition to above listed backflow prevention measures, codes and regulations require the separation of potable and non-potable pipes and the labelling of non-potable plumbing pipes.

5.4.2.1 *Air gap*

An air gap is one of the simplest methods of preventing backflow and involves a physical separation between two sections of pipe that is open to the atmosphere. This physical break prevents the backflow of water since, even if rainwater backed up from the tank to the gap, it would spill from the gap and not come into contact with the potable water supply. The air gap must be located higher than the overflow drainage piping from the tank and the overflow drainage piping must remain free of blockage so that excess rainwater flows to the overflow system and does not back up and overflow at the air gap. It also acts as a visual inspection point to detect trickle top-up system failure.

5.4.2.2 *Check valve*

A check valve (clack valve, non-return valve or one-way valve) are mechanical valves that permits the flow in only one direction, preventing process flow from reversing. Water flows in the desired direction and opens the valve, while backflow forces the valve closed. The mechanics of check valve operation are not complicated.

5.4.2.3 *Atmospheric Vacuum Breaker*

In an Atmospheric Vacuum Breaker, a poppet is pushed to the upper seat when water flows through the assembly: the air inlet valve is closed. The poppet is pulled to the lower seat when the flow stops or when there is a back-siphonage condition: the air inlet valve opens.

5.4.2.4 *Spill-Resistant Vacuum Breaker*

Spill Resistant Vacuum Breaker is designed to prevent contamination of the potable water supply due to back-siphonage. It consists of one loaded check valve and one loaded air inlet valve.

5.4.2.5 *Double Check Valve*

A double check valve or double check assembly is a backflow prevention device designed to protect water supplies from contamination. It consists of two check valves assembled in series. This employs two operating principles: firstly, one check valve will still act, even if the other is jammed wide open. Secondly the closure of one valve reduces the pressure differential across the other, allowing a more reliable seal and avoiding even minor leakage.

5.4.2.6 *Reduced Pressure Zone device*

A reduced pressure zone device is a type of backflow prevention device used to protect water supplies from contamination. The device is similar to a Double Check Valve, with an additional relief valve between the two loaded check valves. If one or both check valves are fouled and cannot prevent backflow, the contaminant or pollutant exits through the vent of the relief valve. A Reduced Pressure Zone Assembly provides protection against back siphonage and backpressure and can be used under continuous operation.

5.5 DESIGN AND INSTALLATION OF DUAL SYSTEM AND BACK FLOW PREVENTION

1. Select the type of dual system

a. Automatic top-up system

b. Manual top-up system

c. No make-up system

2. Plan the layout of the top-up system:

a. A top-up system is generally composed of the following:

i. water level sensors located in the rainwater storage tank;

ii. a solenoid valve located on the potable water supply pipe;

iii. an air gap;

iv. top-up drainage piping conveying make-up water to the rainwater storage tank; and

v. electrical conduits containing wiring from water level sensors and pumps.

b. Determine the location of the solenoid valve and air gap in accordance with the guidelines provided below.

c. Plan route of top-up drainage piping from the air gap to the tank

d. Plan route of electrical conduits from the location of the solenoid valve and power supply to the tank.

e. Contact the municipality and service providers to ensure that there are no buried service lines (gas, electricity, water, stormwater, wastewater, phone or cable lines) in the area where digging will take place to accommodate the buried top-up drainage piping and/or the electrical conduit.

3. Water level sensors

a. Select the appropriate water level sensors for the RWH system (float switch, ultrasonic level sensor or other).

b. Float switches

i. Select the type of float switch.

- Solenoid valve actuation is typically provided by an N/C float switch, for top-up systems.
- Pump dry run protection is typically provided by an N/O float switch.

ii. Electrical requirements

- The voltage rating of the float switch must match that of the device it controls (120 V or 240 V).
- The power rating (watts [W] or horsepower [HP]) of the float switch must be sufficient to carry the total load of the device it controls or, alternatively, float switches may be low voltage and used to activate the pump through relays in a control panel.
- Spliced electrical wiring must be watertight and its electrical rating is determined by the loads handled by the float switch and the total length of wiring.
- All electrical connections for float switches must be made by a licensed electrician in accordance with the manufacturer's instructions.

c. Float switch installation

i. The float switch shall be tethered to a rigid freestanding object, such as a vertical section of pipe or the pump, that:

- permits the float switch to rise and fall without any obstructions; and
- is located in an area where it is easily accessible and can be withdrawn from the tank without requiring entry into the tank.

ii. To set the operating parameters of the float switch:

- to maximize rainwater collection, the tether length should be as short as possible: 75 mm [3 in.]. Refer to the manufacturer’ s installation instructions for details;
- to maximize rainwater collection, the tether point should be as low as possible (so that the float is 50 mm [2 in.] above the pump intake when in the down position); and
- If using a dual float switch configuration, the float switch controlling the solenoid valve should be located a minimum of 75 mm [3 in.] above the float switch controlling the pump.

d. Other water level sensors shall be selected and installed in accordance with applicable National/Provincial/ Local codes and regulations, and all electrical connections must be made by a licensed electrician in accordance with the manufacturer’s instructions.

4. Solenoid valves and shut-off valves

a. a. Select the type and size of solenoid valve and/or shut-off valve.

i. All valves must be suitable for potable water and pressure applications.

ii. Valve openings must be the same size as the piping where the valves are located.

iii. Top-up systems typically use an N/C solenoid valve.

iv. Solenoid valves with a ‘slow close’ or ‘soft close’ are recommended.

b. Electrical requirements

i. Solenoid valves must be wired into a power supply in conjunction with a water level sensor.

c. Solenoid valve and shut-off valve installation

i. Solenoid valves and shut-off valves used as part of a top-up system shall be installed on the potable water supply pipe upstream of the air gap.

ii. Solenoid valves must be installed by a licensed plumber and electrician in accordance with the manufacturer’s instructions.

d. Water hammer protection

i. If a ‘slow close’ or ‘soft close’ solenoid valve is not used, a water hammer arrester shall be installed on the potable water supply piping upstream of the solenoid valve, in accordance with applicable National/Provincial/ Local codes and regulations.

5. Air gap

a. An air gap is required as part of a top-up system for backflow prevention (zone protection).

b. Air gaps shall be designed and installed in accordance with applicable National/Provincial/ Local codes and regulations. For guidance purposes only, the following guidelines are provided.

i. The gap must be unobstructed – mechanical supports, fixing the potable water supply pipe to the top-up drainage pipe or other components located at or between the potable water supply pipe and the top-up drainage pipe, are not permitted.

ii. The air gap must be located in an area where it can be observed and inspected.

iii. The air gap must be installed at a height above the flood level rim (overflow) of the rainwater storage tank. If not, there is a risk that rainwater will back up in the top-up drainage pipe and overflow from the air gap.

iv. The air gap height must be at least 25 mm [1 in.] or twice the diameter of the water supply pipe.

c. Splash and water damage prevention

i. To prevent make-up water from splashing at the air gap, install the following:

- flow restrictor, installed upstream of the solenoid valve; and/or
- aerator, installed where the potable water supply pipe terminates; and/or
- extended length of vertical pipe with the end of the pipe cut at an angle no less than 45° (to produce laminar flow), installed where the potable water supply pipe terminates above the air gap.

ii. To prevent water damage to rooms where the air gap is located:

- locate air gaps near a floor drain;
- install an overflow on the top-up drainage pipe, located downstream of the air gap, to direct excess make-up water to the sanitary sewer (where permitted by local authorities); and
- appropriately size and slope the top-up of the drainage piping.

d. Make-up water flow rate

i. To ensure RWH system operation during top-up, the following measures are recommended:

- the flow rate of make-up water should be equivalent to that of the maximum flow rate of the rainwater supply pump; or
- the water level sensor(s) should be configured to provide a sufficient reserve volume in the rainwater storage tank (where said reserve volume shall be equivalent to that of the average daily rainwater demand for the RWH system).

5.6 MAINTENANCE OF DUAL SYSTEM AND BACK FLOW PREVENTION

1. Following the installation of the RWH system, if the make-up system does not operate, or if it operates when it should not (for example, tops-up the tank when there is a sufficient quantity of rainwater in the tank):

a. ensure that the proper control equipment was selected and arranged in accordance

b. with the Design and installation guidelines provided;

c. visually examine the RWH system

2. Backflow preventer testing and maintenance according to manufacturer's instructions

3. If the make-up system is operating properly, it is recommended that it still be inspected once every six months to:

a. verify that the float switch wires are not tangled with other float switches, the pump or other objects in the tank;

b. remove any dirt and/or debris that have accumulated on the float switches, as necessary; and

c. observe the make-up system while operating to ensure that water is not overflowing from the top-up drainage pipe at the air gap or discharging from the backflow preventers. If any water is leaking or discharging, refer to the troubleshooting instructions above.

4. While inspecting, cleaning or repairing the make-up system, follow all necessary safety precautions, such as disconnecting the power supply, when necessary.

6 GUIDANCE ON POST HARVESTING TREATMENT OF RAINWATER

6.1 INTRODUCTION

Appropriate design and constant monitoring of the rainwater harvesting system will ensure that it performs as expected and therefore, consistently producing rainwater of an acceptable quality. Table 6-1 provides a summary of the different methods that should either be incorporated into the design or used throughout the rainwater harvesting system to ensure that the level of contamination is kept to a minimum or prevented altogether. The selection of appropriate treatment options requires prior knowledge of the quality of the water, as well as how different treatment options work and their effectiveness against different contaminants.

Table 6-1: Treatment and contaminant removal methods during rainwater harvesting (Van Giesen and Carpenter, 2009)

METHOD	LOCATION	RESULT
	SCREENING	
Leaf Screens and Strainers	Gutters and downspouts	Prevents leaves and other debris from entering the tank
	SETTLING	
Sedimentation	Within tank	Settles out particulate matter
	FILTERING	
Roof washer	Before tank	Eliminates suspended material
In-line/multi-cartridge	After pump	Sieves sediment
Activated charcoal	After sediment filter	Removes chlorine, reduces odour
First flush Diverter	Before tank	Reduces suspended material
Sand Filtration	After pump	Removes particulates
	MICROBIOLOGICAL TREATMENT/DISINFECTION	
Boiling/distilling	Before use	Kills microorganisms
Chemical treatments (Chlorine)	Within tank or at pump (liquid, tablet, or granular) Before activated charcoal filter	Kills microorganisms
Ultraviolet Light	After activated charcoal filter Before tap	Kills microorganisms
Ozonation	After activated charcoal filter Before tap	Kills microorganisms

It is worth mentioning that before addressing methods of treating water at the household level, it is important to emphasise the need to prevent and /or reduce source contamination. For domestic rainwater harvesting systems, this amounts to preventing contamination from the catchment area and the conveying system from entering the tank. For domestic rainwater harvesting systems, there are equally diverse options for home water treatment (HWT) technologies to remove different types of contaminants to different levels. Thus, understanding the harvested rainwater quality and potential contaminants will influence the selection of appropriate household water treatment options. The main focus of household water treatments is to remove biological pathogens; because they are capable of causing diseases more rapidly than chemical contaminants. Nevertheless, a number of HWT options can also remove chemicals and improve the physical quality of drinking water.

Furthermore, health gains can only be achieved if HWT systems are properly adopted and sustained. Treatment of harvested rainwater will also depend on the intended use of such water, thus harvested rainwater for non-potable uses such as gardening and vehicle washing will require less treatment compared to the one used for potable purposes such as drinking and dish washing. Household water treatments have proved to be effective on different types of water including harvested rainwater. Therefore, by encouraging the use of HWT options, communities take responsibility of their own water security. Furthermore, if communities are empowered with the knowledge and tools to treat water at home, many microbial diseases will be eliminated. Low cost, safety and efficiency in the removal of contaminants are the desirable qualities of home-based water treatment devices. In South Africa, the most commonly used methods for treatment of household drinking water are boiling, cloth filtration and chlorination (Anderson *et al.*, 2011).

6.2 POST-STORAGE TREATMENT TECHNOLOGIES

The fundamental difference between centralised water treatment works and household water treatment (HWT) is not the underlying mechanism for treating the water, but the point where such treatment is implemented. While the former is a combination of treatment methods, the latter (HWT) tends to rely heavily on a single approach. These approaches comprise: sedimentation, filtration methods and disinfection methods. These methods are discussed in the preceding sections. Post-storage treatment of the water is critical for both the health of the users and maintenance of the system. The level of treatment will depend on the intended use of the water. Water used for irrigation does not require the same level of treatment as water used for potable indoor purposes. To maximise effectiveness, a multi-barrier approach where more than one method of treatment is used is recommended.

6.2.1 Sedimentation

Sedimentation is recommended as a simple treatment of water prior to application of other purification treatments such as filtration and disinfection methods. It is a physical treatment process used to reduce the turbidity of the water. Small particulate suspended matters (sand, silt and clay) and some biological contaminants are removed from water under the influence of gravity. The longer the water is allowed to sediment, the more the suspended solids and pathogens will settle to the bottom of the container. The addition of special chemicals or some natural coagulants, such as indigenous plants, can accelerate sedimentation. Three common chemicals used are aluminium sulphate (alum), polyaluminium chloride (PAC or liquid alum), alum potash and iron salts (ferric sulphate or ferric chloride). Some indigenous plants are also traditionally used in some countries, depending on the local availability, to help with sedimentation. In countries like Malawi, Sudan, Egypt and Malaysia, the application of *Moringa oleifera* seeds extract in water coagulation and softening has received a lot of attention (NRC, 2006). Another natural plant coagulant known to clarify turbid surface water is *strychnos potatorum*. This type of coagulant is reported to be used in countries like Southern and central parts of India, Sri Lanka and Burma (Balachandra, 2013).

Much of the suspended material can be removed by simply allowing the water to stand and settle for some time. This retention time (from one hour up to two days, the longer the better) is required to settle particles to the bottom. Storing water for at least one day will also promote the natural die-off of some bacteria. Simple sedimentation is often effective in reducing water turbidity, but it is not consistently effective in reducing microbial contamination. However, most viruses, bacteria and fine clay particles are too small to be settled out by simple gravity sedimentation. However, attachment of these smaller particles (bacteria and viruses) to suspended particles would result in the formation of flocs that can then settle to the bottom of the tank due to their increased mass (Amagloh and Benang, 2009). The addition of coagulants reduces the time required to settle out suspended solids and is very effective in removing fine particles.

6.2.2 Filtration methods

Filtration is commonly used to reduce turbidity and remove pathogens. It is a physical process that involves passing water through filter media. There are several types of filters; some are designed to grow a biological layer that kills or inactivates pathogens and improves the removal efficiency (Elliot *et al.*, 2008). Various types of filters are used by households around the world, including: biosand filters, ceramic pot filters, ceramic candle filters, membrane filters. Figure 6-1 is a represents the filtration processes that are typically employed for the removal of different contaminants. Particulate filtration methods, e.g. sand have the largest pore size and typically reject large particles, while reverse osmosis membranes have the smallest and reject between 95-98% of all contaminants in the ionic range (Radcliff, 2004).

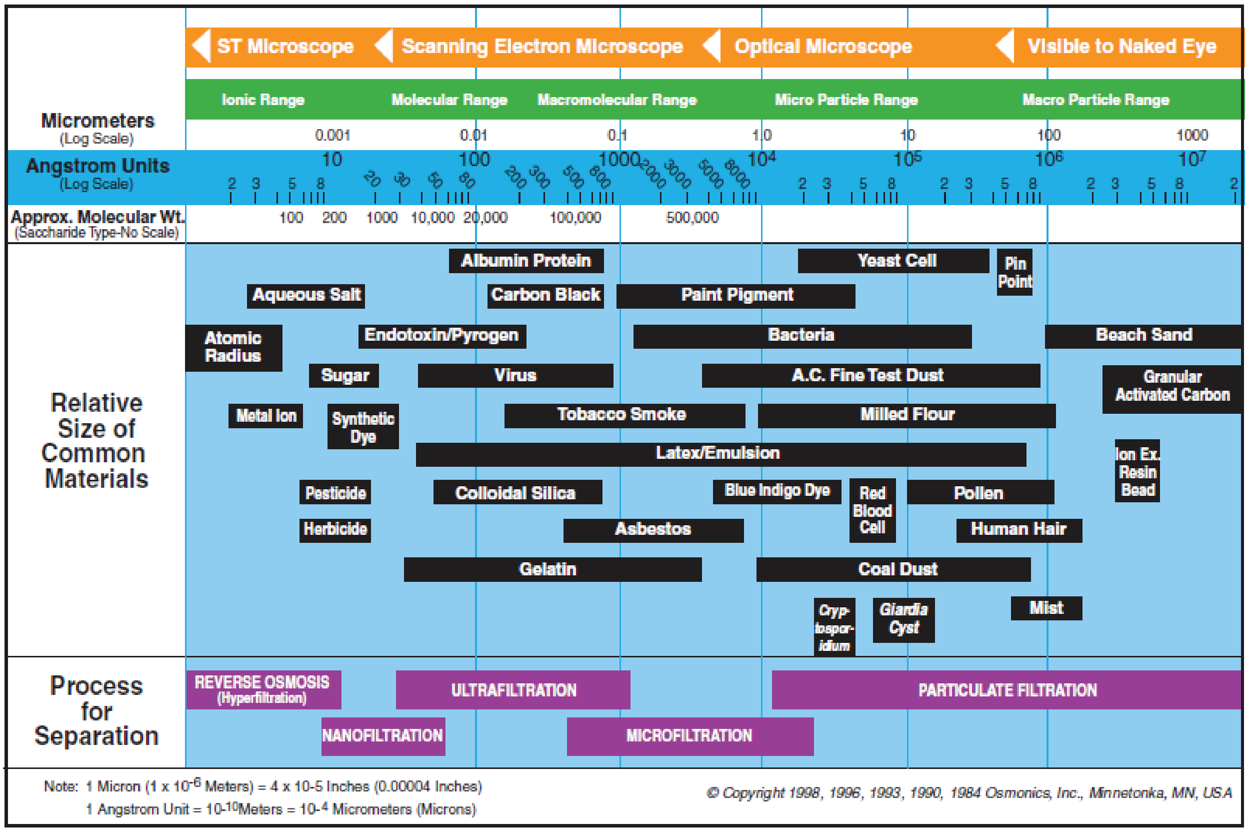

Figure 6-1: Filtration spectrum of reverse osmosis, nanofiltration, ultrafiltration, microfiltration and particulate filtration. Source: Radcliff (2004)

6.2.2.1 *Sand filters*

Studies have reported that biosand filters (BSF,

Figure 6-2) are capable of removing 81-100% bacteria and 99.98-100% protozoa from harvested rainwater (Palmateer *et al.*, 1999; Fewster *et al.*, 2004). Sobsey *et al.* (2008) reported that treatment of harvested rainwater with BSF can reduce bacteria, viruses and protozoa by up to 4-log reduction. Lee (2001) further reported that turbidity can be reduced by 84% with BSF while Buzuinis (1995) reported a 96% reduction in turbidity. Furthermore, a study done by Rahmat *et al.* (2008) reported on the efficiency of sand filters for reduction of physico-chemical properties of harvested rainwater. They found that turbidity was reduced by 76%, suspended solids in harvested rainwater by 54% and pH by 36%. Other studies have also reported on the removal of microorganisms and turbidity by iron oxide coated sand filters (Chen *et al.*, 1998; Scott *et al.*, 2002). Ahammed and Meera (2010) used a sand filter medium coated with iron hydroxide and manganese oxide to remove bacteria and heavy metals from harvested rainwater. Results showed that the coated filter medium was able to remove 99% of coliforms and 96% lead. Biosand filters have however, been reported to have a limited virus removal efficiency (Lantagne *et al.*, 2007).

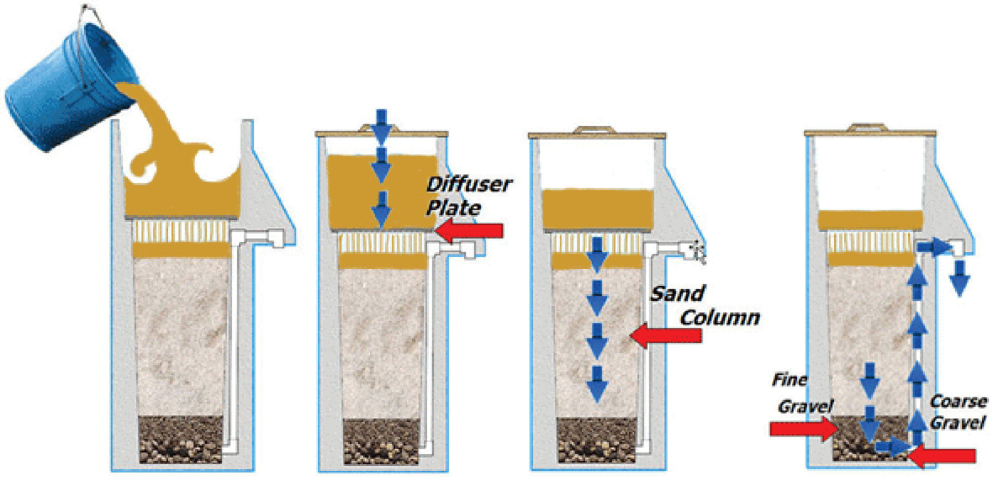

Figure 6-2: Example of a biosand filter

6.2.2.2 *Ceramic filters*

Ceramic water filtration systems generally consist of a porous ceramic membrane, a plastic or ceramic receptacle, and a plastic tap (CDC, 2008). Water is poured into the upper portion of the receptacle, or directly into the membrane, where gravity pulls it through the pores in the ceramic membrane and into the lower portion of the receptacle. Water is safely stored in the receptacle until it is accessed through the tap. There are two main types of ceramic filters, the candle filter and the pot filter which differ in the shape and assemblage of the ceramic membrane.

Ceramic pot filters – The pot filter system is simpler, and consists of a single concave membrane, which sits inside the rim of the receptacle (Figure 6-3). Several field trials carried out in different countries have found ceramic pot filters to be effective in reducing diarrhoea. A study carried out in three regions of Guatemala reported that 91% of the filtered water tested was free of faecal coliforms (AFA, 1995). In Nicaragua, water quality analysis was performed on 24 filters in seven communities. Of 15 homes that had *E. coli* in their water, eight (53%) tested negative for *E. coli* after filtration (Lantagne, 2001). In Cambodia, water quality tests were carried out after 1,000 ceramic filter pots were distributed (Roberts, 2004) and results showed that after up to one year in use, 99% of the filters produced water falling into a ‘low-risk’ range of fewer than 10 *E. coli* per 100 mℓ.

Ceramic candle filters – Candle filter systems consist of an upper receptacle that sits above and is separated from the storage receptacle (Figure 6-4). Candle elements, which are cylindrical, hollow ceramic membranes, are attached to the barrier that divides the two receptacles. The only way in which water can flow into the lower receptacle is if it enters the candle elements, which is where filtration takes place. In a randomized, controlled trial conducted among 80 households, in one community during the six-month design life of the ceramic filter elements, faecal water contamination was consistently lower among intervention households than control households. Geometric mean thermotolerant coliform (TTC) was 2.9/100 mℓ vs 32.9/100 mℓ, $p<0.0001$. Overall, 70.6% of samples from the intervention households met WHO guidelines for zero TTC/100 mℓ compared to 31.8% for control households (Clasen and Boisson, 2006).

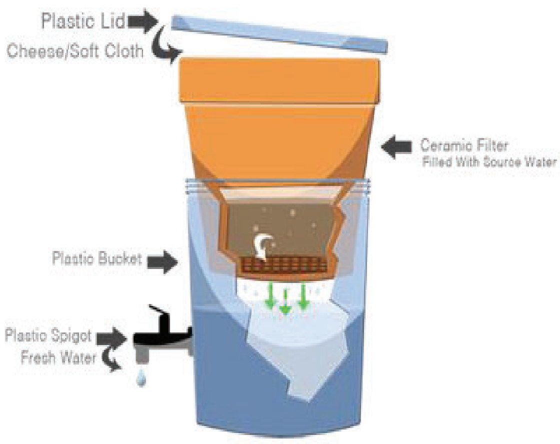

Figure 6-3: Example of a ceramic pot filter

Figure 6-4: Example of a ceramic candle filter

6.2.2.3 *Nanofilters*

Nanofiltration (NF) membranes are an effective technology to remove dissolved organic contaminants (Petersen, 1993). Figure 6-5 and Figure 6-6 are examples of a nano and membrane, respectively. This type of treatment offers an attractive approach to meeting multiple objectives of advanced water treatment, such as the removal of disinfection by product precursors, natural organic matter (NOM), endocrine disrupting chemicals and pesticides (Escobar *et al.*, 2000; Nghiem *et al.*, 2004). Disadvantages of using nano filters include the decrease of permeate flux (membrane fouling) which is a major obstacle to the application of NF membranes to water treatment. Fouling worsens membrane performance and ultimately shortens membrane life, resulting in increased operational cost (Hörsch *et al.*, 2005; Li and Elimelech, 2006). Membrane filters (Figure 6-6) applied as post treatment helps to remove pathogens and suspended solids. Advances in low pressure driven membrane technologies such as microfiltration (MF) and ultrafiltration (UF) have been used in water and wastewater treatment due to their high efficiency, ease of operation and small footprint (Quin *et al.*, 2006). Dobrowsky *et al.* (2015a) evaluated the efficiency of a polyvinyl (alcohol) (PVA) nanofiber membrane/activated carbon column, for the treatment of harvested rainwater. Results indicated that total coliform counts in the unfiltered tank water samples collected from the two rainwater tanks had an average of 6×10^2 CFU/100 mℓ. After filtration, total coliform numbers were reduced significantly ($p=0.008$) as a ≥99% decrease was observed for all the first litres of filtered tank water samples in comparison to the unfiltered tank water samples. Furthermore, in separate experiments, molecular techniques were utilized to investigate the bacterial and viral removal efficiencies from RWH tanks. Genus-specific PCR assays revealed the presence of potentially pathogenic bacteria, commonly associated with tank water. Results indicated that *Klebsiella* spp., *Legionella* spp., *Pseudomonas* spp., and *Yersinia* spp. were detected in all the unfiltered tank water samples and were then sporadically detected in the filtered tank water.

Figure 6-5: Example of a nano filter

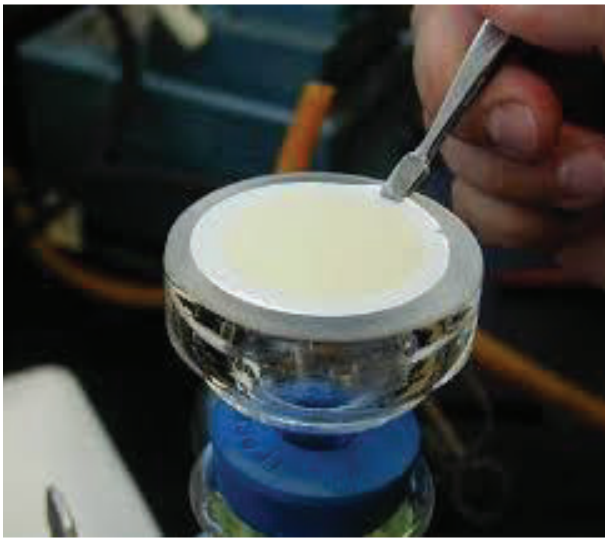

Figure 6-6: Example of a membrane filter

Legionella spp. and *Yersinia* spp. were the most persistent genera, as these bacteria were detected in all the unfiltered tank water samples and in 85 and 80% of the 20-filtered tank water. The PCR assays and BLAST analysis also confirmed the presence of bovine adenovirus 3 in all of the tank water samples collected before microfiltration for both tanks sampled. Other adenovirus strains detected in the rainwater tanks included simian adenovirus B isolate BaAdV-1 and human adenovirus 40 strain M-364. Moreover, once the tank water had undergone filtration through the PVA nanofiber membrane/activated carbon column, the presence of adenovirus was indicated in 75% of the filtered tank water samples. Even though the system was able to remove indicator organisms in an efficient manner, the removal of opportunistic bacteria such as *Yersinia* spp. and the removal of viruses were very poor.

6.2.2.4 *Reverse Osmosis*

Osmosis is a natural phenomenon in which water passes through a semipermeable barrier from a side with lower solute concentration to a higher solute concentration side. Water flow continues until chemical potential equilibrium of the solvent is established. At equilibrium, the pressure difference between the two sides of the membrane is equal to the osmotic pressure of the solution. To reverse the flow of water (solvent), a pressure difference greater than the osmotic pressure difference is applied; as a result, separation of water from the solution occurs as pure water flows from the high concentration side to the low concentration side (Figure 6-7). Reverse osmosis (RO) membranes have been shown to significantly reduce total dissolved solids, heavy metals, organic pollutants, viruses, bacteria, and other dissolved contaminants. However, in order to treat for heavily contaminated water a pretreatment step is necessary to prevent rapid membrane fouling, and thus reduce high system maintenance costs and significant downtime.

Figure 6-7: Reverse Osmosis

6.2.3 Disinfection methods

A traditional approach to treating water at household level is to kill or inactivate pathogens through disinfection (WHO, 2013). The most common methods used by households around the world to disinfect their drinking-water are: chlorine disinfection, solar disinfection (SODIS), ultraviolet (UV) disinfection and boiling. These disinfection methods can be effectively applied at household level (Jordan *et al.*, 2008). However, the common disadvantage associated with most disinfection methods is reduced treatment efficiency on turbid water (Sobsey *et al.*, 2002). Filtration is often required when using disinfection methods to reduce turbidity which can shield certain microorganisms thereby resulting in treatment inefficiency (Qualls *et al.*, 1983). The volume of water that can be treated during solar disinfection is also of concern as it can only treat small volumes of water (Jordan *et al.*, 2008). Three disinfection methods common to RWH systems are chlorination, ultraviolet light (UV), and ozonation. Treatment of harvested rainwater with disinfection has proved to be successful as illustrated in a number of studies (Despins *et al.*, 2009; Mendez *et al.*, 2011, Ahmed *et al.*, 2012).

6.2.3.1 *Solar disinfection*

Solar disinfection (SODIS) has been shown to be an effective treatment method at household level. In SODIS treatment (Figure 6-8), water is exposed to sunlight for about 6-8 hours and pathogens are inactivated by the synergistic effect of both temperature and sunlight radiations (Sichel *et al.*, 2007; Ubomba-Jaswa *et al.*, 2009; Dayem *et al.*, 2011). Ahammed and Meera (2008) studied the effectiveness of SODIS in the treatment of roof harvested rainwater and reported that complete inactivation of total coliforms was observed after 6 hours when solar radiation exceeded 500W/m^2. Limitations of SODIS include inefficiency in treatment of large volumes of water, its ineffectiveness during cloudy or rainy days and it is recommended the method not be used on turbid water (> 30 NTU) (EAWAG, 2012). Amin and Han (2009) investigated the benefits of solar collector disinfection (SOCO-DIS) as a potential treatment system for harvested rainwater for small scale water supply. SOCO-DIS was compared to SODIS with the aim of overcoming the limitations of SODIS. They reported that in the SOCO-DIS system, disinfection improved by 20-30% compared with the SODIS system and that rainwater was fully disinfected even under average weather conditions due to the effects of concentrated sunlight radiation and the synergistic effects of thermal and optical inactivation.

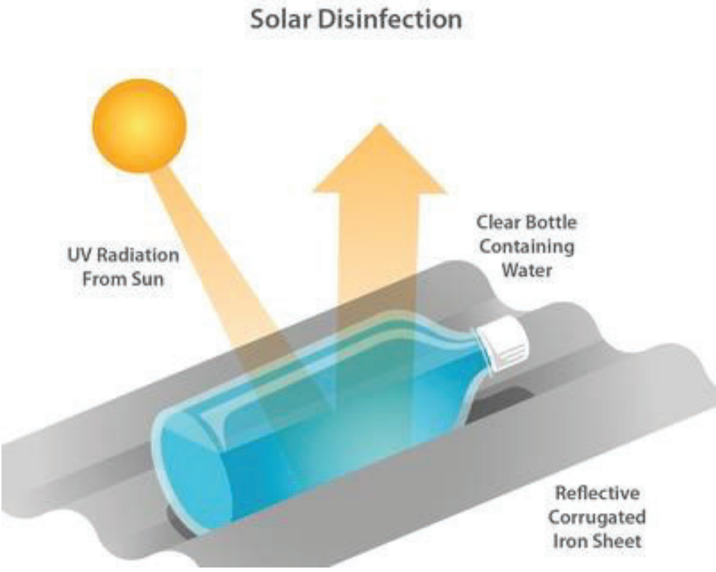

Figure 6-8: Solar disinfection

An advantage of using SODIS on low pH waters include increased inactivation rates due to the depletion of Adenosine triphosphate, the main energy storage and transfer molecule in the cells (Amin and Han, 2009). Dowbrosky *et al.* (2015b) investigated the efficiency of a closed-coupled solar pasteurization system in reducing the microbiological load in harvested rainwater and to determine the change in chemical components after pasteurization. Cations analysed were within drinking water guidelines, with the exception of iron, aluminium, lead and nickel which were detected at levels above the respective guidelines in the pasteurized tank water samples. Indicator bacteria including, heterotrophic bacteria, *E. coli* and total coliforms were reduced to below the detection limit at pasteurization temperatures of 72°C and above. However, with the use of molecular techniques *Yersinia spp*., *Legionella* spp. and *Pseudomonas* spp. were detected in tank water samples pasteurized at temperatures greater than 72°C.

6.2.3.2 *Ultraviolet light*

Disinfection using Ultraviolet (UV) radiation is defined as a physical method where water is exposed to a lamp producing light at a wavelength of nearly 250 nm (Figure 6-9). The wavelength is located in the middle of the germicidal band and is responsible for damaging the DNA of microorganisms (Bolton and Colton, 2008). Ultraviolet light treatment method often requires filtration as a pre-treatment step since it is not effective on turbid water (Qualls *et al.*, 1983; Macomber, 2010). Several studies have reported on the effectiveness of UV as a disinfection method for harvested rainwater (Jordan *et al.*, 2008; Ahmed *et al.*, 2012). Kim *et al.* (2005) reported that the number of total coliform present in rainwater were reduced by 50% even at low exposure to UV. Advantages of using UV radiation in treating harvested rainwater include: its high efficiency in the removal of microbes from water and the fact that it does not introduce chemicals or produce harmful disinfection by-products (Vilhunen *et al.*, 2009). Despite its positive attributes in the treatment of harvested rainwater, UV treatment has disadvantages which include: (i) lack of disinfectant residual to protect the water from recontamination or microbial regrowth after treatment, (ii) turbidity and certain dissolved constituents can interfere with or reduce its disinfection efficiency and (iii) high electricity usage is required to power the UV lamps (Kowalski *et al.*, 2000).

Figure 6-9: UV Water Filters for Rainwater Harvesting

6.2.3.3 *Chlorination*

Among common point-of-use interventions, household chlorination (Figure 6-10) is the most cost effective when resources are limited (Clasen *et al.*, 2007). Chlorination requires that the appropriate dosage be administered. Chlorination is known to be effective against bacteria, viruses and protozoa. Several studies reported on chlorination as an effective intervention strategy to prevent diarrhoeal diseases (Semenza *et al.*, 1998; Quick *et al.*, 1999 and Quick *et al.*, 2002). Free chlorine inactivates more than 99.99% of enteric pathogens except *Cryptosporidium* and *Mycobacterium* species (WHO, 2002). One of the disadvantages of water chlorination process is the formation of disinfection by-products which may pose a health risk to consumers (Baker *et al.*, 2002). However, when compared to the other disinfection method, it has residual disinfection. Nath *et al.* (2006) reported that chlorination is less effective in turbid water of >30 NTU and that microbial contaminants may be protected by particulates in the water.

Figure 6-10: Chlorination

6.2.3.4 *Silver disinfection*

Nawaz *et al.* (2012) studied the efficacy of silver ($AgNO_3$) in the removal of *P. aeruginosa* and *E. coli* in rooftop harvested rainwater supplies. The efficiency of silver disinfection was evaluated at concentrations, ranging from 0.01 to 0.1 mg/ℓ; the safe limit approved by WHO. AgNO3 in crystal form was dissolved in distilled (non-ionized) water to a stock concentration of 100 ppm of silver ions and then 0.1-1 mℓ volume of this stock solution was added to 1 ℓ of the test rainwater samples to obtain the final concentrations of 0.01-0.1 mg/ℓ of silver. Prior to disinfection, samples were found to contain between 350-440 cfu/100 mℓ *P. aeruginosa* and 740-920 cfu/100 mℓ *E. coli*. The disinfection rate and residual effect of silver was determined using final silver concentrations between 10-100 µg/ℓ over a period of up to 168 hours. Samples were taken for microbial analysis every two hours for 14 hours after the application of silver and then daily for 1 week, to examine regrowth.

At higher concentrations (80-100 µg/ℓ) complete inactivation of both microorganisms was seen in 10 hours, with no regrowth of *E. coli* seen after 168 hours. Inactivation was slower at lower concentrations (95-99% inactivation for silver concentrations between 10-40 µg/ℓ after 14 hours) and regrowth was also observed (e.g. 7.5% survival of *P. aeruginosa* exposed to 10µg/ℓ silver for 168 hours compared to approximately 4.5% survival at 14 hours), thus, at the lower concentrations, silver only delayed bacterial reproduction and did not cause permanent damage. Adler *et al.* (2013) also researched the effectiveness of silver disinfection as part of rainwater harvesting treatment. Ten rainwater harvesting systems in Mexico, equipped with silver electrodes were evaluated for a number of water quality parameters. The silver electrodes were located in line with the filtering system (after a mesh filter, designed to remove large particles, and before an activated carbon filter). On average, the ionisers reduced the level of total coliforms by approximately 1 log and *E. coli* by approximately 0.4 log and resulted in a silver concentration of approximately 0.01 mg/ℓ in the final water. The systems, as a whole, delivered water containing zero *E. coli* and less than 10/100 mℓ CFU total coliforms.

6.2.3.5 *Boiling*

Enteric bacteria, protozoa and viruses in water are sensitive to inactivation at temperatures of about 60°C (WHO, 2013). Boiling (Figure 6-11) is one of the oldest methods used in household water treatment (Conant, 2005). The World Health Organisation (WHO) recommends bringing water to a rolling boil to indicate that a disinfection temperature is reached (WHO, 2008). Howard and Bartman (2003) reported that bringing water to a rolling boil for 2 minutes showed a 97% reduction of heterotrophic bacteria and complete elimination of coliforms while 5 and ten minutes showed complete elimination of all bacterial contaminants. Heating water to 55°C inactivates most pathogens such as bacteria, viruses, helminths and protozoa (Feachem *et al.*, 1983). Other studies also reported on boiling as a water treatment option (Sobsey and Leland, 2001; Conant, 2005). A major disadvantage of boiling is its consumption of energy, cost and sustainability of fuel. In areas of the world where wood and other biomass fuels or fossil fuels are in limited supply and must be purchased, the costs of boiling water are excessive (Sobsey, 2002). The use of wood and wood-derived fuels is also a concern because it contributes to the loss of woodlands and the accompanying ecological damage caused by deforestation (Sobsey and Leland, 2001). Thus, boiling is highly efficacious, killing human pathogens even in turbid water and at high altitude. It however does not provide any residual protection.

Figure 6-11: Boiling water in a pot

6.2.3.6 *Ozonation*

Ozonation disinfects by introducing ozone gas to the water (Figure 6-12). It is produced by passing an electrical current through air or oxygen. It has a very short half-life in water (few seconds to minutes) and therefore must be efficiently introduced into the water. It is a colourless gas that disinfects, oxidizes, deodorizes, and decolorizes. Ozone gas is toxic and installation and maintenance of this type of system must be done by a licensed professional. Ozone systems can be positioned to treat the rainwater in the tank by recycling the water through an ozone injection system or by continuously bubbling the ozone in to the storage tank. Ozone is a broad-spectrum biocide that treats all of the water in the tank as well as preventing the formation of biofilms on the tank surfaces. In addition, ozone can remove colour and odours from water that allow the water to be used in a wider array of applications. Ozonation is also effective against parasites, viruses and chemicals (organic and inorganic). Disadvantages include no residual disinfection and may result in ozonation by-products.

Figure 6-12: Example of an ozone system for water treatment

6.3 GUIDANCE ON THE STORAGE, FILTRATION AND DISINFECTION OF RAINWATER

Rainwater for non-potable use should be stored in leak proof containers with tightly covered lids to ensure that mosquitoes and other contaminants do not enter the tank. Sunlight should not be allowed to enter the tank in order to prevent growth of algae. Depending on the desired final water quality, one or a combination of the methods in Section 6.2 can be used to treat the harvested water. A detailed review on the quality of harvested rainwater by De Kwaadsteniet *et al.* (2013) reported on the importance of treatment systems connected to rainwater harvesting tanks. They reported that debris that collects on catchment areas not only serves as a source of chemical contamination but also as a nutrient source of bacterial survival and growth. A course leaf screen or fine filter can then be effectively employed, anywhere between the rooftop and the inlet to the rainwater storage tank, to collect the debris and, in so doing, prohibit the pollutants from entering a DRWH tank. In addition, it is recommended that the filter or screen be durable, easy to clean, and cost effective (Abbasi and Abbasi, 2011).

Filtration in combination with UV disinfection has also been utilized in a DRWH treatment system for privately owned cisterns in the USA. Three filters, namely a 20-µm spun polypropylene progressive density cartridge filter, 5-µm spun polypropylene progressive density cartridge filter, and an activated carbon filter were used. The high capacity ultraviolet sterilizer was equipped with a 22-W UV lamp. The system was effective in reducing total coliforms, *E. coli*, and enterococci numbers but had a marginal impact in reducing total heterotrophic bacteria (Jordan *et al.*, 2008). The filters need to be correctly sized to minimise any interruptions to water flow and to maintain the pressure of the water supply. A 5 micron (um) has been shown to be sufficient for non-potable indoor use of rainwater. Chlorination and ultraviolet light (UV) disinfection are largely sufficient to ensure that microorganisms are killed and microbial growth is limited in water for non-potable use. Bleach (6% sodium hypochlorite) can be directly added to storage tanks in regular intervals or through the use of an injection pump which maintains the chlorine dose at 0.2 parts per million (Table 6-2) (TRHEC, 2006).

Table 6-2: Recommended treatment method for potable use of rainwater (TRHEC, 2006)

TREATMENT	TECHNOLOGY
Prefiltration	First flush, roof washer and/or other appropriate pre-filtration method
Storage	Storage of rainwater only in tanks approved for potable use
Cartridge filtration	3 micron sediment filter
Disinfection	A chlorine residual in the distribution system has to be maintained at all times or ultraviolet light for disinfection with a dosage of 186 mJ/cm^2 for virus inactivation.

A UV dose of > 40 mJ/cm^2 is usually sufficient to inactivate most bacteria, parasites and viruses. However, the recommended dose of UV for potable water treatment is at > 186 mJ/cm^2 (Georgia, 2009; TRHEC, 2006). This dose is able to effectively destroy viruses with double stranded DNA, which have been known to cause waterborne disease outbreaks. Through the use of first flush diverters and other screening methods, rainwater needs to be pre-treated before it is stored in a leak proof storage container. Similar to tanks containing water for non-potable use, tanks must be able to keep out contaminants and prevent algae growth. The tanks should be covered tightly, properly ventilated and kept from sunlight. To improve the aesthetic quality of the water, an activated charcoal filter can be added.

6.4 CONJUNCTIVE USE OF RAINWATER HARVESTING AND MUNICIPAL POTABLE WATER SUPPLY

In Australia, Asia and Europe, rainwater is already being used in conjunction with municipal potable water supply in order to reduce the demand on municipal supply. The focus however, is to use rainwater for non-potable uses. For outdoor use, rainwater can be used for irrigation and landscape watering. While for indoor use, rainwater can be used for laundry services and flushing of toilets. In order to maintain water quality and prevent contamination of municipal water supply systems, proper cross-connection control needs to be in place, the RWH system should be clearly marked, and system maintenance should be performed regularly. Guidelines that were mentioned earlier pertaining to catchment area, collection, storage tanks and water treatment are also applicable when rainwater is harvested to be used in conjunction with the public water distribution system. Protection from cross-contamination which is likely to occur during a drop in pressure is avoided by using a backflow prevention device (TRHEC, 2006). Alternatively, an air gap can be used as well. The pump that is used for rainwater harvesting should also have prior approval for use in a potable water system. The approval ensures that the pump will not contribute any toxic materials or metals to the liquid being pumped, will not support the growth of micro-organisms and will not change the taste or appearance of your water. Furthermore, it ensures that the pump delivers the relevant minimum pressure required by the system. Different coloured pipework and labels must be used to distinguish between rainwater and potable pipework. In addition, fixtures that use rainwater should be labelled as well, namely, toilet, irrigation outlet, *etc*. (TRHEC, 2006*).* Personnel who manage and operate public water distribution systems should have knowledge about rainwater harvesting systems to ensure both systems function optimally.

6.5 DESIGN AND INSTALLATION OF TREATMENT OPTIONS

Table 6-3: Factors affecting rainwater quality and recommendations for mitigating rainwater contamination through maintenance best practices

COMPONENT OF RWH SYSTEM	RISK FACTORS	DESIGN AND INSTALLATION BEST PRACTICES
Catchment surface	• Overhanging tree branches and animal activity • Leaching of chemicals and/or metals from catchment material • Grease and lint on catchment surface from kitchen cooktop vent and • dryer vent, respectively • Proximity to sources of air pollution (industry, major roadways, etc.).	• Trim overhanging tree branches • Direct dryer and kitchen cooktop vents under gutters • Do not collect runoff from sections of catchment area at risk for poor quality
Conveyance network	• Entry of potentially poor quality water from poorly sealed joints • Entry of animals and/or insects through poorly sealed joints	• Ensure underground pipe connections and fittings are secure • Use downspout-to-PVC pipe adapters
Rainwater storage tank	• Sediment settled on bottom of tank • Ingress of insects, rodents or debris • Algae growth in tank • Leaching of chemicals and/or metals from tank material or components located inside tank	• Locate pump intake at a suitable distance above tank floor • Ensure tank hatch is properly covered and vents have screens • Prevent entry of direct sunlight into tank • Store rainwater in SABS certified tanks

COMPONENT OF RWH SYSTEM	RISK FACTORS	DESIGN AND INSTALLATION BEST PRACTICES
Overflow system	• Backflow of storm sewage during extreme rainfall events (if overflow is connected to storm sewer)	• Ensure overflow system is adequately designed for intense rainfall events and use backwater valve on overflow drainage piping

1. Determine rainwater quality and treatment requirements.

a. Consult the applicable National/Provincial/ Local codes and regulations to verify the fixtures for which connection to rainwater is permitted

b. Consult the applicable National/Provincial/ Local codes and regulations and local authorities regarding quality and treatment requirements for the permitted rainwater fixtures.

c. Treatment recommendations (provided for guidance purposes only) for typical single-family residential dwellings consult the recommendations in Table 6-5.

Table 6-4: Treatment recommendations for typical single-family residential dwellings

RAINWATER FIXTURES	RECOMMENDED DEGREE OF TREATMENT
Toilet and urinal flushing	• Treatment by pre-storage treatment device in addition to the adoption of best practices outlined in Table 6-3
Directly connected underground irrigation system dispensing water below the surface of the ground	• Treatment by pre-storage treatment device in addition to the adoption of best practices outlined in Table 6-3 • Treatment by post-storage filtration devices as required by irrigation system manufacturer/contractor

2. Select and install pre-storage treatment devices.

a. Pre-storage treatment devices must be sized to handle the peak runoff from the catchment surface (refer to section 3.4 Design and installation guidelines for further details regarding design rainfall intensity).

b. First-flush diverters

i. Size the first-flush chamber based on the desired amount of runoff (typical diversion height is 0.5-1.5 mm) to divert from the storage tank, using Equation 2.10

ii. Estimate the collection losses

c. Settling tank or settling chamber

i. Size the settling tank or settling chamber based on the temporary storage of a prescribed volume of runoff.

- Where the prescribed volume can be based on rainfall (for example, 5 mm of rain)12, using the following formula:

$$V_s\ (L) = \text{Rainfall (mm)} \times CA \qquad \text{Equation 6.1}$$

- Where the prescribed volume can be based on a percentage of the rainwater storage tank capacity (for example, settling chambers in two-compartment tanks typically have 1/3 the capacity of the storage chamber).

d. Pre-storage treatment filtration devices

i. The following components may be included as part of the filtering system:

- high quality gutter guards, available from gutter suppliers;
- leaf screens placed on the downspout, available from gutter contractors; and/or
- commercially supplied rainwater filter installed in line with conveyance drainage pipe, or inside tank.

ii. Estimate the collection losses.

- Initial loss factor – Reported by the supplier or can be assumed to be negligible (0 mm)
- Continuous loss factor – Reported by the supplier or can be conservatively estimated at 20%

e. Pre-storage treatment devices shall be installed in accordance with applicable provincial/municipal codes and regulations and standards and manufacturer's instructions.

f. Pre-storage treatment devices shall be installed so that they are readily accessible. Access openings to facilitate entry into the device and/or tank shall be in accordance with the guidelines in section 3.5 DESIGN AND INSTALLATION OF RAINWATER STORAGE TANK

3. When selecting and installing post-storage treatment devices

a. Pre-storage treatment devices should also be used to minimize wear on post-storage treatment devices.

b. Post-storage treatment devices shall be sized in accordance with the maximum flow rate of the pressure system and manufacturer's requirements.

c. Post-storage treatment devices shall be installed in accordance with applicable National/Provincial/Local codes and standards and manufacturer's instructions.

d. Post-storage treatment devices shall be installed so that they are readily accessible.

6.6 MAINTENANCE OF WATER QUALITY TREATMENT OPTIONS

1. **Identify the factors that can impact the quality of rainwater in the RWH system and take steps to mitigate the risks posed by these factors by implementing the following maintenance activities listed in Table 6-5: below.**

Table 6-5: Factors affecting rainwater quality and recommendations for mitigating rainwater contamination through maintenance best practices

COMPONENT OF RWH SYSTEM	RISK FACTORS	MAINTENANCE BEST PRACTICES
Catchment surface	• Proximity to sources of air pollution (industry, major roadways, etc.) • Overhanging tree branches • Animal activity • Leaching of chemicals and/or metals from catchment material	• At least once every 6 months: • inspect catchment surface for sources of contamination (accumulated debris, leaves, pine needles, etc.) and clean area; and • trim overhanging tree branches.
Conveyance network	• Entry of potentially poor quality groundwater/surface water through poorly sealed joints • Entry of animals and/or insects through poorly sealed joints	• At least once every 6 months: • inspect gutters for sources of contamination (accumulated debris, leaves, pine needles, etc.) and clean gutters as required; • inspect area(s) where downspouts connect to conveyance network to ensure fittings are secure; and • inspect pre-storage treatment devices connected to conveyance network and clean devices as required. •
Rainwater storage tank	• Leaching of chemicals and/or metals from rainwater storage tank material • Leaching of chemicals and/or metals from components located in rainwater tank • Pump intake located at bottom of tank where it can draw in sediment	• At least once annually: • inspect components inside tank for signs of corrosion and/or degradation and replace components as necessary; and • monitor rainwater quality at point-of-use for indications of sediment accumulation in tank.

2. **Pre-storage treatment devices should be inspected at least twice a year, or more frequently as required by manufacturer's instructions and site conditions.**

   a. Observe rainwater passing through the devices during a rainfall event or simulate a rainfall event by discharging water from a hose onto the catchment surface. Look for potential problems such as:

   i. accumulated dirt and debris blocking flow through filter;

   ii. loose fittings or other problems with the treatment devices such that rainwater is passing through without treatment taking place; or

iii. other problems with the treatment devices.

b. Clean the filtration devices according to the manufacturer's maintenance instructions, repair as required.

3. **Post-storage treatment devices should be inspected at least quarterly, or more frequently depending on manufacturer's instructions and site conditions.**

a. Observe the devices as water flows through the pressure system, looking for problems such as:

i. water leaking from treatment devices; or

ii. warning/indicator lights on treatment devices indicating fault with device and/or required replacement of components.

b. Maintain post-storage treatment devices as necessary through the regular cleaning of filtration devices and/or replacement of filter media, lamps or other components as specified by the product manufacturers.

4. **While inspecting, cleaning or repairing the pre-storage treatment and/or post-storage treatment devices or other components of the rainwater harvesting system, follow all necessary safety precautions.**

6.7 GENERAL RECOMMENDATIONS

There exists significant potential to increase the water supply in South Africa in rural, peri-urban and urban areas through the use of rainwater harvesting. This is illustrated through various small-scale projects that have taken place around the country. However, in most of these small-scale projects, the focus has been on ensuring rural supply especially under drought conditions when water is limited and to reduce the demand on groundwater supply. If the use of rainwater is to be considered as a viable option of water supply and upscaled for use in urban supply systems, the quality of the harvested and stored rainwater must be guaranteed. The development and use guidelines specifically designed around the process of rainwater harvesting and subsequent storage and use will ensure that the quality of water is of a high standard. The following recommendations are intended to help shape the development of these guidelines to suit the South African rainwater harvesting context:

- Identifying the critical control points (chemical and microbial entry points) that occur within the rainwater harvesting process and putting in place barriers to entry of these contaminants. Routinely testing for these contaminants will provide evidence that the barriers to entry of the contaminants are functioning effectively.

- Setting up different types of rainwater harvesting systems around the country and conducting epidemiological and laboratory-based studies to determine the pre- and post-treatment quality of harvested rainwater. This will highlight which contaminants are found in which areas and which systems are efficient in maintaining the quality of rainwater irrespective of location. These results will also help in the standardising of the design and materials that should be used for rainwater harvesting systems.

- Long term and frequent sampling regimens of harvested and stored rainwater will pick up slight changes in the microbial population of the harvested rain water as well as the chemical composition. These sampling results will better inform guidelines as to how often water sampling must be done in rainwater harvesting systems to ensure quality. An accurate estimation of how much initial water must be diverted (first flush) from the rainwater harvesting system can also be determined with more deliberate sampling routines.

- Even though chemicals only pose a long-term health risk, there are exposure points within the rainwater harvesting system which favour chemical contamination. A more concerted effort should be made to identify possible chemical contaminants that need to be routinely measured during rainwater harvesting and develop guidelines that will aid in their monitoring. Internationally and locally, the default is to measure chemical contaminants in rainwater and then use drinking water guidelines to determine if the chemical is within the limits set out by the guidelines.

- Implementation of recommended guidelines to determine ease of use, compliance and ultimately if the quality of rainwater is maintained nationally.

7 FINANCIAL ASSESSMENT

7.1 INTRODUCTION

For the financial assessment, the most appropriate approach is the whole life costing (Roebuck *et al.*, 2011) which provides a robust rationale for asset management as it considers the costs and performance over extended periods of time. It is also able to take operation and maintenance costs into account at appropriate times. The main components of the financial model developed by Roebuck and Ashley (2007) are presented in Figure 7-1 and Figure 7-2, both for the mains-only water system and the RWH system.

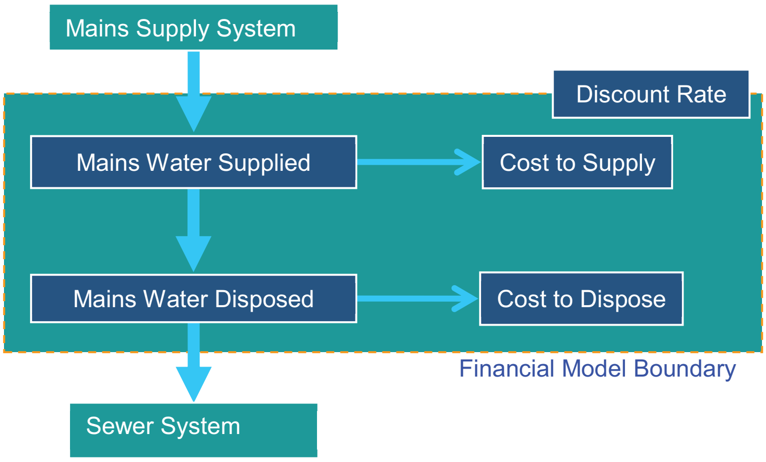

Figure 7-1: Schematic representation of mains-only financial model (Roebuck and Ashley, 2007).

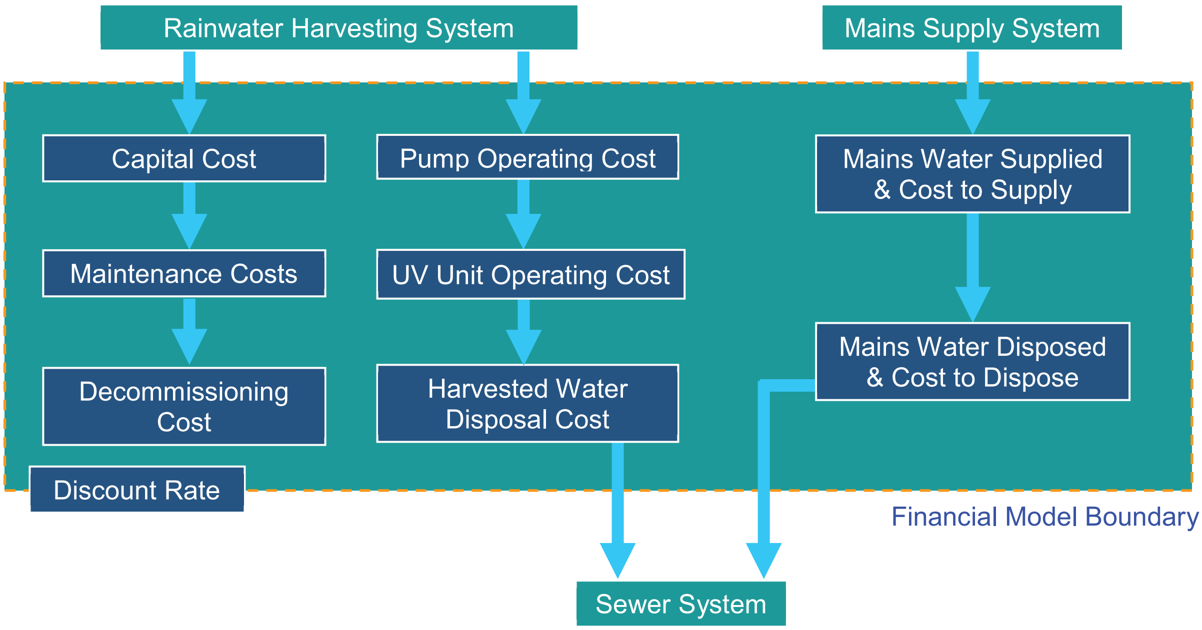

Figure 7-2: Schematic representation of the RWH financial model (Roebuck and Ashley, 2007).

The financial variables included in the whole life costing methodology are provided in Table 7-1.

Table 7-1: Financial variables included in the whole life costing methodology (Roebuck *et al.*, 2011)

COST ITEM	ASSOCIATED PARAMETERS	UNITS
Capital/decommissioning expenses	Capital costs	ZAR
	Decommissioning costs	ZAR
Water and sewerage charges	Volumetric supply charge	ZAR m^{-3}
	Supply standing charge	ZAR yr^{-1}
	Volumetric sewerage charge	ZAR m^{-3}
	Sewerage standing charge	ZAR m^{-3}
Operating expenses	Electricity cost	p/kW h
	Discount rate	%
Maintenance activities	Activity frequency	Months or years
	Associated cost	ZAR $activity^{-1}$

7.2 CAPITAL AND DECOMMISSIONING EXPENSES

Although significant, the capital cost of the mains water supply is the same whether there is a RWH system or not. It can therefore be ignored. The cost of purchasing and installing the RWH equipment can also be significant, especially in the case of dual systems. This cost cannot be ignored. Decommissioning of the system only occurs at the end of its lifespan.

7.3 MAINTENANCE EXPENSES

Maintenance costs comprises of costs associated with the scheduled cleaning of system components, the maintenance of the different components of the system and the replacements of components that have reached their service lives (UV units, valves, tap, pipework, etc.). One can argue that the cost of cleaning the catchment surface by hosing or sweeping and, if applicable, trimming overhanging tree branches/foliage, fixing roof, gutters or downspout should not be added to the RWH system.

7.4 OPERATING EXPENSES

The operating cost of the UV units and the pump is related to the energy usage, which in turn is dependent on their operating time and power rating. The replacement cost of the various filters is part of the maintenance expense.

7.5 WATER AND SEWERAGE CHARGES

Municipal charges have a step-wise structure called block tariffs. The charge is set per unit (e.g. cubic meters of kilo watts) of water/electricity consumed and remains constant for a certain quantity of consumption (first block). As the water/electricity use increases, the tariff shifts to the next block of consumption and so on for each block of consumption until the highest one. Cross subsidisation from high water/electricity users to low water users ensures that the most water/electricity expenditures are recovered.

Property-related taxes include municipal rates (abusively referred to as ‘property taxes’) and charges for refuse and sewerage. Sewerage charges only apply mainly to urban areas; there are no sewerage services in most rural areas. Sewerage is usually charged in two parts: a fixed charge depending on the value of the property, and a variable charge according to the water consumption.

The relevant 2016/2017 municipal tariffs for residential households are presented in the tables below. Water tariffs are presented in Table 7-2. 12 kℓ water per 30-day period are granted free of charge to registered indigent households.

Table 7-2: 2016/17 water tariffs for residential households of Tshwane municipality (City of Tshwane, 2016)

Category (kℓ per 30-day period)	Tariffs (Per kℓ R)
0-6	8,66
7-12	12,36
13-18	16,23
19-24	18,78
25-30	21,47
31-42	23,20
43-72	24,83
> 72	26,58

Sanitation charges are calculated according to the percentage water discharged as indicated in Table 7-3. A zero-based tariff is charged for registered indigents for the first 6 kℓ discharged.

Table 7-3: 2016/17 sanitation charges for residential households of Tshwane municipality (City of Tshwane, 2016)

Category (kℓ per 30-day period)	% Discharged	Tariffs (Per kℓ R)
0-6	98	6,12
7-12	90	8,27
13-18	75	10,65
19-24	60	10,65
25-30	52	10,65
31-42	10	10,65
> 42	1	10,65

The tariff structure with regard to households provides for inclining block tariffs. Registered indigents are granted 100 kWh free of charge.

Table 7-4: 2016/17 electricity tariffs for residential households of Tshwane municipality (City of Tshwane, 2016)

Tariff Blocks (KWh)	Tariff (c kWh^{-1})
0-100	130,00
101-400	152,50
401-650	169,10
>650	180,70

Until we are able to quantify with a reasonable degree of confidence, mains water savings from rainwater tanks, it is pointless to continue the financial analysis.

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