The feasibility of rainwater and stormwater harvesting within a winter rainfall climate context: A Commercial Building Focus

by

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Declaration

I declare that:

"The feasibility of rainwater and stormwater harvesting within a winter rainfall climate context: a commercial building focus" is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references. This research report is submitted to the Department of Environmental Sciences, College of Agriculture and Environmental Sciences (CAES), University of South Africa (UNISA), in partial fulfilment of the requirements for the degree of the Master of Science Environmental Management.

N S Viljoen

Ethical Considerations

During this research study all research participants' rights to privacy were respected. The research was conducted with integrity, in an honest and professional way and with respect of the welfare of others. An application for ethics clearance approval was submitted to the Research Ethics Committee of the College of Agriculture and Environmental Sciences, UNISA. Ethics approval was granted by the Committee on 4 March 2013 (please refer to Annexure E).

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i) Abstract

Cape Town, South Africa, falls within a winter rainfall region, making it difficult to assess the feasibility of rain- and stormwater harvesting. The reason for this is because the region's high water demand period coincides with the low rainfall summer season, thereby limiting the availability of this alternative water resource when most needed. During this study, rainwater harvesting for toilet flushing purposes, collected from roof surfaces, was practically assessed by means of inserted flow meters at a pilot study site in Kommetjie, Cape Town. The combined and single system roof- and land surface runoff yields and savings of commercial buildings within the Kommetjie business area, were also theoretically assessed by making use of a mathematical roof- and land surface runoff model specifically developed during this study. The statistical testing of the hypotheses statements relating to the pre- and post-harvesting savings at the pilot study building, compared against the average actual municipal water usage, were performed. Hypotheses testing were also performed in order to compare the theoretical rain- and stormwater runoff yields for the commercial business area against the average actual municipal water consumption. The conclusions drawn from this study indicated that valuable potable water, as well as related financial savings, can be achieved within a winter rainfall region, thereby making rain- and stormwater harvesting a feasible option for commercial businesses in Cape Town.

ii) Key Words

Below-surface reservoir, catchment surface, collection tank, electronic rain gauge, garden irrigation, measurement, non-potable uses, potable top-up system, rainwater harvesting, runoff model, stormwater channelling, stormwater harvesting, stormwater runoff, toilet demand, toilet flushing.

iii) Glossary

Term	Definition
Alternative water resources	Water resources other than normal municipal treated tap water. These are usually decentralised sources, and include rainwater, greywater, blackwater and groundwater.
Blackwater	Used water that has been excessively contaminated, and that consequently needs intensive treatment in order to ensure safe disposal or re-use - such as wastewater from a toilet (Van der Walt, 2012).
Catchment	An area that contributes surface water to an intake/outflow point (Armitage, Vice & Fisher-Jeffes, 2012).
Corrugated iron	Galvanized sheet iron that has been shaped into straight parallel ridges and hollows.
First flush	Any system or device designed to discard the initial roof runoff at the start of any rainfall.
Greywater	The water originating from a building that has been used for bathing, showering, in bathroom basins or washing machines and that is being re-used for non-potable purposes such as garden irrigation. Greywater is considered as less contaminated than blackwater (Van der Walt, 2012).
Impervious Surfaces	Impervious surfaces are surfaces that are impermeable, i.e. surfaces where the infiltration of water is prevented or limited, such as concrete, asphalt, paving and compacted exposed areas.
Potable Water	Treated municipal (tap) water. This is water fit for human consumption purposes.
Rainwater Harvesting	The capturing (usually from roof surfaces), storage and use of rainwater for any usage type (Van der

	Walt, 2012).
Runoff	Water from rain, snowmelt or other sources, that flows over land surfaces or in streams and rivers. Before reaching a channel it is also called overland flow (Kibert & Grosskopf, 2007).
Runoff Coefficient	The ratio of the volume of water which falls on a specific collection surface to the volume of water which runs off that surface.
Stormwater	Rainwater that runs off all pervious or impervious surfaces such as roofs, pavements, car parks, roads, gardens or natural open spaces.
Stormwater Harvesting	The capturing, storage, treatment and use of stormwater runoff from urban impervious or pervious areas. It differs from rainwater harvesting, as the runoff is collected from land-surface areas rather than roofs (Armitage, Vice & Fisher-Jeffes, 2012).

iv) List of Acronyms

AADD :Average Annual Daily Demand
AMEC :Arctic Military Environmental Cooperation
BWP :Berg Water Project
CCT :City of Cape Town
CR :Roof Runoff Coefficient
CS :Land Surface Runoff Coefficient
CSIR :Council for Scientific and Industrial Research
CW :Cost of Water
DM :Demand Met
DECNSW :Department of Environment and Conservation - New South Wales
DTU :Development Technology Unit
DWA :Department of Water Affairs
DWAF :Department of Water Affairs and Forestry (Previous Name of DWA)
FS :Financial Saving
GI :Galvanized Iron
GDRC :Global Development Research Centre
IWRM :Integrated Water Resources Management
IPCC :Intergovernmental Panel on Climate Change
JSCWSC :Joint Steering Committee for Water Sensitive Cities
MAR :Mean Annual Runoff
NWRS :National Water Resources Strategy
RA :Roof Area
RF :Average Rainfall for Period
RH :Rainwater Harvested
SA :Area of Land Surface
SAP :Systems Applications and Products
SAS :Statistical Analysis System
SH :Stormwater Harvested
TAMSD :Total Average Monthly Seasonal Demand

TAMSY	:Total Average Monthly Seasonal Yield
TEARS	:The Emma Animal Rescue Society
UNEP	:United Nations Environmental Programme
V	:Variable
WC	:Water Conservation
WCWSS	Western Cape Water Supply System
WDM	:Water Demand Management
WRC	:Water Research Commission
YAS	:Yield After Spillage
YBS	:Yield Before Spillage

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1 Introduction

In most urban areas, the population density is increasing at a rapid rate. The supply of adequate water to meet societal needs, and to ensure equity in access to water, is therefore one of the most urgent and significant challenges faced by decision makers. Various alternative technologies to augment freshwater resources must be investigated in order to find a solution to this growing problem, or else water demand will soon exceed supply. Rain- and stormwater harvesting and utilization are an environmentally sound solution which can avoid many environmental problems often caused in conventional large-scale projects using centralised approaches (GDRC, 2009).

South Africa has low levels of rainfall, relative to the world average. Average rainfall ranges from < 100 mm/a to over 1 500 mm/a, with an average of approximately 450 mm/a. Linking this low rainfall rate to the high level of aridity, results in a mean annual runoff (MAR) of less than 10% - a very low percentage when compared to countries with similar average rainfall (DWA, 2012).

The City of Cape Town (CCT) is located in the Western Cape Province on the south-eastern corner of South Africa as indicated in Figure 1. The total area is approximately 2 474 km^2 and its coastline is 371 km long.

Figure 1: The location of the City of Cape Town.

The topography varies, and includes mountains, hills and flat plains. High mountains are located fairly close to the sea and urban edge, and can exceed 1 000 m, as is the case with the well-known Table Mountain. Other mountains include the Hottentots-Holland, Stellenbosch, Helderberg, Jonkershoek, Franschhoek, Wemmershoek, Du Toits, Limiet, Paarl, Slanghoek, and Elandskloof mountains, which form an eastern perimeter around the City of Cape Town (City of Cape Town, 2011a).

Cape Town has well-defined seasons, with a Mediterranean-type climate. It receives a mean annual rainfall of 515 mm, and has an average temperature of 16.7ºC (City of Cape Town, 2011a). The city falls within a winter rainfall climatic region, where winter cold fronts sweep across the Atlantic Ocean and bombard Cape Town with rain and heavy north-west gales. The winters are cool, with an average minimum temperature of approximately 7°C. Most of the rainfall occurs in the winter, and varies extensively due to the unique topography of the area. In the valleys and coastal plains, the average rainfall is approximately 500 mm per annum, but in the more mountainous areas, the average rainfall can reach as much as 1500 mm per annum (City of Cape Town, 2011a).

Long, dry spells frequently occur, due to meteorological depressions moving past to the south of the area (and the land mass) during the summer. It is during the dry summer months that the city's demand for water is at its highest. The summer temperatures average at a maximum of approximately 26°C (City of Cape Town, 2011a).

The city is experiencing increasing challenges relating to water pollution, as well as high climatic variability and evaporation levels. These challenges cause serious constraints on the amount of water available for use (DWA, 2012). The Western Cape area is mostly receiving winter rainfall whilst the rest of the country is generally receiving summer rainfall. This unevenly spread rainfall pattern across the country's catchments leaves most of the northern and western parts dry (DWA, 2012).

By harvesting rain- and stormwater, the valuable potable (municipal) water supply is substituted, and this essential drinking supply can therefore be conserved. Urban streams are also protected by the reduction in stormwater runoff volumes, which reduce flooding, river bank erosion and ecological imbalances. The capturing of this alternative water resource also reduces the load of some stormwater pollutants, such as nitrogen and other constituents, entering waterways (JSCWSC, 2009).

The study sites chosen for investigation during this research is the Heron and Fish Eagle Business Park sites within the Kommetjie commercial business study area, and "The Emma Animal Rescue Society" (TEARS) practical pilot study site which is also situated in the Kommetjie commercial business area.

TEARS is a non-profit, pro-life, organisation whose core aims are to rescue, rehabilitate, reunite and re-home abandoned, lost and abused domestic animals. They also educate the neighbouring community of Masiphumelele on the care and value of animals. Masiphumelele is an informal settlement area situated next to the TEARS and commercial building study sites within the Kommetjie commercial area. Tears mainly provide the following services within the community:

- free sterilisations of domestic companion animals;
- primary health care such as vaccinations, parasite control and deworming;

- a scheduled daily mobile clinic, offering basic health care and food to the animals;
- empowering and supporting the community through effective education and guidance;
- establishing an essential working relationship with the residents in order to protect the rights of the animals;
- veterinary care in a registered clinic situated on the TEARS premises.

Because this is a non-profit organisation they are solely relying on donations to pay their monthly water account, and would therefore greatly benefit from the substitution of their municipal water usage with rainwater. TEARS was therefore chosen as a suitable recipient of the potable top-up rainwater system, which was donated by Coca Cola Canners, for the purpose of this research study.

1.1 Differentiating Between Rainwater and Stormwater Harvesting

The terms "stormwater harvesting" and "rainwater harvesting" are used interchangeably in literature, and it is therefore important to define what the differences are between the two terms, within the context of urban water management in South Africa. The following are conventional definitions of the two terms:

- "Rainwater harvesting is the direct capture of stormwater runoff, typically from rooftops, for supplementary water uses on-site" (Armitage, Vice & Fisher-Jeffes, 2012).
- "Stormwater harvesting is the capturing, treatment, storage and use of stormwater runoff from pervious or impervious land surface urban areas" (DECNSW, 2006).

The focus of this study will be on the harvesting of rainwater from rooftops and impervious surfaces at ground level. The two terms will therefore be clearly differentiated, in this study, by the type of collection surface, to fit the purpose of this document, and will be referred to with the following definitions in mind:

- Rainwater harvesting: rainwater captured from rooftops of buildings, and channelled into an above-ground storage tank to be pumped for supplemental indoor or outdoor use.
- Stormwater harvesting: rainwater captured from any hard, impervious surfaces at ground level, such as vehicle parking areas, pathways, roads, compacted area, etc., and channelled into an underground storage tank or reservoir to be pumped for supplemental outdoor use.

1.2 The Green Building Concept

Green buildings are designed with environmental sustainability in mind, and usually employ one or more of the following strategies (Kibert & Grosskopf, 2007):

- closed loop material systems
- local ecosystem integration
- the optimization of hydrologic cycles of buildings
- the full implementation of indoor environmental quality measures
- the maximum use of renewable energy and passive design methods

The design of most buildings is done in such a way as to address water supply, wastewater and stormwater as separate issues rather than in an integrated approach. The primary means of reducing potable water consumption used by most current generation green buildings, are ultra-low flow fixtures (Prins, 2012). A limited number of buildings are also incorporating rainwater harvesting from building roofs, and stormwater harvesting from impervious surfaces, to further reduce their potable water consumption. Information regarding the potential of these alternative water resources and related infrastructure, should therefore be made available to current and future green business owners and developers (Kibert & Grosskopf, 2007).

This study will focus on rainwater and stormwater harvesting in commercial business areas, with emphasis on the value of these practices for green commercial buildings.

1.3 Literature Review

1.3.1 Cape Town's Water Crisis

The issue of water resources is of increasing concern in major metropolitan cities all over the world. Every citizen has basic water consumption needs, yet clean, fresh water is a limited resource. According to Kirby (2003), 97.47% of the world's water supply consists of saltwater, 2.53% consists of freshwater that people do not have access to - such as glaciers, groundwater and permafrost, and only 0.01% is fresh water which is in a form that is available for human consumption.

Water is also a scarce resource in the major South African metropolitan city of Cape Town (City of Cape Town, 2011b). Frequent dry periods are occurring in Cape Town, especially in the Cape Peninsula catchment area, which is a major challenge for the delivery of water to all suburbs within the city. Drought can be seen to act as a catalyst for thinking about alternative, and potentially more flexible, infrastructures.

According to the City of Cape Town (2007b), the availability of water resources to meet the growing water demand in the City of Cape Town (CCT) is a limiting constraint to the social upliftment and economic prosperity of the city. That is why the City implemented a long-term water conservation and water demand management (WC/WDM) strategy in 2007, in which a range of guidelines for developing future urban settlements was set out. According to DWA (2004), additional interventions, beyond those set out in the City's long term strategy, will be needed, without which the demand will exceed the supply. Figure 2 show that by 2019 a new water resource may be required.

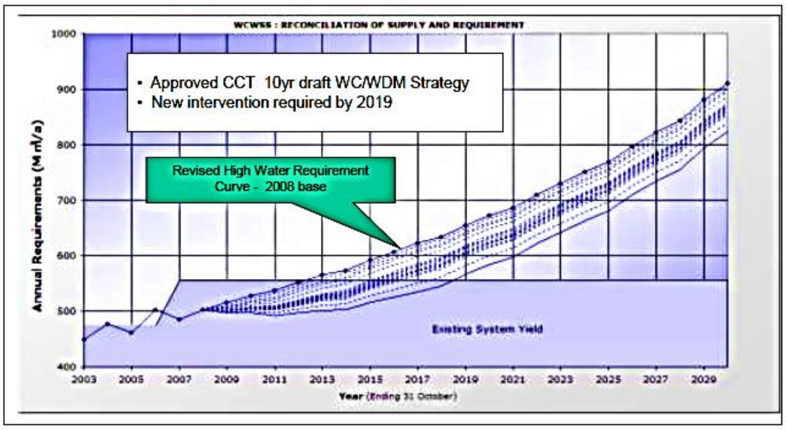

Figure 2: Predictions of future water demand (City of Cape Town, 2011a).

The City of Cape Town has identified that the Table Mountain Group Aquifer, the Cape Flats Aquifer, the Eerste River and Lourens River Diversion schemes are all possible short-to-medium-term water resource development opportunities. None of these alternatives, however, fully consider the environmental impacts, or whether the water being used is appropriate for its use. Little, if any, consideration has been given to decentralised infrastructure such as that of rainwater harvesting systems, as a potential solution to Cape Town's water crisis (Prins, 2012).

1.3.2 Climate Change

The Intergovernmental Panel on Climate Change (IPCC) published a report in 2007, which was written by over 450 leading scientific authors from 130 countries, and has been peer reviewed by over 2 500 scientific experts. Table 1 presents the key direct observations and future projections from the latest IPCC report (IPCC, 2007). These scientists agreed with 90% certainty that humans are at fault for increasing global temperature and causing climate change.

Table 1: The key direct observations and future projections from the IPCC (2007) report.

Key Direct Observations from the IPCC (2007) Report	**Key Future Projections from the IPCC (2007) Report**
Carbon dioxide levels have increased from 280 parts per million (ppm) to 379 ppm since the industrial revolution.	Probable temperature rise likely, between 1.8^{o}C and 4^{o}C.
The global average air temperature has increased by 0.74^{o}C (0.56^{o}C – 0.92^{o}C) in the past 100 years.	Possible temperature rise likely, between 1.1^{o}C and 6.4^{o}C.
11 out of the past 12 years have been among the warmest years in recorded history.	Sea level likely to rise by 28 – 43 cm.
Since the 1980's, average atmospheric water vapour content has risen, because warmer air can hold more water vapour.	Arctic summer ice disappears in second half of century.
Mountain glaciers and snow cover have decreased in the past 100 years.	Increase in heat waves very likely.
Global sea levels have increased at an average rate of 1.8 mm (1.3 mm – 2.3 mm) per year from 1961 to 2003.	Increase in tropical storm intensity likely.

Modifying the global energy cycle directly affects the world's water resources. Global warming increases the amount of land evapotranspiration and ocean evaporation, which, in turn, causes longer and more frequent droughts in some parts of the world, and higher intensity precipitation in other parts, through the increase in moisture availability and cloud cover (Hengeveld & Banks, 2005).

Average precipitation is predicted to increase between 5% and 20% in certain regions of the world, and will cause greater extremes in weather than is being experienced now, with stronger and more intense rainfall (Houghton, Ding, Griggs, Noguer, Van Der Linden, Dai, Maskell & Johnson, 2001). The rate of rainfall intensity is expected to increase at a greater rate than that of average precipitation. This will cause extreme rainfall events to occur more often. The stormwater infrastructure of urban areas will fail to control greater runoff volumes, and flooding will become more prevalent (Semadeni-Davies, Elliott & Reed, 2008). A study done by Groisman, Knight, Karl, Hegerl & Razuveav (2005) (Figure 3) indicates that the whole of South Africa has experienced an increase in precipitation over the past 100 years (regions with a blue 'plus' signify an increase in precipitation, and regions with a red negative sign signify a decrease in precipitation):

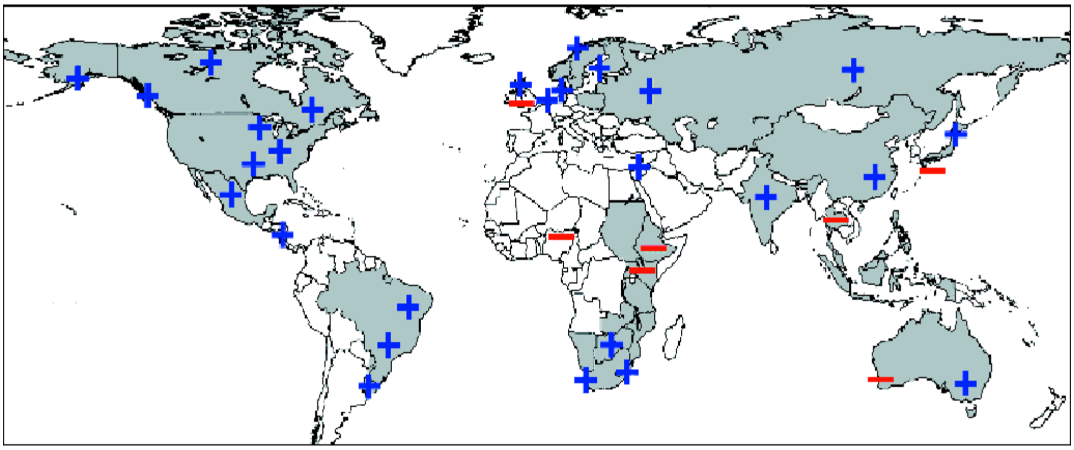

Figure 3: The changes in precipitation over the last 100 years (Groisman *et al*, 2005).

1.3.3 Urbanisation and Water Resources

Urbanisation affects many resources and components of the environment (Marsalek, Karamouz, Goldenfum & Chocat, 2006). Serious changes in the natural water cycle are caused by the construction of urban buildings (AMEC Earth & Environmental, 2001). The changes to the water cycle are highlighted in Figure 4:

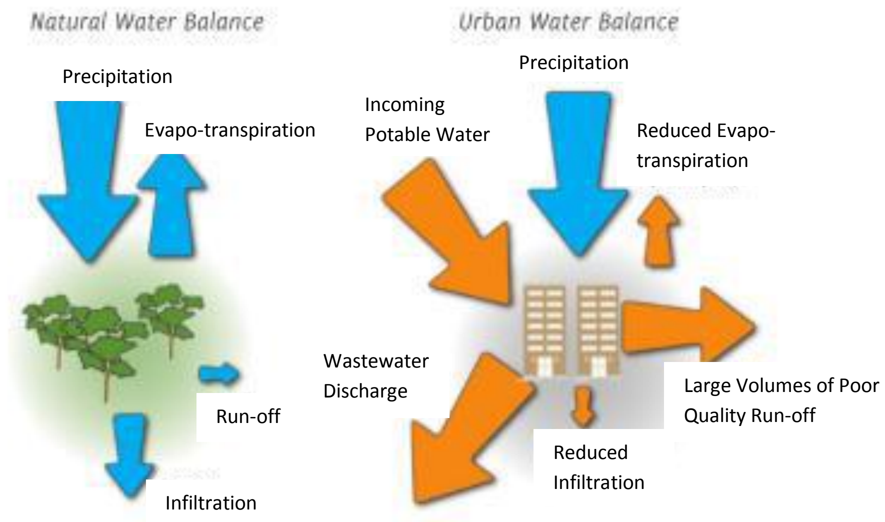

Figure 4: The urban water cycle showing changes to the natural water cycle with traditional urban development (Hoban & Wong, 2006).

Urban building development causes the following water cycle changes:

- An increase in surface imperviousness – resulting in a decrease in infiltration which, in turn, decreases groundwater recharge while increasing runoff volumes and peak flows (AMEC Earth & Environmental, 2001).
- Changes in runoff conveyance networks.

A number of sources highlight that urbanisation, and the related infrastructure development, has resulted in wide scale changes to the water cycle. These changes have significant environmental impacts. As a result, it is widely accepted that a new, integrated - or holistic - approach to urban water management is required (Brown, Keath, & Wong, 2008; Marsalek, *et al*., 2006; Mitchell, Mein & McMahon, 2001).

1.3.4 Water Sensitive Building Design

Water sensitive building design can be defined as an approach to building infrastructure planning and design that integrates land and water management. It aims to minimise the impact of urbanisation on the natural water cycle. The principles of water sensitive building design can be applied to a single building or to a whole subdivision (Dillon, 2005). This is based on the premise that building development must address the sustainability of the environment, with special emphasis on water (Engineers Australia, 2006). According to Wong (2006), water sensitive building design aims to reduce potable water demand through water-efficient appliances and infrastructure, facilitating rainwater harvesting, impervious surface runoff harvesting and channelling, infiltration, greywater re-use, and so on. A study quoted by Van der Walt (2012) indicates that the rainwater runoff in an industrial area is approximately 55%, compared to natural areas, where it is only 10% - as can be seen in Figure 5:

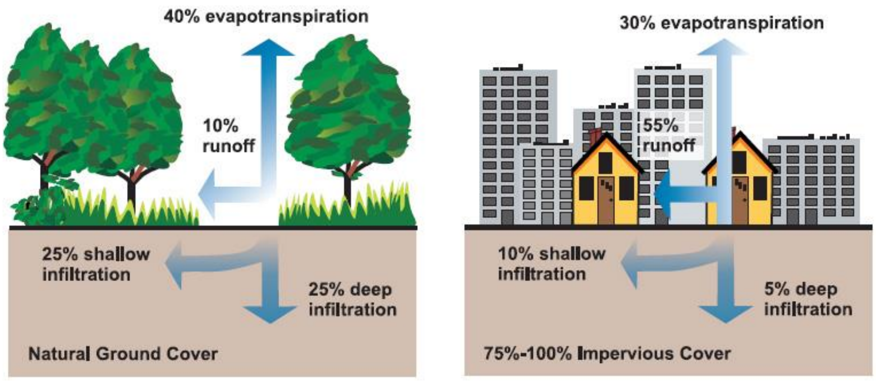

Figure 5: The relationship between natural ground cover runoff and impervious cover runoff (Caramouz, Nazif & Falahi, 2013).

1.3.5 Rainwater Harvesting

Rainwater harvesting involves the collection of rainwater from a capturing surface, usually the roof of a building, which is then stored and utilised for various uses. Most rainwater systems are very simple, and work according to the principle that as the water storage levels are drawn down due to use, they are filled up on the onset of rain (Jacobs, 2010).

The rainwater system investigated during this study is a potable top-up system which includes -

- a collection surface (roof);
- a catchment tank with a pump;

- a floating system to activate the potable mains water if the rainwater level falls too low; and
- a suitable infrastructure system feeding the water to the toilet for flushing purposes.

With a potable top-up system, municipal water will be allowed to supplement the system if the water storage tank should reach a predetermined low level - usually during the dry, rain-scarce summer period. During the winter months when rain is usually plentiful, the excess rainwater will run to stormwater, once the capacity of the tank has been reached (Cape Water Solutions, 2013).

According to Jacobs (2010), the viability of rainwater harvesting systems could be drastically influenced by external factors such as rainfall patterns, climatic conditions, and the end-users of the rainwater. This study will include the assessment of the rainwater for toilet flushing usage at the TEARS pilot study site in Kommetjie, which will allow for the maximum benefit of this renewable resource.

It is recommended that in conjunction with municipal water supply, harvested rainwater may be used for garden irrigation and non-potable indoor uses (washing machines and toilets). Maximum benefits are gained from rainwater tanks when the collected water is regularly used - that is, if tanks are plumbed into the house and used for applications such as toilet flushing and washing machine supply (Prins, 2012).

Toilets and washing machines consume about 40% of the water that is used inside the home (Vickers, 2001). If these two indoor uses can be served with rainwater, significant water savings will result; however, it is important to provide adequate protection such as backflow prevention at the meter, and an air gap at the public water supply entry into the storage tank (Hari & Krishna, 2005).

Another important benefit of rainwater harvesting is the water saving and consumption interest that is created in consumers, by means of the increased perceptions due to fluctuations in tank volume when water is used and when being replaced by inflowing rainwater. This can be an important mechanism to facilitate alternative water resources education and awareness initiatives within the City (JSCWSC, 2009).

The following general advantages and benefits of rainwater harvesting were identified:

- mitigating floods and reducing pressures on water resources around urban areas;
- reduction of river stormwater inflows with the consequent reduction in river/stream bank soil erosion/stability;
- reduction of stormwater inflows into wetlands currently overflowed, causing a restoration function such as restoring flood retention/purification abilities;
- rainwater harvesting being able to relieve the pressure on other water sources by supplementing them;
- rainwater harvesting providing a water supply buffer for use in times of emergency or droughts (UNEP, 2009);
- ability to reduce urban flooding and lift the pressure of storm drainage;
- users of the rainwater systems being, usually, the owners of the systems, and therefore being more likely to exercise water conservation methods;
- rainwater harvesting technologies being flexible and being able to be built to meet almost any consumer requirements;
- the construction, operation and maintenance of rainwater harvesting systems not being labour intensive; and
- downstream stormwater treatment devices potentially become more efficient by the reduction on the hydraulic load (Prins, 2012).

1.3.6 Stormwater Harvesting

Stormwater is rainwater that runs off all hard, impervious or pervious land surfaces such as pavements, footpaths, car parks, roads and open spaces. Stormwater can be captured for many non-potable purposes. As the development in urban areas is increasing, more roads, car parks, paving, compacted open spaces and other hard surfaces are appearing. During heavy rains, the amount of water that is able to soak into the ground is reduced, so a higher surface runoff rate is occurring. This means that there is a faster build-up and greater volume of stormwater runoff occurring in urban areas, causing severe flooding and related damage, and risk to human health (Prins, 2012).

Impervious surface stormwater harvesting includes all systems that collect and conserve surface runoff after a rainstorm, for storage in some kind of collection area or tank to be used at a later stage as an alternative to municipal water (Peters, 2006; Bouwer, 2002; Dillon, 2008).

Stormwater harvesting has the following advantages/benefits:

- the offsetting of potable water for non-drinking outdoor purposes;
- the protection of natural systems;
- the protection of river/stream water quality, and
- the reduction of runoff and peak flows, thereby reducing flooding and flood damage (Peters, 2006; Bouwer, 2002; Dillon, 2008).

By harvesting stormwater, the detrimental impacts of urban stormwater runoff on rivers and natural ecosystems can be reduced. It can re-establish natural water system flow and habitat equilibrium, and improve water quality (Peters, 2006; Bouwer, 2002; Dillon, 2008).

Harvesting stormwater can also delay the need for major new water resource infrastructure, because it reduces the demand for water from the municipal supply and therefore increases water security. Stormwater harvesting has low pumping costs, since the source is often close to the point of use (Peters, 2006; Bouwer, 2002; Dillon, 2008).

1.3.7 Catchment Surface Types

There are many different types of catchment surfaces that can be used to collect runoff. They can range from natural surfaces to constructed catchments built from a variety of materials including cement, tiles, or metal sheets. Many already built structures such as roofs, roads, children’s playgrounds and parking areas, make excellent rainwater catchments. An advantage in using an existing structure is that the cost of construction has generally already been covered. This can be an important saving within the total cost of putting together a system.

1.3.7.1 Roof Surface Runoff Catchments

For rainwater harvesting, the most common catchment surface is the roof of a house or building. The roof construction material type and style affect its effectiveness as a catchment surface. Typical roofing materials that are most appropriate for rainwater harvesting include corrugated galvanized iron (GI) sheets, tiles and asbestos sheets (DTU, 2002).

Gutters are the most common delivery system associated with roof harvesting. There is a wide variety of shapes and forms, ranging from factory-made polyvinyl chloride pipes to folded sheet metal gutters. Guttering is usually fixed to a building just below the edge of the roof, and channels the rainwater as it runs of the roof into a catchment tank. Due to high installation and maintenance costs, gutters are often the weakest link of a rainwater harvesting system in developing countries as many buildings do not have gutters, the gutters are in poor condition or are overflowing due to blockages from debris build-up (DTU, 2002).

Plant material, dust or bird faeces can collect on the roof catchment area, and when the first rainfall arrives this unwanted material will be washed into the storage tank. Rainwater harvesting systems can therefore also include a system for diverting the contaminated “first flush” water, so that it does not enter the tank, and by doing so greatly improve the water quality. First flush devices can vary between simple, economical systems to more sophisticated and costly systems. Installers often recommend that very simple, easily maintained systems be used, since they are more likely to be repaired if failure occurs.

Roof catchments may also use filtration systems and settling tanks to help remove debris and sediment at the inlet and outlet of the storage tank. Similar to the first flush devices, the level of sophistication for filters varies from rudimentary to complex technology. Surface tanks are most commonly used to store rainwater captured from rooftops.

1.3.7.2 Land Surface Runoff Catchments

Land surface catchment systems use natural, treated or covered land surfaces to collect rainwater. The delivery system for a land surface catchment usually consists of a channel or trench to direct the water into an underground tank or reservoir. A trap or filtering device can be used to reduce the amount of silt or dirt that enters the tank or reservoir. The catchment can be specifically built, or it may already exist for another purpose – for example, a threshing floor, parking area or road (DTU, 2002). Ground catchments are normally used when a suitable roof surface is not available, or in combination, to maximise the harvesting effort. Collected rainwater is usually of poor quality, since it can become easily contaminated by pollutants and excrement. It is recommended that rainwater collected from the ground surface only be used for non-potable purposes such as toilet flushing or garden irrigation. Sub-surface tanks are generally used to store rainwater runoff collected by ground catchments.

1.3.8 Rain- and Stormwater Harvesting Calculations

A variety of factors influence the volume of rain- and stormwater runoff from a specific catchment area. Most fundamental of the factors influencing discharge, is the sheer size of the catchment area. The amount of runoff depends primarily on the total volume of water that falls in the catchment area. The rain- and stormwater runoff from a small area will respond rapidly to changes in the rate of rainfall, as well as the speed at which the runoff water moves. The character of the collection area also exerts a profound effect on runoff processes.

Two very common hydrologic models used to predict runoff is the Rational Runoff formula and the Curve-Number Method. The Rational Runoff formula relates the runoff rate to the simple product of the rate of rainfall, the basin area, and the runoff coefficient. The runoff coefficient is a number which expresses the fraction of the rain falling on a collection surface area that is actually available for use. A different runoff coefficient is given for different land and roof surface types. A highly pervious, forested ground surface is usually assigned a value close to 0%, because almost no water will reach the collection tank, whereas an impervious pavement is usually given a value of between 95%-100% (Hawkins, 1975).

The Curve-Number Method is an improvement of the Rational Runoff formula, and was developed to improve hydrologic predictions. With this model, greater flexibility is allowed in the matching of catchment area conditions with runoff coefficients, and the results have been more extensively calibrated with actual data. None of these models are, however, taking the collection tank/storage vessel into consideration - which is an extremely important aspect when it comes to storage sizing and feasibility predictions (Hawke, 2003).

A simple mass balance equation can be successfully used to calculate the potential yield of rain- and stormwater harvesting systems, while also considering tank storage capacities. Two possible formulas that were described by Fewkes and Butler (2000) are the 'yield before spillage' (YBS) and the 'yield after spillage' (YAS). In the YBS formula, the yield is subtracted before the water has spilled, and in the YAS formula the water first spills and then the yield is taken from the volume in storage. These two main formulas are shown in equations 1 to 4 (Fewkes and Butler, 2000):

YBS:

$Y_t=Min(D_t,S_{t-1}+Q_t)$ *Equation 1*

$S_t = Min(C_a,S_{t-1} + Q_t-Y_t)$ *Equation 2*

YAS:

$Y_t=Min(D_t,S_{t-1})$ *Equation 3*

$S_t = Min(S_{t-1} + Q_t-Y_t,C_a)$ *Equation 4*

Where:

D_t: Demand at time t

Y_t: Yield at time t
C_a: Storage capacity of tank/s
S_t: Storage at beginning of time t
Q_t: Inflow during t^{th} time interval

The choice between using the YBS or YAS formula depends on various factors, and can be greatly influenced by the ratio of supply to demand (Liaw and Tsai, 2004). Fewkes and Butler (2000) found that the YAS formula can produce a conservative estimate of the overall volume of rainwater collected, while being independent of the selected time interval.

At the commercial level, water is normally obtained through the municipal reticulation water network (Figure 6). Alternatives may not be able to completely decentralise a building from the municipal network system, but by incorporating alternatives in the most feasible way, a certain degree of decentralisation can be achieved (Fewkes & Butler, 2000).

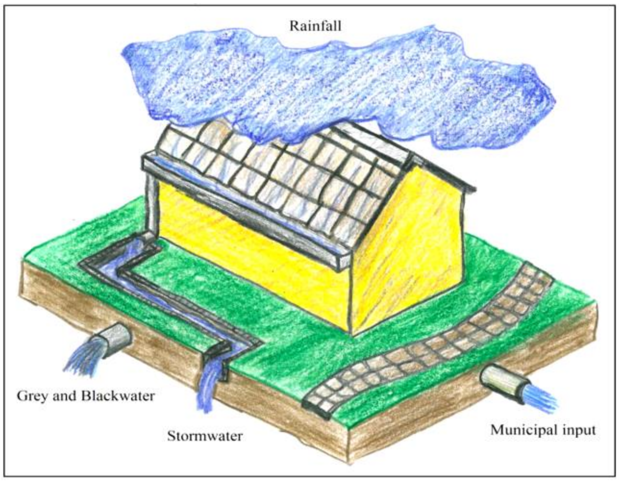

Figure 6: The most common in and return flows of a building (Van der Walt, 2012).

1.3.9 Economic Calculations and Assumptions

Cape Town is facing a situation where demand for water will exceed the available supply. The failure to meet the growing water demand in the City of Cape Town is restricting social upliftment and economic prosperity within the City (City of Cape Town, 2007a). As demand for water exceeds supply, it will be necessary to look at alternative options for meeting or managing the demand. Residential water usage accounts for approximately 58.68% of all water usage in Cape Town. Table 2 below illustrates the City of Cape Town's water consumption and cost composition.

Table 2: Water usage in Cape Town (City of Cape Town, 2007a).

Water Usage in Cape Town (water throughputs) (City of Cape Town, 2007a)				
Cost/annum	**Use Sector**	**Kl/annum**	**%**	
R 668,981,000	Residential: Homes	122,300,000	37.34	*** Residential Water Usage:** 58.68%
R 382,353,000	Residential: Gardens	69,900,000	21.34	
R 279,840,000	Industry	48,000,000	14.66	
R 127,094,000	Commerce	21,800,000	6.66	
R 112,270,000	Public: Municipal	21,800,000	6.66	
R 67,465,000	: Sports	13,100,000	4.00	
R 169,218,000	Unaccounted	30,600,000	9.34	
R 1,807,221,000	**TOTAL**	327,500,000	100.00	

*****Residential water usage was calculated by adding the home and garden water usage.

Table 3 is a projection of the business as usual costs for the City of Cape Town. The following is a brief explanation of the aspects of which costs were calculated as shown in Table 3:

- The Berg River dam is a 68 metre high dam constructed in the Western Cape. It is the centrepiece of the Berg Water Project (BWP) which was designed to capture the winter rainfall and store it for supply to Cape Town's residents during the dry summer months. The project in turn forms an important part of the Western Cape Water Supply System (WCWSS), an intricate system of dams and bulk water infrastructure that provides water to more than 3 million people (City of Cape Town, 2007a).
- The infrastructure costs are the total costs of new infrastructure and of the rehabilitation of existing infrastructure. It also allows for the inclusion of capital required for any special infrastructure projects such as major water pipe replacement projects. Typically, there is a target year set for the elimination of

backlogs (Swilling, 2006). This will require a lot of expenditure in the short term as can be seen as the higher infrastructure costs over the first two years shown in the Table. Once these backlogs have been eliminated the capital expenditure is required only to provide services to new households. This can be seen as the trend in declining infrastructure costs over the last four years as shown in Table 3.

- The opportunity costs of business as usual were conservatively calculated at 30% of the current direct investment flowing into the city (City of Cape Town, 2007a). The opportunity costs relate to any physical development, particularly in an environmentally sensitive area, that carries irreversibility and uncertainty with regard to its ecological footprint (Swilling, 2006). The City of Cape Town water consumption projections of business as usual can be seen in Table 3:

Table 3: Projections of business as usual consumption (City of Cape Town, 2007a).

Projections of Business as Usual Water Consumption (Scenario: Business as Usual – Water) (City of Cape Town, 2007a)						
Costs	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Water Costs	R 1,807,221,000	R 1,807,221,000	R 1,807,221,000	R 1,807,221,000	R 1,807,221,000	R 1,807,221,000
Berg River Project	R 250,000,000	R 250,000,000	R 250,000,000	R 250,000,000	R 250,000,000	R 250,000,000
Infrastructure Costs	R 296,000,000	R 296,000,000	R 261,000,000	R 225,000,000	R 208,000,000	R 194,000,000
Opportunity Costs	R 34,673,839	R 35,797,711	R 36,958,010	R 38,155,918	R 39,232,466	R 40,339,388
Total	**R 2,387,894,839**	**R 2,389,018,711**	**R 2,355,179,010**	**R 2,320,376,918**	**R 2,304,453,466**	**R 2,291,560,388**

According to Swilling (2006), the households falling within the highest income bracket uses nearly 60% of all domestic water. Table 4 illustrate the benefits if all high income households in Cape Town acquires a 2 000 litre rainwater tank against the costs of the Berg River Dam project and the projections of what it will cost the City to meet the infrastructure backlogs and future ongoing demand. The Berg River project will only increase Cape Town’s water supply by 18%, and if compared against the reduction of conventional water by 40% by the implementation of rainwater harvesting, it would have made more sense to provide the R737 million for rainwater harvesting infrastructure as opposed to the R1.5 billion of the Berg River project (Swilling, 2006).

Table 4: Rainwater tanks for the richest households in Cape Town (City of Cape Town, 2007a).

Scenario: Rainwater Tanks for richest households (City of Cape Town, 2007a)						
Costs	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Water Costs	R 1,271,615,878	R 1,271,615,878	R 1,271,615,878	R 1,271,615,878	R 1,271,615,878	R 1,271,615,878
Berg River Project	R 250,000,000	R 250,000,000	R 250,000,000	R 250,000,000	R 250,000,000	R 250,000,000
Infrastructure Costs	R 149,480,000	R 149,480,000	R 131,805,000	R 113,625,000	R 105,040,000	R 97,970,000
Opportunity Costs	R 17,510,289	R 18,077,844	R 18,663,795	R 19,268,739	R 19,812,395	R 20,371,391
Total	**R 1,688,606,167**	**R 1,689,173,722**	**R 1,672,084,673**	**R 1,654,509,617**	**R 1,646,468,273**	**R 1,639,957,269**
Percentage Reductions	**-41.41%**	**-41.43%**	**-40.85%**	**-40.25%**	**-39.96%**	**-39.73%**
Rainwater Tank Costs		**737,658,831**		**R 737,658,831**		

According to City of Cape Town (2007a), the savings obtained from rainwater harvesting can reduce the City's income revenue and relieve pressure on the municipal network's infrastructural capacity (City of Cape Town, 2007a). It is anticipated that the use of rain- and stormwater harvesting will result in a favourable cost-benefit ratio for the consumer, producer, and society as a whole.

Most water sector experts agree that South Africa has only between 1.2% and 1.7% extra fresh water capacity left (Lee & Visscher, 1992). The increasingly costly implication of over-exploitation when the ceiling has been reached, will cause a reduced growth as the costs of remedial action kick in (Liaw & Tsai, 2004). To invest in technologies and systems that uncouple economic growth from rising raw water consumption therefore seems to be the economically sensible route to take. Investing in alternative water technologies are an economic growth stimulant, and the result of such interventions will prevent later growth retardation (City of Cape Town, 2007b).

1.4 Research Motivation

The motivation for rain- and stormwater harvesting research is regarded as key to the initiation of any new research study. Some motivational factors for this research are further discussed below.

1.4.1 Knowledge Contribution

Key factors assisting in the growth of rainwater harvesting systems are the availability of pertinent information and literature on rain- and stormwater harvesting feasibility (which includes information like the technology available, as well as its costs and efficiency to harvest rainwater), the benefits of harvesting rainwater to the consumer, the community, the environmental benefits, and also the positive benefits of being part of the City's water resources management strategy (Prins, 2012).

In Cape Town, very little data on alternative water sources such as rainwater, greywater, groundwater, spring water, blackwater and seawater desalination - as well as the benefits associated with these resources - is available. One of the reasons for this is that limited surveys have been conducted on the perception, knowledge and attitudes of consumers when it comes to the usage of these resources (Nevondo & Cloete, 1999). The Water By-law of the City of Cape Town (2012) is promoting the use of alternative water resources, but a serious gap exists when it comes to information on the infrastructure needed, suitable usages, and the water quality of these resources.

According to Van der Walt (2012), the combined usage of alternative water resources at a particular building, such as rainwater for toilet flushing and greywater for irrigation purposes, can produce water savings of between 6% and 9% higher than what is achieved with the use of a single resource.

Further research is needed to establish the water savings capacity and viability of alternative water resources - in particular, rain- and stormwater harvesting. Considering how alternative water sources could reduce the demand on the City's water distribution system, combined with the apparent prevalence of alternative water resources in South Africa, it is astonishing to note the acute lack of research into the topic over the years (Jacobs, 2010).

To assess the need for rain- and stormwater harvesting information worldwide, and in South Africa, a Google Scholar citation string search was conducted (see Table 5):

Table 5: Google Scholar citation results.

Search string	Number of articles	Number of articles for "Cape Town"	SA articles as a % of total
Alternative Water	3,350,000	136,000	4.1
Runoff Harvesting	98,000	10,700	10.9
Rainwater Harvesting	27,400	3,560	12.9
Commercial Building Rainwater Harvesting	20,800	3,130	15.04
Stormwater Harvesting	9,320	745	7.9
Commercial Building Stormwater Harvesting	7,390	804	10.9
Green Building Rainwater Harvesting	18,300	2,560	13.9
Green Building Stormwater Harvesting	2,710	222	8.1
Commercial Building Rainwater Harvesting Water Save	11,200	1,650	14.7
Commercial Building Stormwater Harvesting Water Save	2,600	297	11.4

Based on these results, the following conclusions can be drawn:
The terms "alternative water" and "runoff harvesting" are the most numerous, in terms of English-language articles worldwide, indicating a huge interest and need. It is interesting to note that, for Cape Town, only 4.1% of alternative water use literature is applicable to Cape Town, in comparison with the total worldwide figure.

The results indicated that there is a wide interest, in Cape Town, in rainwater harvesting, but limited local literature was available on stormwater harvesting, especially at commercial buildings. It is interesting to note the low worldwide figures on stormwater harvesting and related water savings at green buildings. The results indicate the same lack of local literature in Cape Town.

Due to the above results, it can be concluded that there is a gap in literature on, especially, green building stormwater harvesting and related water savings, and that there is a need for more information on alternative water resources in Cape Town. This is, therefore an area worthy of investigation, particularly given the lack of local literature available. The focus of this research project will therefore be on the benefits of rain- and stormwater harvesting use at commercial businesses in the water-stressed, winter rainfall, metropolitan city of Cape Town.

1.4.2 Society and Health

Access to clean water in reasonable quantities is essential to human health. In the early 1990s it was estimated that 1.2 billion people were without access to a convenient supply of clean water (Bastermeyer & Lee, 1992).

According to Gleick (1996), there is a direct link between the provision of clean water, adequate sanitation and improved health. An inadequate water supply is a contributing factor to poor sanitation. For the prevention of diseases, it is important to have access to good-quality sanitation services (Kahinda, Taigbenu & Boroto, 2007). In South Africa, however, 16 million people were still without adequate sanitation services in 2006 (Info, 2006). According to a status of sanitation report from DWA (2012), 11% of South Africa’s population had no access to sanitation services, and 26% had access to inadequate sanitation services, in 2011. A high assurance of water supply and quality is essential for human health, and play a major role in laying the foundation for economic growth (Phillips, Daoudy, McCaffrey, Ojendal & Turton, 2006).

As the global population is increasing, and the demand for water grows, there may also be an increase in the worldwide use of rainwater and stormwater harvesting (Maller, Townsend & Pryor, 2006). The increase in population growth is also causing a related increase in potential catchment surfaces, therefore increasing the potential for the application of these alternative water resources (Gould & Nissen-Petersen, 1999).

Rainwater and stormwater harvesting represents a cheap supply of good quality water, and there is limited transport costs needed, as the captured water is transported via a decentralised system. To install rain- and stormwater harvesting systems require low to moderate technical skill, depending on the type of system and end-use (Lee & Visscher, 1992).

Rainwater and stormwater harvesting has, in many cases, not only improved human well-being and ecosystem services, but also acted as a way of improving equality and gender balance, and strengthening social capital in a community (Vickers, 2001). Improving domestic water supply by rainwater and stormwater harvesting, saves women and children from the tedious work of fetching water. In many instances woman have benefitted from having water for a small kitchen garden, thus improving diet and income. The economic upliftment of communities, empowered by the implementation of rainwater harvesting for vegetable gardening, has strengthened communities and allowed them to address other issues related to development, health and knowledge of their livelihoods and environment (Barron, 2009). This research study will however be focusing on the value of rain- and stormwater harvesting from commercial buildings, and the social value for low income communities will therefore not be addressed.

1.4.3 Economy

It has, and will, become more financially viable to install rainwater and stormwater harvesting systems, due to the high water costs which have been escalating far faster than the inflation rate over recent years. The City of Cape Town has presented a draft budget of R31.8 billion for the city's 2013/14 financial year, with increases of up to 9.53 percent for water (City of Cape Town, 2013). Economists have warned that the increases would not bode well for families and small businesses, given that it would be higher than the inflation rate, which is currently 5.9 percent.

The cost-benefit analysis of rainwater and stormwater harvesting systems during this study, will take into account the associated monetary cost and savings associated with this resource. For the average business owner, the result of using this alternative resource could mean a reduced water account at the end of the month, as well as the resultant water savings for the city. The additional savings from the reduced wastewater volumes and treatment costs may also be significant (City of Cape Town, 2007a).

1.4.4 The Environment

The result of harvesting rainwater and stormwater could be reduced stormwater pollution levels, as well as reduced surface runoff volumes and rates. Reduced stormwater runoff volumes and rates will release the pressure on South Africa's natural rivers, streams and wetlands, by means of reduced flooding risks and damages - especially in the case of increased rainfall intensities due to climate change.

The unique ecological balance of these water systems is mostly non-existent, with the result of dead systems (no living creatures) prone to eutrophication. A reduction of water inflow levels can relieve the amount of pollutants carried into systems, reduce river bank erosion, and give the systems chance to get back their natural equilibrium. It can also enable currently overflowed wetlands to recover and regain their natural flood control abilities. Rainwater and stormwater harvesting has, therefore, an ecosystem-protective function.

Rainwater and stormwater harvesting research would also provide valuable information regarding rainfall intensities, which could, in turn, provide valuable information regarding the trend in rainfall pattern shifts due to the effects of climate change. The Intergovernmental Panel on Climate Change (IPCC) projects a decrease in runoff of 10%-30% in Southern Africa, and a decrease in groundwater recharge due to changes in the timing and quantity of rainfall (IPCC, 2007). According to Wilson (2011) the "hotspot" in South Africa is the Western Cape, which is a winter rainfall area where 5%-30% less rain could fall during winter and autumn, with dramatic implications for water provision.

1.4.5 Knowledge Dissemination

If the outcomes of this study are in favour of rainwater and stormwater harvesting, the following are envisaged:

- programmes and frameworks for the promotion of rain- and stormwater harvesting installations in green commercial buildings;
- conference presentations relating to water conservation/demand management and the results of this research; and
- information being made available to different stakeholders in the water sector, such as the DWA, and also tertiary and other institutions.

1.5 Hypothesis and Key Research Questions

1.5.1 Problem Statement

The viability of rainwater and stormwater as an alternative water resource in a winter rainfall region is dependent on the costs, benefits, and social and environmental factors. Many conclusions for and against rain- and stormwater harvesting feasibility are made by water professionals, leaving a certain degree of uncertainty as to whether rain-and/or stormwater harvesting can, indeed, be a viable alternative water option for a water-scarce, winter-rainfall city such as Cape Town.

1.5.2 Research Objectives

This study will attempt to do the following:

- Assess the viability and feasibility of rainwater and stormwater harvesting systems, as well as the water savings efficiency of these systems, for green businesses in a winter rainfall area, by means of comparison, theoretical models and a perception survey. During this study only green business buildings in the Kommetjie, South Peninsula area will be focused on.
- Determine the average amount of potable water being used by green businesses in Kommetjie, Cape Town.

- Determine the potential uses of harvested rain- and stormwater, as well as the percentage of municipal water these usages account for.
- Assess how much rain- and stormwater can be collected off the roof and hard land surface catchment areas of commercial businesses in Kommetjie, by means of calculations relating to the surface area sizes and precipitation volumes; assumptions on the percentage of rainfall runoff that can be captured, will also be made.
- Develop a model in order to facilitate calculations and assumptions on the volume of runoff that can occur, as well as the potential amount of rain- and stormwater which can be captured when considering tank usage and re-filling behaviour.
- Assess the effectiveness of the different runoff models most commonly used in scientific literature, and identify the model/s most appropriate to this study.
- Assess the average amount of municipal water used for toilet flushing, and assess the percentage of this water that can be offset by rainwater usage for the same purpose.
- Identify suitable uses of harvested rain- and stormwater for businesses, and determine different communities' attitudes towards these uses, by analysing questionnaire results.
- Identify any challenges that can be improved upon, and report on key recommendations.

1.5.3 Key Research Questions

This research seeks to test and analyse whether the harvesting of rain- and stormwater is a viable alternative water resource for commercial businesses in a winter rainfall region by using the Kommetjie business catchment area as a case study.

The following key research questions will be addressed in this study:

- Is rainwater and stormwater harvesting a viable supplemental water option for commercial businesses in a winter rainfall region?

- What is the potential of rainwater and stormwater harvesting for reducing demand on potable water for commercial businesses in Cape Town?

1.5.4 Hypothesis Testing

The following hypothesis will be tested:

TEARS Pilot Study Site

- $H:_0$ There is no statistically significant difference between the pre-rainwater harvesting level of water usage in the pilot study building, and the post-rainwater harvesting level of water usage.
- $H:_1$ There is a statistically significant positive difference between the pre-rainwater harvesting level of water usage in the pilot study building, and the post-rainwater harvesting level of water usage (there is greater post- than pre-rainwater harvesting level of water usage).
- $H:_2$ There is a statistically significant negative difference between the pre-rainwater harvesting level of water usage in the pilot study building, and the post-rainwater harvesting level of water usage (there is greater pre- than post-rainwater harvesting level of water usage).

Commercial Business Area

$H:_0$ There is no statistically significant difference between the level of average municipal water usage in the Kommetjie business district buildings, and the average theoretical harvested water yields at the buildings for winter and summer ($\mu_1 = \mu_2$).

$H:_1$ There is a statistically significant positive difference between the level of average municipal water usage in the Kommetjie business district buildings, and the average theoretical harvested water yields at the buildings for winter and summer ($\mu_1 \neq \mu_2$) (the yield is greater than the municipal usage).

$H:_2$ There is a statistically significant negative difference between the level of average municipal water usage in the Kommetjie business district buildings, and the average theoretical harvested water yields at the buildings for winter and summer ($\mu_1 \neq \mu_2$) (the yield is less than the municipal usage).

1.5.5 List of Dependant and Independent Variables

The independent variable is the variable that is changed to test the effects on the dependent variable. The dependent variable is therefore "dependent" on the independent variable. As changes to the independent variable are considered, the change in the dependent variable is observed and recorded (De Vos, 2002). In Table 6, the independent and dependent variables of this research study are listed:

Table 6: The dependent and independent variables of this research study.

Dependent Variables	Independent Variables
Information to Determine Yield	
Average Rain- and Stormwater Runoff Yield	Total Surface Area (m^2)
Average Roof Runoff Yield	Roof Surface Area (m^2)
	Roof Runoff Coefficient
Average Impervious Land Surface Runoff Yield	Impervious Land Surface Area (m^2)
	Land Surface Runoff Coefficient
Monthly Average Rain-and Stormwater Yield	Monthly Average Rainfall (mm)
Collected rain- and Stormwater Yield	Rain- and Stormwater Collection Tank/ Reservoir Size
Average Rainfall and Consumption	
Average Winter and Summer Consumption	Monthly Average Rainfall (mm)
Average Winter and Summer Harvested Yields	
Monthly Average Municipal Water Consumption (Kl)	Theoretical Monthly Runoff (mm)
	Toilet Flushing Demand
Green Business Survey Questionnaire	
Participated	Participation
	Non-participation
Use Rainwater	Yes
	No
Roof Catchment Types	Asbestos
	Corrugated Iron
	Corrugated Iron/Asbestos Mix
Land Surface Catchment Types	Paved
	Tar
	Paved/Tar Mix

Dependent Variables	Independent Variables
	Cement/Tar Mix
	Paved/Cement/Tar Mix
Highest Water-Use Category	Factory Floor Washing
	Factory Operational Washing
	Garden Watering by Hand
	Irrigation
	Kitchen
	Surface washing
	Toilet
	Wash-bay
Sell Green Products	Yes
	No
Applying Green Practices	Yes
	No
Think They Can Benefit from Rain- and/or Stormwater Harvesting	Yes
	No
Water Saving Fixtures/Devices	Yes
	No
Irrigate?	Yes
	No
Time controller?	Yes
	No
Number of Toilets in Building	1
	2
	3
	4
	6

1.5.6 Validity of Research Results

The validity of the survey results is concerned with whether the actual measuring reflects the intended measure (Rose & Sullivan, 1996). For the purpose of this research study, only content and construct validity was elaborated upon. Content validity is concerned with the representativeness or sampling adequacy of the content of a measuring instrument (De Vos, 2002), while construct validity refers to the extent that a measuring instrument can be shown to measure a particular hypothetical construct. The descriptive analysis of the survey results was indicated in table format for ease of reference. Each variable was tested to fall within the set boundaries.

2 Materials and Methods

2.1 The Research Methodology

Below is a detailed summary of the research methodology that was followed:

- Literature review:
  - The review also included an assessment of the effectiveness of the different runoff models most commonly used in scientific literature, and identifying appropriate data for use in the development of a model.
- Quantifying the potential amount of rainwater which can be harvested off rooftops and impervious land surfaces of commercial buildings, by means of calculations and models relating to average roof sizes, surface areas and rainfall assessed at the Kommetjie study area in the Cape Peninsula, South Africa:
  - The development of a model to assist business owners and developers to assess how much water can be captured, and the required infrastructure needed to optimise the rainwater and stormwater harvesting efforts.
  - The retrieval of district rainfall and commercial consumption data records from municipal records.
  - The retrieval of data relating to the average commercial building roof and impervious land surface area sizes within the Kommetjie business district.
- TEARS practical pilot case study site – the insertion of flow measurement metering on a Coca Cola sponsored potable top-up rainwater system (Figure 7) that will be studied:
  - The installation of 15 mm Kent meters (Figure 8) for flow measurement at the inflow (rainwater harvested), outflow (rainwater mixed with municipal water) points, to measure harvested rainwater and potable

water consumption components.

Figure 7: The Coca Cola sponsored potable top-up roof harvesting system installed at the TEARS pilot study site**.**

Figure 8: One of the 15 mm Kent mechanical flow meters inserted on the TEARS potable top-up system.

- The flow volumes of this 5 000 L rainwater (potable top-up for toilet flushing purposes) system were measured, to evaluate the effectiveness of the rainwater tank's ability to harvest water, and the amount of usage of this harvested water, in order to complement the theoretical study results.
- Assumptions on the water savings capability of different types of systems; according to received results and interviews; and the identification of usage recommendations.
- The installation of an electronic rainfall measurement gauge (bucket-type) at the study site (Figure 9):

Figure 9: The electronic bucket-type rain gauge installed at the TEARS study site.

- The analysis of before and after installation water account information, by means of retrieval from the municipal SAP information management system (to assess how much municipal water was used before and after installation).

- A perception and attitude survey conducted on businesses in the Heron and Fish Eagle Business Park sites within the Kommetjie commercial business study area, by means of a survey questionnaire.
  - Door to door visits to commercial buildings in the Kommetjie business area. A telephonic pre-survey was conducted in order to assess the time taken to complete the survey questionnaire, and any challenges experienced with the survey questions, in order to facilitate planning for the main survey.
- A cost-benefit and future projection analysis in order to assess the economic viability of the rainwater harvesting systems/technology.
  - Assessing the current costs to install a rainwater harvesting system, as well as the costs of municipal water, in order to assess economic feasibility.

2.2 Statistical Analysis

Statistical data analysis can be defined as the process of bringing structure, order and meaning to any collected data (De Vos, 2002). The primary objective with the statistical analysis during this study, was to prove that rain- and stormwater harvesting is feasible within a winter rainfall area - more specifically, for commercial businesses within the Kommetjie area.

The statistical analysis entailed three major steps, as described by De Vos (2002:

- the data preparation step, which is the cleaning and organising of the collected information. Data cleaning consisted of the removal or correction of any unreadable or corrupt data;
- describing the information that was collected, which is called descriptive statistics; and
- testing the assumptions made through hypothesis and modelling, which is called inferential statistics.

The data has been analysed by using SAS software. Descriptive statistics such as frequency tables were used, showing the distributions of the statement responses (descriptive statistics were used to summarise the data). As a measure of central tendency and dispersion, the means and standard deviation of the statements with an ordinal/ratio scale of measurement, were shown.

2.2.1 Statistical Tests Used

Descriptive statistics were performed on all variables, displaying means, standard deviations, frequencies, percentages, cumulative frequencies and cumulative percentages. The following statistical tests were used for this study, as described by Siegel (1956):

- The Kruskal-Wallis test - for interval data with more than two independent samples. The *Kruskal-Wallis one-way analysis of variance* by ranks is a non-parametric method for testing equality of population medians among groups. Intuitively, it is identical to a one-way analysis of variance with the data replaced by their ranks. It is an extension of the *Mann-Whitney U test* (Wilcoxon Two-Sample Test) which compares two groups to three or more groups. Since it is a non-parametric method, the Kruskal-Wallis test does not assume a normal population, unlike the analogous one-way analysis of variance. However, the test does assume an identically-shaped and scaled distribution for each group, except for any difference in medians.

- The Mann-Whitney *U* test or Wilcoxon rank-sum test - for ordinal data with two independent samples. The Mann-Whitney *U* test (also called the Mann-Whitney-Wilcoxon (MWW), Wilcoxon rank-sum test, or Wilcoxon-Mann-Whitney test) is a non-parametric test for assessing whether two samples of observations come from the same distribution. The null hypothesis is that the two samples are drawn from a single population, and, therefore that their probability distributions are equal. It requires the two samples to be independent, and the observations to be ordinal or continuous measurements – that is, one can at least say which is the greater of any two observations.
- The Wilcoxon signed-rank test - a non-parametric statistical hypothesis test, used when comparing matched samples, two related samples, or repeated measurements on a single sample, to assess whether their population mean ranks differ.

3 Study Area

The Heron and Fish Eagle Business Park sites within the Kommetjie commercial business area, and the Tears practical case study site is located in the southern part of Cape Town; an area commonly known as the Cape Peninsula. The research conducted during this study focused mainly on practical and theoretical research methods within these sites.

3.1 The Kommetjie Business Area

In the aerial photo below, the Kommetjie business area stretches' over a wide area within (see Figure 10). The bulk of the businesses are concentrated near the bottom right of the photo.

Figure 10: An aerial photograph of the Kommetjie commercial business area.

Common businesses that can be found here are bakeries, cleaning product suppliers, confectionary and biltong stores and gift shops, to name just a few.

It must be noted that although many businesses are concentrated in this business park sites, there are numerous other businesses throughout Kommetjie which will not form part of this study.

3.2 The TEARS Kommetjie Case Study Site

The TEARS Animal Welfare Organisation is situated on the Kommetjie Road, between the suburbs of Fish Hoek and Kommetjie, near the far southern point of Cape Town, approximately 45 km outside the central city, as can be seen in Figure 11. It can be located at GPS co-ordinates: 34008’S, 18019’E.

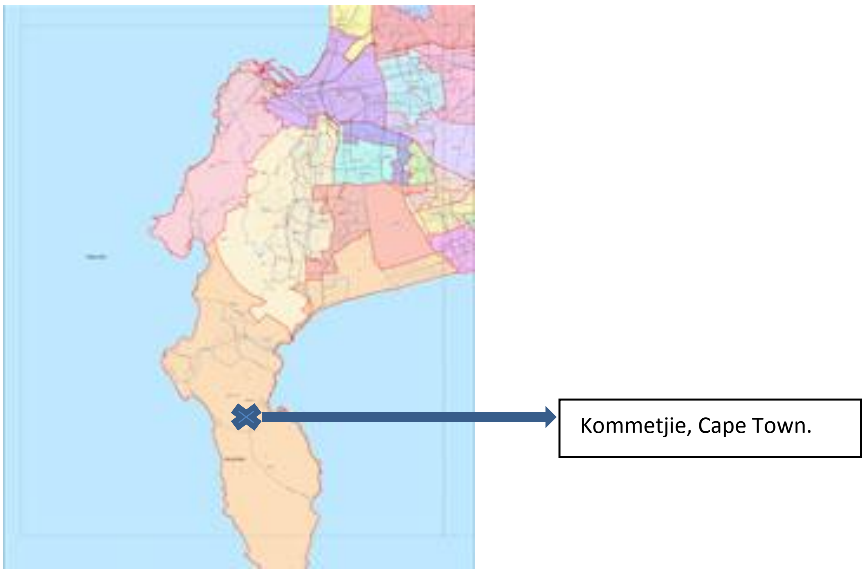

Figure 11: The location of the Kommetjie study area.

3.3 Rain- and Stormwater Harvesting Within a Winter Rainfall Region

Cape Town experiences five months of rainfall in the winter that is above 50 mm/month, as can be seen in Figure 12, below. It is over this period that gardens require little to no irrigation. This is, however, the period when rainwater tanks are either filling up or are filled to capacity, and excess water overflows to waste.

This is the very reason that rain- and stormwater harvesting has been looked upon as being a less viable option of alternative water resource. This study will test this common opinion, and also assess the use of rainwater towards a higher, year-round requirement such as, for instance, toilet flushing.

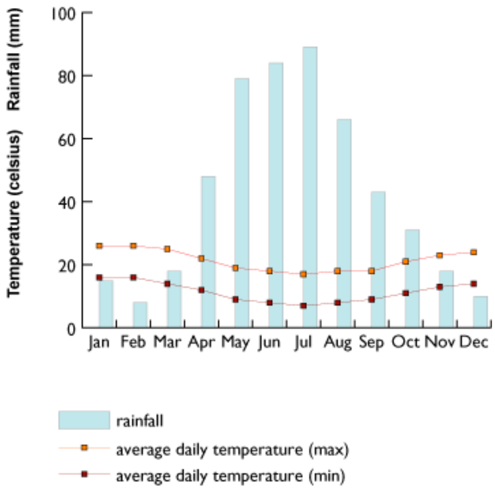

Figure 12: Average historical rainfall figures - Cape Town airport (past 38 years), (Freewater, 2012).

3.4 Delimitation of Study

Practical flow measurement; as was done with the TEARS pilot site; was not implemented in the commercial business area and only potential figures, according to the theoretical runoff model, were used. Irrigation, as mentioned as a suitable use for harvested stormwater, was not further analysed regarding usage and volumes in this study. This study is also not focusing on rain- and greywater combined usage due to study impracticalities.

4 Results and Discussion

The research results indicated important key findings. These results and findings are discussed in detail below:

4.1 Precipitation and Consumption Assessment

During this study, it was found essential to establish whether there is a direct link between seasonal potable water consumption and rainfall patterns. This will enable a better understanding of the impact of rain- and stormwater harvesting within a winter rainfall area.

4.1.1 Historic and Current Rainfall Comparison

Rainfall is highly variable and unpredictable, especially in dry climates that are susceptible to droughts. Since rainfall may vary greatly from year to year, it is important to use historical data of at least 10 years, but preferably for a longer period (100 years), to increase the probability of a successful rain- and/or stormwater harvesting system design.

For this study, rainfall data was measured by means of an electronic bucket-type rainfall gauge installed at the TEARS pilot study site. The data was measured from 1 November 2012 to 31 September 2013. By comparing the observed rainfall with the 100-year average historic figures, it can be seen that seven out of the 12 months received less rainfall, compared with the average historical rainfall for those specific months (Table 7). The results also indicated that the month of February are receiving significantly more rainfall (150%), and that June and August received an increased rainfall of approximately 50%:

Table 7: The average observed rainfall compared with the average historical rainfall figures, showing the percentage difference.

Month	2012/2013 Observed Rainfall (mm)	100 Year Average Rainfall Data (mm) (Freewater, 2012)	Percentage Difference Relative to the 100 Year Average Rainfall Data (%)
November	7	33	-78.79
December	2	25	-92
January	6	21	-71.43
February	54	21	157.14
March	32	30	6.67
April	44	64	-31.25
May	44	114	-61.40
June	214	144	48.61
July	30	138	-78.26
August	199	127	56.69
September	66	80	-17.5

In Figure 13, it can be seen that January, May, July, November and December received 71% to 92% less rainfall, while February, June and August received significantly more:

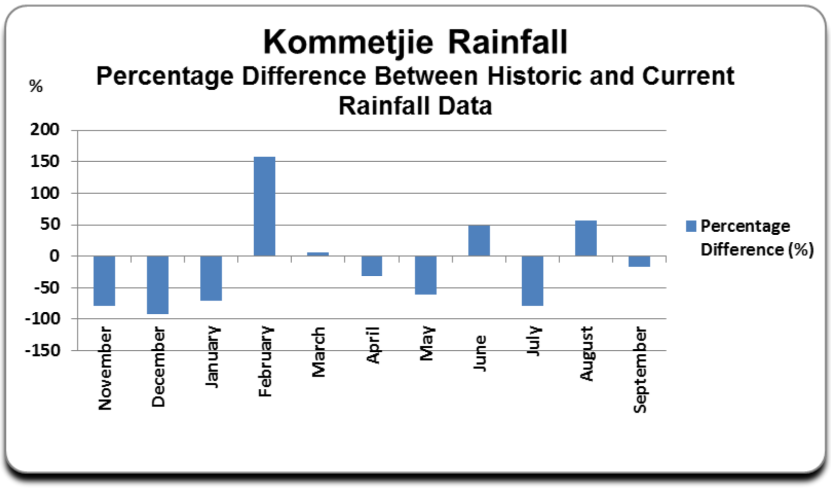

Figure 13: The percentage difference between the historical and current rainfall figures in Kommetjie.

4.1.2 Winter and Summer Water Consumption Variations

Water consumption data of the CCT consumers, as well as the Kommetjie commercial business area consumers, were drawn from the municipal data management system. After careful analysis of this data, the results for the CCT consumption revealed some months with high consumption figures, and others with low consumption figures, as can be seen in Figure 14, below. It can also be seen in Figure 14, that the rainy season is shorter (5 months) than the dry season(7 months), (indicated by the horizontal blue arrows), which are having a profound effect on the City's reservoirs, in carrying the demand through the longer dry months.

Due to the consumer consumption analysis done during this study, a trend of re-occurring low consumption months and high consumption months was identified. The identified months (Figure 15, further below) corresponded with the City's annual winter and summer seasons, showing a clear low consumption trend during the wet, winter months, and a high consumption trend during the dry summer months.

This can potentially be ascribed to the seasonal consumer usage factors such as garden irrigation, and water leisure activities such as swimming pool usage, for example, during the hot, dry summer months, thereby causing the higher average water consumption trend. During the colder, wet winter season there is less garden irrigation, due to constant winter rainfall, and very little water leisure usage, causing the much lower water consumption trend.

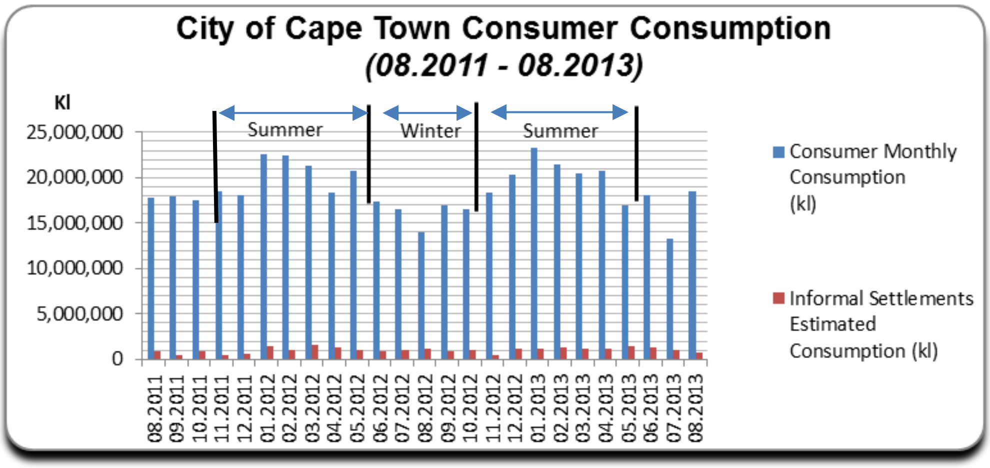

Figure 14: The average two-year consumer consumption within the City of Cape Town, showing a clear low and high consumption seasonal pattern. The horizontal arrows indicate a much shorter wet (winter) season.

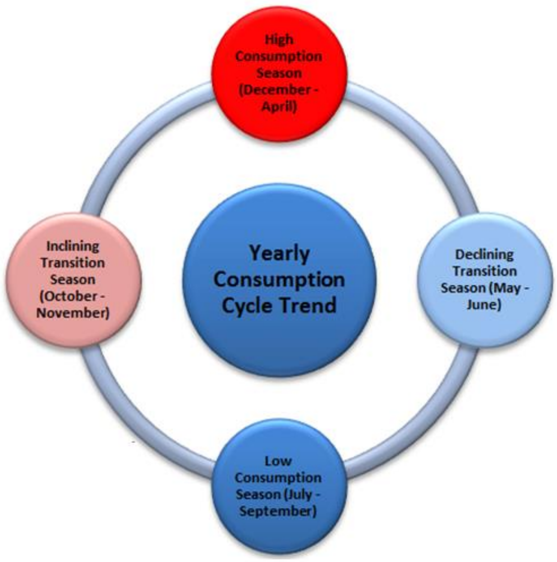

Figure 15: The low and high consumer consumption seasons identified through the consumer consumption analysis done during this study.

The Kommetjie commercial business area results, however, showed a much lower percentage difference between the summer and winter consumption pattern (Figure

16). This can be due to the fact that the commercial businesses in the Kommetjie business area have a lower percentage ratio of garden/lawn irrigation land use than that of residential properties. Most of the commercial properties had no gardens or lawn; or had only small patches of gardens or lawn at their front reception areas. Due to this factor limited summer irrigation activities were taking place in the Kommetjie commercial area, thereby causing the much lower difference between the winter and summer consumption pattern, as can be seen in Figure 16:

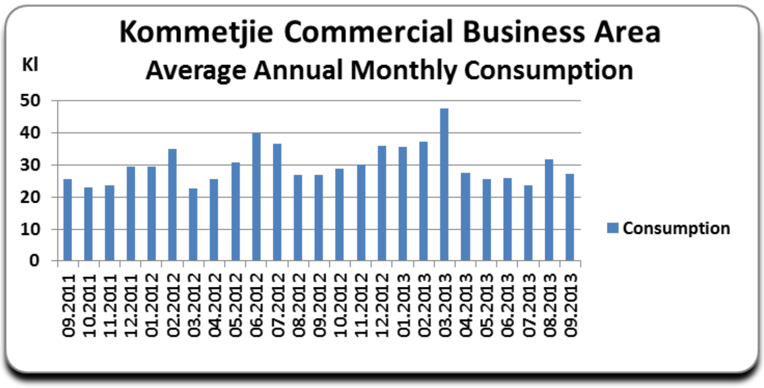

Figure 16: The average annual monthly consumption per building of the Kommetjie commercial business area.

Most of the businesses in the study area had either completely tarred or paved land surface coverage around their buildings, or a small percentage of land patches covered with lawn or flowerbeds at the front of their business reception areas, for ornamental purposes. There are almost no water leisure activities taking place at the commercial businesses. In spite of this, a 10.1% difference between the annual average summer and winter consumption levels were revealed by the consumption analysis results (Table 8):

Table 8: The average annual and seasonal water consumption figures of the Kommetjie commercial business study area.

The Kommetjie Commercial Business Area Average Annual and Seasonal Water Consumption.	
Average Annual Monthly Consumption	32.25 Kl
Average Summer Monthly Consumption (taken over 7 months: Nov. - May)	33.77 Kl
Average Winter Monthly Consumption (taken over 5 months: Jun. - Oct.)	30.35 Kl
Percentage Difference Between Summer and Winter Consumption	10.1%

4.2 Rain- and Stormwater Harvesting Collection Systems

The area of the catchment surface is critical to the commercial viability of a collection system for commercial buildings. The main difference between a residential and commercial collection system would be the potential combined harvesting from hard land surfaces as well as the roof surfaces - which could have a major effect on the viability of the commercial system (GDRC, 2009). The viability of a rainwater system should be evaluated for commercial buildings on a case-by-case basis, taking into account the potential of rainwater collection from all hard surfaces.

Collection systems can vary from simple economical systems to more sophisticated systems where very large catchment surfaces are used to harvest the rain-and/or stormwater. In both cases, the water is either channelled by gravitational flow, or pumped to its intended end-use. The preferred collection systems which can be used depends on such factors as the size and nature of the catchment areas, the average rainfall of the specific area, and the preferred end-usage (GDRC, 2009). The above and below-ground collection systems are described in section 4.2.1 below.

4.2.1 Above-ground Roof Collection Systems

Roof water collection systems can vary from economical installations to more costly potable top-up systems. The harvested water from the more economical systems can be used for small scale garden irrigation, as well as outdoor washing purposes. The more costly potable top-up systems are perfect for indoor toilet flushing usage -

which represents a large percentage of the commercial businesses' water use (GDRC, 2009).

The main components of the above ground collection system are the following:

- the gutter/s and piping that channel the rainwater from the catchment surface to the collection tank, as can be seen in Figure 17;
- from the collection tank the water can be channelled gravitationally, or by pumped pressure, to the intended end-use;
- some systems can have a first flush system installed in order to improve water quality after extended dry periods;
- most systems will also include rainwater filters, which acts as a sieve to catch any large particles, such as leaves and tree debris, before they enter the collection tank; and
- some installers my also include more sophisticated water treatment- or filtering systems, in order to ensure quality in cases where the intended end-use requires this (GDRC, 2009).

The degree of system sophistication and extra material additions largely depends on the initial capital investment.

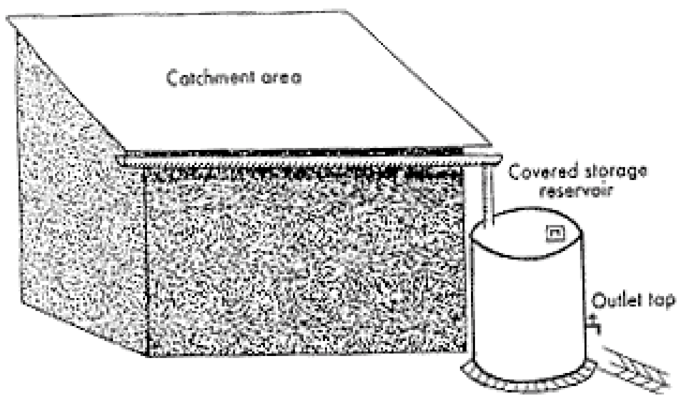

Figure 17: Example of an above-ground roof collection system (GDRC, 2009).

4.2.2 Below-ground Land Surface Collection Systems

In most cases the below-ground harvesting system is used for the harvesting of stormwater from ground or land surface catchment areas. Compared to rooftop catchment techniques, ground catchment techniques provide more opportunity for collecting water from a larger surface area, and are appropriate for harvesting at large properties such as schools, industrial or commercial buildings and shopping centres (GDRC, 2009). By the collection of surface runoff in large underground storage reservoirs (Figure 18), this technology can possibly meet water demands during dry periods (GDRC, 2009).

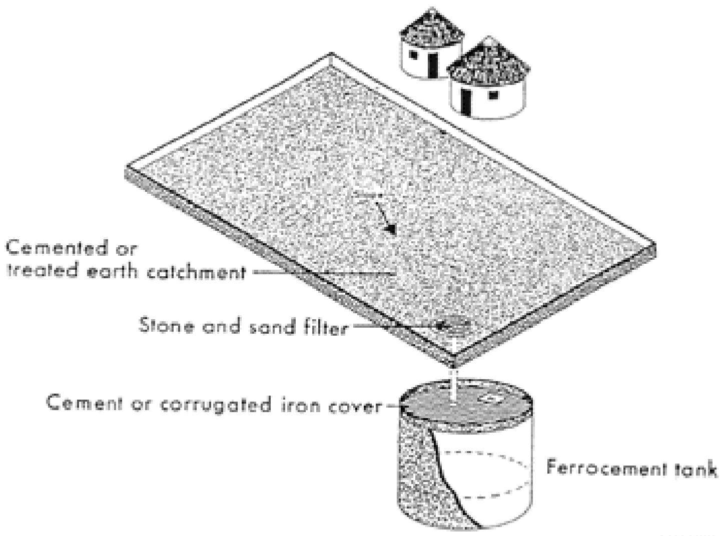

Figure 18: Example of a below-ground collection system (GDRC, 2009).

When harvesting stormwater from a land surface area, the main recommended end-usage should be for non-potable purposes such as toilet flushing or irrigation, due to the wide variety of land surface pollutants which can contaminate the water (GDRC, 2009). In order to ensure human safety, it is preferred, by most system installers, to connect a 'sub-surface' irrigation system to the underground reservoir. In this way, the water is delivered below the ground directly to the plant roots, enabling a smaller volume of water to be used, and therefore reducing the risk of human contact with the water.

4.2.3 Combined Roof and Land Surface Collection Systems

A combination of the roof and land surface collection systems can be used, in order to maximise on the benefits. For commercial businesses like nurseries, where a large percentage of the water use is going towards the irrigation of plants/greenhouses, a below-ground system, incorporating the combined collection of roof and land surface harvesting, is recommended (Figure 19).

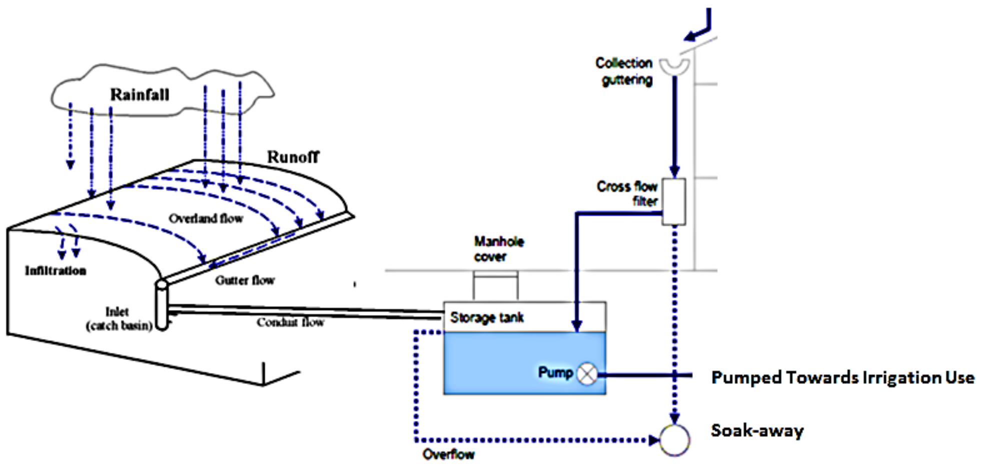

Figure 19: A schematic representation of a below-ground roof and surface rainwater catchment system, which is ideal for nursery irrigation use (GDRC, 2009).

In the study area, the commercial buildings consisted mostly of corrugated iron roof collection surfaces, and tarred or paved land surface collection areas such as roads and parking bays. This setup would therefore suit the combined use of roof and land surface harvesting systems.

According to the survey and interview results obtained during this study, toilet flushing was identified as the highest water use category within the commercial buildings situated in the study area. The potable top-up roof harvesting system is therefore highly recommended for commercial businesses, as it ensures that there is always water available in the collection tank, for toilet flushing. This roof harvesting system should, however, be used in conjunction with the below-ground system, as it is a common occurrence for the roof-harvested rainwater to be insufficient to carry the demand through the dry summer season within a winter rainfall region.

4.3 Calculation of Required Storage Size

When designing a rainwater catchment system, it is very important to size the water tank correctly, in order for it to provide adequate storage capacity. Often, the only variable that the installer can influence is the tank size, since existing roofs are used as catchments, and the amount of rainfall cannot be changed. Rainfall is not constant throughout the year, and it is therefore important to design the system to have an adequate capacity, to enable the constant use of rainwater even well into the dry periods. Knowledge of seasonality, the rainfall quantity, the volume of the storage tank, the area of the catchment surface, and the quantity and period of use required for water supply purposes, is critical (Gould & Nissen-Peterson, 1999).

In practice, the exact volume of water which can be harvested cannot be assessed, since a portion of the rainwater is absorbed by the collection substrate by evaporation from the surface, and a portion may be lost to the first flush system. A portion may also be lost as overflow from the storage tank or reservoir, if it has insufficient capacity to store the entire collected volume - especially during a heavy rainstorm. The available amount of rainwater harvested from a specific surface area would usually be approximately 70% to 80% of the gross volume of rainfall (GDRC. 2009).

Different tank sizing methods are available, but a preferred method is the cumulative monthly water supply and demand method. With this method, the most appropriate tank or reservoir size can be calculated by using a spreadsheet (for example, Microsoft Excel) or by hand, as can be seen in the practical example shown in Table 9 below:

Table 9: An example of the cumulative tank size assessment method for a theoretical hospital building (Gould & Nissen-Peterson, 1999).

Calculation of Cumulative Supply, Demand and Storage Requirement (hypothetical example) (Gould & Nissen-Peterson, 1999).						
Column 1	**Column 2**	**Column 3**	**Column 4**	**Column 5**	**Column 6**	**Column 7**
Month	**Rainfall (mm)**	**Rain/Stormwater Yield (m^3)**	**Cummulative Yield (m^3)**	**Water Demand (m^3)**	**Cummulative Demand (m^3)**	**Storage Requirement (m^3)**
Oct.	88	15.05	15.05	15.05	15.05	0.00
Nov.	124	21.20	36.25	15.05	30.10	6.16
Dec.	134	22.91	59.17	15.05	45.14	14.02
Jan.	114	19.49	78.66	15.05	60.19	18.47
Feb.	101	17.27	95.93	15.05	75.24	20.69
Mar.	136	23.26	119.19	15.05	90.29	28.90
Apr.	214	36.59	155.78	15.05	105.34	50.45
May.	75	12.83	168.61	15.05	120.38	48.22
Jun.	3	0.51	169.12	15.05	135.43	33.69
Jul.	5	0.86	169.97	15.05	150.48	19.49
Aug.	15	2.57	172.54	15.05	165.53	7.01
Sep.	47	8.04	180.58	15.05	180.58	0.00
Total	1056	180.58	-	180.58	-	-

Note: Numbers may not add exactly due to rounding.

In Table 9 the following calculations will apply:

- Column 2 - the average monthly historical rainfall data collected over a 12-year period.
- Column 3 - the monthly rain/stormwater yield (rainfall (mm/month) x catchment area (m^2) x runoff coefficient).
- Column 4 - the cumulative supply (Nov. is found by adding Oct. and Nov. rain/stormwater yields. Dec. is found by adding Oct., Nov. and Dec. yields, etc.
- Column 5 - the water demand is calculated by dividing the total annual water supply by 12 months. Column 6 - the cumulative demand (Nov. is found by adding Oct. and Nov. water demand. Dec. is found by adding Oct., Nov. and Dec. water demand, etc.) Column 7 – the difference between Column 4 (cumulative supply) and Column 6 (cumulative demand).

The largest difference would be the required tank/reservoir storage size. In the example above, the optimum storage reservoir size for this hospital would be 50.45 m^3 (Gould & Nissen-Peterson, 1999).

4.4 Water Category Quality and Preferred Runoff Uses

The following water uses were identified for commercial buildings, and were allocated a water quality value from 1 - 3, where 1 is potable standard and 3 represents a quality not fit for human consumption or leisure activities. In the commercial business survey questionnaire (Annexure G, question 6), respondents were asked to assign a water quality value to certain water usage categories. According to the results obtained from this survey, most respondents considered toilet flushing and water fountains to require a quality value of 2, in order to be fit for these usage types, whereas they considered garden irrigation to require water with a quality value of 3, as indicated in Table 10. All the respondents considered rain- and stormwater to be suitable for these non-potable commercial business water usage types.

Table 10: Quality values for different water category uses in a commercial building.

Water Use	Quality Value
Bath	1
Shower	1
Washing Machine	1
Toilet	2
Dishwasher	1
Kitchen Sink	1
Bathroom Basin	1
Garden Irrigation	3
Water Fountain	2

Rainwater is known to be very "soft", meaning that it has very little to no magnesium, calcium or dissolved salts, and is therefore generally considered to be of a fairly good quality (Van der Walt, 2012). According to the level of air pollution in an area, the quality can, however, be influenced by the levels of dissolved atmospheric contaminants. Environmental or other conditions, as well as the type of catchment surface, can also greatly affect the quality of collected rainwater. Debris that is deposited on roofs, such as dust, faeces from small animals, leaves from overhanging trees, as well as the roof type, can also contaminate the rainwater to various degrees.

Considering the above, the most preferred end-use of rainwater runoff should be for non-potable purposes, such as garden irrigation and toilet flushing. For the TEARS pilot practical case study, the use of roof runoff for toilet flushing purposes was practically investigated.

4.5 Roof Runoff Harvesting - TEARS Practical Pilot Case Study

4.5.1 TEARS Roof Runoff Coefficients

The efficiency of a rainwater harvesting system is greatly influenced by its design, but almost all rainwater harvesting systems experience a certain degree of secondary losses. These losses can occur due to spillage as water is transported to the tank, roof substrate absorption, or during a high-intensity rainfall event causing gutter overflow. In order to take into consideration the amount of rainwater losses occurring due to these factors, runoff coefficients were used in the mathematical model developed during this study, which gave an indication of the potential amount of runoff water that can actually reach the collection tank.

According to a study done by Hari and Krishna (2005), different types of roofs can have different runoff coefficients, due to the percentage of water absorption capabilities of certain roof surface substrates (Table 11). For this study, the approximate values of the roof and land surface runoff coefficients, as described by Fewkes and Warm (2000), were used in the mathematical runoff model developed to assess the combined roof- and land surface runoff yields of commercial buildings within the study area.

Table 11: Roof surface types and runoff coefficients (Fewkes and Warm, 2000).

Roof Run-off Coefficients for Different Roofs (Fewkes and Warm, 2000)	
Roof Type	**Runoff Coefficient**
Corrugated Iron	0.90 – 0.95
Pitched roof covered with tiles or slates (total flow type).	0.90 – 0.95
Pitched roof covered with tiles of slates (diverter flow type)	0.80 – 0.90
Flat roof covered with impervious material	0.50 – 0.80

4.5.2 TEARS Flowmeter Calculations & Savings

According to Surendran and Wheatley (1998) and Lazarova *et al*. (2003), in South Africa the toilet flushing demand in commercial developments typically consumes between 30% and 65%. At the TEARS pilot study site, the installed system was therefore specifically designed for toilet flushing purposes.

This roof harvesting system consists of an automatic potable top-up system, in order for the storage tank to always have a supply of water available during dry seasonal periods, to meet the building's toilet flushing demand. As the toilet is flushed, the rainwater is pumped automatically into the toilet, as long as the toilet lever is held down; the pump switches off, however, when the lever is released.

Due to this specific water saving design, the toilet flushing demand was quite accurately assessed by means of calculations relating to the potable/rainwater outflow, as measured by the flow meters installed on the system. By means of simple mathematical calculations, the amount of rainwater and potable water, respectively, used for toilet flushing, could be relatively accurately assessed.

The total toilet flushing demand of the TEARS building was assessed by means of the flow meter inserted at the tank outflow point. The total outflow was measured over a period of 12 months, from September 2012 – September 2013. Measured outflow (mixed rain- and municipal water) was taken as an indication of the toilet flushing demand, as the outflow was diverted only for toilet flushing use within the building. The building has two toilets connected to the tank outflow and both of these toilets were therefore monitored at 100%.

The results indicated that the average monthly toilet flushing demand for the TEARS building was 42.6 Kl. Because the TEARS building is an animal shelter, a large number of people (an average of 15 people on any given day), is always present in the building, which explains the extraordinary high toilet flushing usage for this building. An average monthly toilet flushing demand per person was calculated by dividing 42.6 Kl by 15, as can be seen in Table 12:

Table 12: The average monthly toilet flushing demand for the TEARS pilot site building.

TEARS Toilet Flushing Demand as Measured by the Inserted Flowmeter (Kl)	
Total Outflow (09.2012 – 09.2013)	554.1
Average Monthly Toilet Flushing Demand (± 15 people)	42.6
Average Monthly Toilet Flushing Demand (per person)	2.8

Due to the rainwater harvesting system at the TEARS study site being a potable top-up system, the tank outflow to the toilet consisted of either a mix of rain and potable water, or just rainwater, depending on the seasonal precipitation changes. In order to ascertain the amounts of rain and /or potable water leaving the tank, a mathematical formula was developed specifically for the practical measurement at this pilot site:

Formula: Rainwater (R) = Outflow (O) (usage) – Potable inflow (P)

$$R = O - P$$

Where: O = Outflow (usage)
P = Potable inflow
R = Rainwater

The financial savings were calculated by multiplying the volume of rainwater harvested (in Kl) by the current municipal commercial building water tariff - which is R 12.51, excluding VAT (Table 13):

Table 13: The City of Cape Town 2013/2014 commercial building tariff (per Kl).

City of Cape Town Municipal Water Tariff (excl. VAT) per Kl (City of Cape Town, 2012).	
Commercial	R 12.51
Industrial	R 12.51
Schools	R 11.06

Due to the unique measurement method designed for the TEARS pilot study practical assessment, the roof-harvested rainwater yields at this site could be directly assessed by means of the flow meter inserted at the tank outflow point. This meant that the potential water losses which could have occurred on the roof, and in the delivery system, did not need to be accounted for, as the volume of available harvested rainwater was directly measured. The descriptive statistics, and summary of the results and figures obtained through this practical assessment, are shown in Tables 14 and 15:

Table 14: TEARS descriptive statistics - mean, median, standard deviation and range.

Variable	N	Mean	Std. Dev.	Median	Range
Consumption, Rainfall Figures and Savings					
Municipal Consumption (Kl) (Monitored Over 32 Month Period)	32	59.82	51.64	40.00	182.70
Rainfall (Before and After Installation) (mm)	26	55.93	59.43	39.75	212.00
Rainfall Harvested (Potable Water Saving) (Kl)	19	12.31	7.31	9.41	26.74
Financial Savings (Rainwater Harvested X R 12.51)	19	154.06	91.45	117.69	334.46

Table 15: The TEARS practical assessment results summary.

TEARS Results Summary (Potable Top-up System Installation Date = 07.2011)									
Average Consumption Before System Installation (6 months) (Kl)	Average Consumption After System Installation (6 months) (Kl)	Percentage Drop in Average Consumption (Kl)	Average Summer Rainfall (mm)	Average Winter Rainfall (mm)	Average Volume of Rainwater Harvested During Summer (Kl)	Average Volume of Rainwater Harvested During Winter (Kl)	Average Summer Financial Saving (R)	Average Winter Financial Saving (R)	Average Monthly Toilet Flushing Demand (Kl)
152.7	36.7	76%	27	106.4	9.0	14.2	112.59	177.64	42.62

- Percentage of Toilet Flushing Demand Met During Summer = 21.3%
- Percentage of Toilet Flushing Demand Met During Winter = 33.3%

The rainwater system installation at TEARS was finished in August 2011. Figure 20 shows the municipal water consumption as measured six months before the system installation, and the consumption of the months following the installation in August. Since then, a drastic drop in municipal consumption can be seen in Figure 20 - except for a consumption spike during November 2012. Building occupant interviews and municipal consumption reports were investigated for a possible reason for this spike, but nothing was found. The assumption was made that this spike can be ascribed to a potential corruptive or faulty meter reading or an invisible water leak which could have occurred during that time.

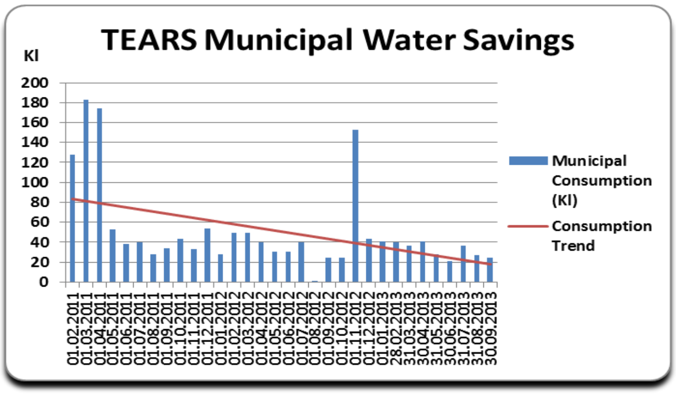

Figure 20: The TEARS municipal water savings before and after the system installation in August 2011, showing a drop in potable water consumption after installation.

The outflows from the TEARS system were relatively accurately measured, due to the inserted 15 mm Kent mechanical meters which were installed on the rainwater system in February 2012. Accurate measurement was made possible by the pump pressure which caused high flow rates through the metered pipe, making measurement by this type of metering; which generally do not pick up low gravitational flow rates; possible. By making use of this economical metering method, the amount of outflows containing rain and/or municipal water respectively, were assessed, making the differentiation between the amount of rainwater harvested and that used for toilet flushing possible. Figure 21 shows the volumes of rainwater harvested since the flow meter installation on the system in February 2012:

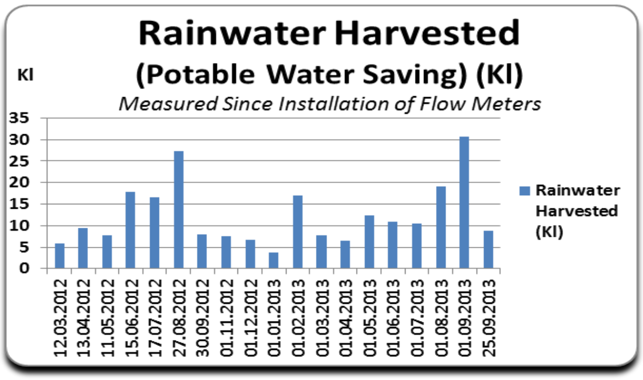

Figure 21: The volume of rainwater harvested at the TEARS site, as measured by the inserted flow meters since its installation in February 2012.

The unique mathematical calculation method can only be successfully used by other researchers in similar circumstances – that is, where the system is a potable top-up device where the municipal inflows and rain and/or municipal outflows are practically measured by means of flow meters. The reason for the lack of measurement of the rainwater inflow point is due to the fact that the pipe entering the collection tank is usually between 80 mm and 100 mm in size, and the water usually enters by gravitational flow rates, making it difficult to use economical mechanical flow meters at the inflow point.

The rainwater inflows could have been successfully measured with expensive types of metres such as electromagnetic flow metres, which would have been able to pick up the low gravitational flows accurately. However, considering the sizes and financial costs involved with this type of metering - two electromagnetic metres can cost approximately R30 000 – R40 000 (ZAR) - it was not considered a viable option for this research study.

The choice was therefore to rather avoid the unnecessary expense of an electromagnetic meter, when the same results could be successfully achieved by means of the measured outflows and the formula calculation - as long as the building was occupied and the toilet was flushed daily. The challenge with this method is that if there were no occupants present in the building, with consequently no toilet usage, there would have been no outflows (which only occurred when the toilet was flushed), and the calculations would therefore not have been effective.

4.6 Land Surface Harvesting - Commercial Building Theoretical Assessment

4.6.1 Stormwater Channeling

Channelling can be used to divert excess precipitation running over an impervious surface area. The idea is that runoff flows from the upper drainage areas to the lower drainage areas, with the aid of channels which meet at the lowest point. From this point onwards, the collected runoff can now flow into the underground collection tank (or other form of storage reservoir) from where it can be pumped for toilet flushing, garden irrigation or other suitable usage.

Where overland flow on impervious surfaces predominates, much of the precipitation is potentially available to be channelled into the collection reservoir. The runoff from these impervious surfaces is expected to move at rapid surface flow rates, although these rates depend, in part, on the nature of the impervious surface – that is, flow on smooth cemented surfaces is expected to be faster than on a rough, tarred road.

4.6.2 Water Usage Breakdown for Commercial Buildings

Considering the below-average annual precipitation figures for South Africa, this country can be classified as a semi-arid region (Figure 22). A rainwater harvesting system is therefore unlikely to meet total demand, but can be considered as an effective way of offsetting the potable demand when used for purposes such as toilet flushing:

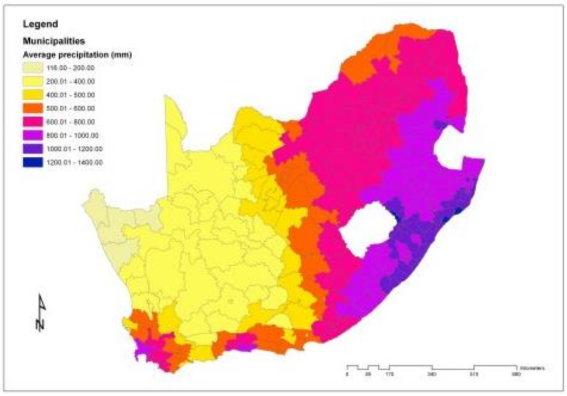

Figure 22: South Africa is classified as a semi-arid region with below average annual precipitation (DWA, 2012).

In South Africa, the toilet flushing demand in commercial developments typically consumes between 30% and 65% (Surendran & Wheatley, 1998; Lazarova *et al*., 2003). According to the commercial building survey results obtained from this research study, 70% of the respondents indicated that toilet flushing is the highest water use category within their respective buildings (Figure 23). On average, commercial office buildings use the majority of their water for toilet flushing and urinals.

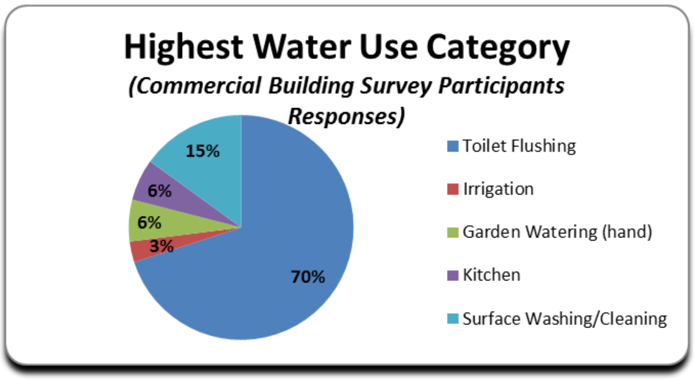

Figure 23: Highest water use category according to survey results.

Rainwater harvesting systems are therefore appropriate for toilet flushing use in commercial buildings. Commercial buildings also mostly have large areas of impervious land surfaces, and if the roof harvesting can be combined with land surface harvesting for toilet flushing, as well as irrigation and other non-potable purposes, then the system becomes much more viable (SE, 2008). The demand imposed on any rainwater harvesting system will also be a determining factor in the design of the system.

4.6.3 Commercial Building Toilet Flushing Demand

In South Africa, a traditional area-based method is mostly used for estimations of the average annual daily demand (AADD), which is normally linking usage with stand size (CSIR, 1983). This method, however, tends to overestimate the demand, which may result in the possible overdesign of services (Jacobs, Geustyn, Loubser & Van der Merwe, 2004).

The average monthly toilet flushing demand (in litres per day) was calculated by multiplying the total average number of flushes per person per day, by the average number of staff and the average size of the toilet bowl - as can be seen in Table 16. The information used for these calculations was obtained from the survey interview information obtained during the commercial building survey.

Table 16: The toilet flushing demand in the commercial building study area, according to the survey results.

Commercial Building Toilet Flushing Demand Estimates (According to Survey Results)							
Average size of Toilet Bowl	Average Type of Flush System	Average Number of Staff per Building	Average Number of Flushes per Person per 8 Hour Day	Potential Toilet Flushing Demand per Day (L)	Potential Toilet Flushing Demand per Month (L)	Converted to Kl (Litre / 1 000)	Potential Financial Savings per Month at R12.51 (excl. VAT) per Kl (Municipal Tariff for Commercial Users)
9L	Single Flush	4	5	180	5 400	5.4	R 67.554

4.6.4 Rain- and Stormwater Runoff

The physical processes that convert rainfall to runoff cannot be exactly mathematically replicated, because it is highly variable and complex. A mathematical model can, however, relatively accurately predict runoff volumes and rates by simulating these processes through the use of empirical data and simplified assumptions (Beckwith, Ciarametaro, Dehner, Rossiter & Siew, 2007).

The total amount of rainfall primarily influences the runoff volumes, but the rainfall intensity, over a period of time, primarily influences the runoff rate (Beckwith *et al.,* 2007). Natural ground infiltration is inhibited by impervious surfaces which lead to a higher stormwater runoff and peak flows. Tarred, paved or cemented surfaces such as roads and parking areas, as well as compacted open spaces, are some examples of impervious runoff areas.

This study has mainly focused on assessing the runoff from impervious land surfaces within the business area watershed. Most of the impervious surface area types which could be found in the study area consisted of tarred/asphalt, paved or cemented surfaces.

4.6.5 Stormwater Runoff Coefficients

Stormwater runoff coefficients are used to express the fraction of the catchment surface runoff that actually reached the collection tank or reservoir (Beckwith *et al*., 2007). Different runoff coefficient values were used for different land surface types, as per Fewkes and Warm (2000), (Figure 17). Highly pervious open areas are usually assigned a value of close to 0.0, because very little water will actually reach the tank or reservoir, due to ground infiltration, whereas paved, cemented or tarred surfaces are usually given values approaching 1.0:

Table 17: Stormwater harvesting land surface runoff coefficients used in the impervious surface runoff calculations (Fewkes and Warm, 2000).

Stormwater Harvesting Coefficients (Fewkes and Warm, 2000)	
Surface Type	**Run-off Coefficient**
Tar/Asphalt	0.95
Paving	0.85
Cemented	0.90

4.6.6 Commercial Building Area Statistics

The commercial building study area (50 buildings) had a total combined roof surface catchment area of 26 113 m^2 and an impervious land surface area of 86 342 m^2, as can be seen in Figure 24:

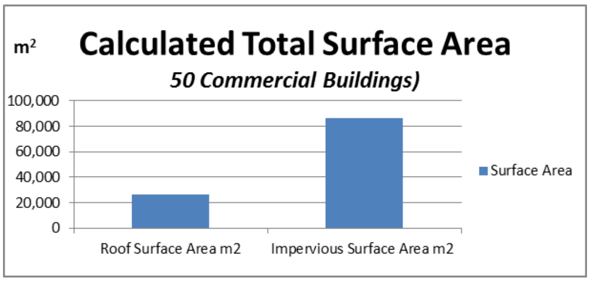

Figure 24: The calculated total roof and land surface areas of the Kommetjie commercial business area studied.

The descriptive statistics as set out in Table 18, below, portray the statistics of the 33 buildings that participated in the survey study. It indicates a total average monthly potential winter yield of 293.55 Kl and a total average monthly summer yield of 66.90 Kl:

Table 18: Commercial building area descriptive statistics - mean, median, standard deviation and range.

Variable	N	Mean	Std. Dev.	Median	Range
Surface Area Information					
Total Roof and Land Surface Area (m^2)	33	3538.34	5879.12	149.33	29896.16
Roof Surface Area (m^2)	33	801.74	660.66	620.00	3102.00
Impervious Land Surface Area (m^2)	33	2736.59	5795.68	781.33	29780.45
Annual Rainfall and Consumption					
Monthly Average Rainfall (mm)	12	56.98	53.03	43.00	144.00
Monthly Average Municipal Water Consumption (Kl)	12	32.25	36.99	19.51	152.70
Information to Determine Yield					
Roof Surface Area (m^2)	33	801.74	660.66	620.00	3102.00
Impervious Land Surface Area (m^2)	33	2736.59	5795.68	781.33	29780.45
Calculated Total Roof and Land Surface Area (m^2)	33	3538.34	5879.12	149.33	29896.16
Roof Coefficient	33	0.92	0.06	0.95	0.15
Land Surface Coefficient	33	0.92	0.05	0.95	0.15
Winter Water Consumption (Kl)	33	30.35	32.52	19.92	134.77
Summer Water Consumption (Kl)	33	33.77	41.98	15.33	192.00
Average Winter Rainfall (mm)	33	89.69	0	89.69	0
Average Summer Rainfall (mm)	33	20.44	0	20.44	0
Total Average Monthly Yield (Winter) – Converted to KL	33	293.55	500.87	118.66	2547.38
Total Average Monthly Yield (Summer) – Converted to KL	33	66.90	114.15	27.04	5805.70

A summary of the commercial business area results and savings for roof and land surface harvesting can be seen in Table 19, and a summary of the results and savings for roof harvesting only, is shown in Table 20. It indicates that the average monthly winter and summer water demands can be met at above 100%, and the combined use of roof and land surface harvesting systems could, therefore, potentially take a commercial building completely off the municipal grid. The results also indicates that if only roof rainwater harvesting is implemented, the winter municipal water demand can potentially be met at above 100%, and nearly half of the summer municipal water demand can be met:

Table 19: The Kommetjie commercial building roof and land surface harvesting results summary.

Commercial Building Roof and Land Surface Harvesting Yield and Savings Results Summary									
Average Actual Monthly Winter Municipal Water Consumption (Kl)	Average Actual Monthly Summer Municipal Water Consumption (Kl)	Average Monthly Summer Rainfall (mm)	Average Monthly Winter Rainfall (mm)	Total Average Monthly Yield (winter) in KL	Total Average Monthly Yield (summer) in KL	Percentage Monthly Municipal Water Demand Met During Summer	Percentage Monthly Municipal Water Demand Met During Winter	Average Monthly Summer Financial Saving ***** R	Average Monthly Winter Financial Saving***** R
30.35	33.77	20.44	89.69	293.55	66.90	198%	967%	836	3 672

***** Savings were calculated with the assumption that all the surplus water in the storage vessel is utilised.

Table 20: The Kommetjie commercial building roof harvesting only results summary.

Commercial Building Roof Harvesting Yield and Savings Results Summary									
Average Actual Monthly Winter Municipal Water Consumption (Kl)	Average Actual Monthly Summer Municipal Water Consumption (Kl)	Average Monthly Summer Rainfall* (mm)	Average Monthly Winter Rainfall* (mm)	Total Average Monthly Yield (winter) in KL	Total Average Monthly Yield (summer) in KL	Percentage Monthly Municipal Demand Met During Summer	Percentage Monthly Municipal Demand Met During Winter	Average Monthly Summer Financial Saving # (R)	Average Monthly Winter Financial Saving***** (R)
30.35	33.77	20.44	89.69	66.16	15.08	44%	217%	188	827

Savings were calculated with the assumption that all the surplus water in the storage vessel was utilised.

***** Rainfall as measured by the Kommetjie weather station (Le Roux, 2013). Please note that figures may differ then that of the TEARS pilot site where rainfall was measured by an on-site rain gauge.

4.7 Total Building Catchment Area Runoff Spreadsheet Model

The model that was developed in order to assess the total commercial building catchment runoff, was derived from a simple calculation commonly used to assess runoff:

1 millimetre (mm) rainfall × 1 square metre (m^2) of catchment area = 1 litre (L) of rainwater.

This general principle were kept, but with added aspects such as taking cognisance of losses and seasonal variation. The result is a user-friendly mathematical formula and spreadsheet calculation model, which will give the consumers a breakdown of their roof and surface runoff volumes, as well as the difference between these volumes for winter and summer. Together with the incorporation of the savings, this model will help the commercial consumer to make an informed decision regarding the feasibility and expected savings, the type of system to install, and for what usage it would be most suitable.

Because this model is intended for impervious surface runoff only, aspects such as rainfall intensities, runoff speed, and so on, most commonly used in other runoff model calculations, were excluded. For this reason, this runoff calculation model is not suitable for the assessment of runoff occurring over vegetated, uncovered ground or other types of surfaces, where infiltration would be expected to occur.

4.7.1 Formula to Determine Monthly Winter or Summer Yield and Savings

The mathematical formula that was developed during this research study consists of four equations. The flow diagram in Figure 25 explains the usage of the model in more detail. The excel spreadsheet runoff and savings calculation resource tool (Figure 26) was also developed to facilitate a user-friendly approach. The user-friendly approach included the simplification of the identified 5 month winter and 7 month summer seasonal periods, as indicated in Figure 14, to a winter and summer seasonal period of 6 month each to enable consumers from different rainfall regions to also make use of this formula and spreadsheet. The end result of the calculations would therefore not be as accurate, but it will still provide a general indication of the total average monthly runoff for winter and summer. The commercial building consumers can therefore easily use it to assess the feasibility and savings for their buildings:

Formula:

TAMSY (L) = $\frac{RF*[[RA*CR]+[SA*CS]]}{6}$ **Equation 1**

TAMSY (Kl) = $\frac{TAMSY\ (L)}{1\ 000}$ **Equation 2**

DM (%) (Kl) = $\frac{TAMSY}{TAMSD}$ x100 **Equation 3**

FS = TAMSY (Kl) x CW **Equation 4**

Where:

TAMSY	= Total average monthly seasonal yield
RH	= Rainwater harvested
SH	= Stormwater harvested
RA	= Roof area
SA	= Area of land surface
RF	= Average rainfall for period (in this case, the winter /summer months) calculated as average for the period per month*
CR	= Runoff coefficient for roof
CS	= Runoff coefficient for land surface
DM	= Demand met (Kl)
TAMSD	= Total average monthly seasonal demand (Kl)
CW	= Cost of water
FS	= Financial saving
PS	= Potable savings

- * Average rainfall for the winter period taken over 6 months (simplified from 5 month period as indicated in Figure 14), is the sum of May, June, July, August, September and October months, divided by the number of months; and
- * Average rainfall for the summer period taken over 6 months (simplified from 7 month period as indicated in Figure 14), is the sum of November, December, January, February, March and April months, divided by the number of months.

The formula has been calibrated by using actual yields of rain- and/or stormwater, so that the theoretical yields can be tested against the actual figures, in order to determine whether the formula will provide accurate figures of yield.

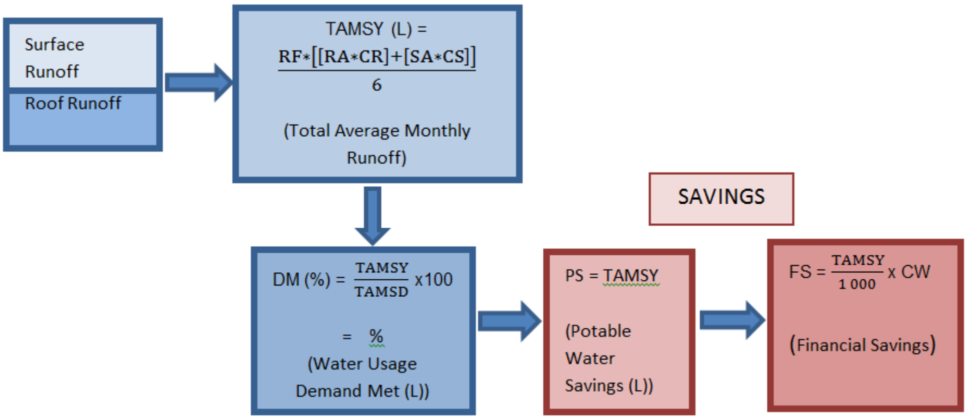

Figure 25: A flow diagram of the rain- and stormwater runoff model.

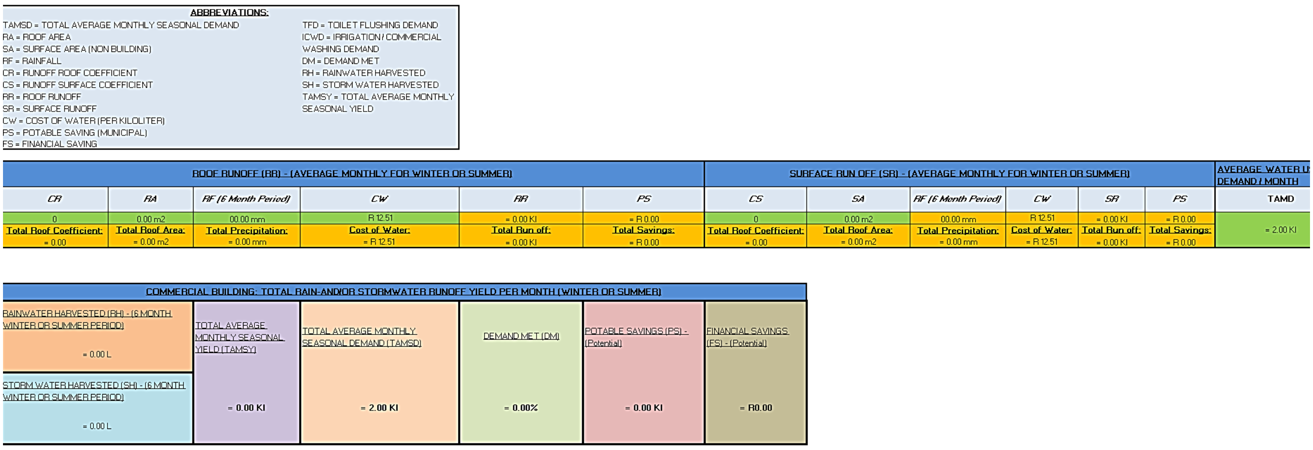

Figure 26: An example of the excel spreadsheet resource tool that was developed as part of this research study.

4.8 Theoretical Calculation Method Tested Against Actual Measured Results

The theoretical calculation method was tested against the actual, practically measured results at the TEARS pilot study site. Over a period of 26 months, six exceptional high rainstorm events occurred (>100 mm/month). According to Table 21, an overestimation of 15.39 Kl (or 55.6%) occurred, when comparing the theoretical roof harvesting results, which includes exceptional high rainstorm events with the actual TEARS result, while a much more accurate result of 0.75 Kl or a 5.8% difference were achieved when the theoretical results, without the exceptional high rainstorm events, were compared with the actual results:

Table 21: The theoretical runoff calculation method compared with the actual TEARS results.

Theoretical Roof Runoff Results Compared with Actual Results as Measured at TEARS Study Site						
Theoretical Average Monthly Runoff/Yield (exceptional high rainstorm events included) (Kl)	Theoretical Average Monthly Runoff/Yield (exceptional high rainstorm events excluded) (Kl)	Actual Average Monthly Runoff/Yield (as measured by flow meters) (Kl)	Difference: Theoretical with Exceptional High Rainstorm Events and Actual (Kl)	Percentage Difference Theoretical with Exceptional High Rainstorm Events versus Actual (Kl):	Difference: Theoretical without Exceptional High Rainstorm Events versus Actual (Kl	Percentage Difference: Theoretical without Exceptional High Rainstorm Events versus Actual (Kl
27.7	13.1	12.31	15.39	55.6%	0.75	5.8%

This indicates that if the theoretical runoff calculation method is used, an overestimation can occur if the annual average monthly rainfall is used which included any exceptional high rainstorm events. According to the specific tank size, during high rainstorm events it can be assumed that a very high percentage of overflow may occur, and the results will therefore not be an accurate estimation of the actual yield which can be collected in the storage tank/vessel.

When using a tank which was sized according to normal rainstorm events, and which excludes exceptional high events (which are normally done in practice), the theoretical results without the high rainstorm events should be used, and will provide a relatively accurate result when compared with the actual results.

For the assessment of the theoretical commercial building runoff, the assumption was made that, according to the results obtained by using the theoretical figures which included the high rainstorm events, tank sizing can be done by the consumer, by keeping in mind the theoretical result and the constant daily water usage draw offs. The theoretical runoff yields and savings as indicated for the commercial buildings during this study, can therefore be achieved with the assumption that the total theoretical runoff volumes of rain- and stormwater are harvested and utilised.

4.9 Rain- and Stormwater Harvesting - Commercial Building Survey

A perception and attitude survey was conducted by means of a questionnaire in order to assess the current rain- and stormwater harvesting practises and awareness, highest water usage category, green building practises and water conservation behaviour of the commercial building occupants within the study area.

4.9.1 Perception and Attitude Survey - Focus Area

The commercial building focus area for this survey was the Heron and Fish Eagle Business Park sites within the Kommetjie study area. Most of the businesses in these parks were found to be smaller business types, and consisted of businesses such as glass product manufacturers, lumber suppliers, kitchen designers and automotive workshops, amongst others. The buildings surveyed had catchment surface types which consisted mainly of corrugated iron roof types, as well as tar and paved surface areas such as parking and drive-through areas. It was found that the number of buildings with variations of these types of catchment surfaces, was minimal, and most buildings consisted of similar building structures and materials.

4.9.2 Survey Data Collection Design and Methodology

The use of questionnaires to obtain information falls within the sphere of descriptive survey research. The questionnaires for the survey section of this research study were drawn up in order to obtain reliable responses from the survey participants in the commercial business study area. The questions were carefully structured, and were tested and piloted to ensure that they reflected a high degree of validity. Closed-ended questions were used to allow survey participants to quickly rate a list of questions with predetermined answers to choose from. The main aim of this survey research was to establish the knowledge, attitudes and toilet flushing demands of the respondents in the sample, as well as the general water saving aids implemented by them.

Questions were prepared and piloted to ensure they reflected a high degree of 'validity'. The data was collected from a simple random sample of 50 commercial business buildings in the Kommetjie study area. In total, the responses from the 50 green businesses in the Kommetjie area surveyed, were analysed with respect to the uses of rain- and storm water harvesting, as well as the attitudes of the respondents with respect to these uses. Descriptive statistics were given for each variable, and respondents who completed at least some portion of the questionnaire were utilized in the inferential statistics.

4.9.3 Survey Ethics

According to Watkins (2008), research ethics refers to the appropriateness of a researcher's behaviour in relation to the rights of those who become the subject of, or are affected by, the research work.
The following ethical principles were followed during the commercial business survey research:

- The respondent's rights to privacy were respected, and the information that was provided was kept strictly confidential.
- The respondents were informed of the nature of the research study, and allowed the choice to participate or withdraw if they wished to do so.
- The findings were reported in an honest and professional way, without any misrepresentations.

4.9.4 Commercial Building Survey Sample Sizing

Sample sizing was assessed, in order to incorporate representativeness.
This means that all constituencies in the population had a known chance of being selected in the sample, and the sampling procedure ensured that the sample contained the same characteristics as most of the buildings in the business area.
The following formula was used, in order to establish the desired sample size for the study area:

$$N_S = \frac{(NP)(P)(1-P)}{(NP-1\left(\frac{B}{C}\right)^2+(P)(1-P)}$$

$$N_S = \frac{(100)(0.5)(1-0.5)}{(100-1\left(\frac{0.1}{1.960}\right)^2+(0.5)(1-0.5)}$$

= 49 (rounded off to 50)

Where:

N_S = completed sample size needed

N_P = size of population

P = proportion expected to answer a certain way (50% or 0.5 is most conservative)

B = acceptable level of sampling error (margin of error) (0.1 = $\pm$10% of the true population value)

C = Z statistic associated with confidence interval (1.960 = 95% confidence level)

According to the results obtained from the above formula, if 50% of the population was expected to answer a certain way, and the average number of commercial buildings in the business park was 100, a sample size of 49 businesses was needed to be 95% confident that the sample estimate was within $\pm$ 10% of the true population value. For convenience purposes, this figure was rounded off to a sample size of 50 commercial businesses.

4.9.5 Survey Response Rate

The survey response rate was calculated by means of the following equation:

$$\text{Response Rate} = \frac{C}{E}$$

$$= \frac{33}{50}$$

$$= 66\%$$

where:

C = number of completed questionnaires
E = total number of eligible respondents

For a questionnaire to have been considered "completed" at least some portion of it had to be completed.

For this survey the response rate was 66% - as can be seen in Figure 27:

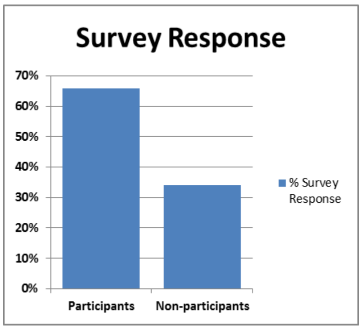

Figure 27: A survey response rate of 66% was achieved.

4.9.6 Descriptive Statistics

Table 22 shows the descriptive statistics for all the categorical variables, with the frequencies in each category, and the percentage out of total number of questionnaires. It should be noted that the descriptive statistics are based on the total sample. These descriptive statistics are also shown in Annexure A and B:

Table 22: Descriptive statistics for all the commercial business survey categorical variables.

Variables	Categories	Frequency	Percentage out of Total
Section A: Green Businesses Questionnaire			
Participated	Participation	33	66.0%
	Non participation	17	34.0%
Distribution of Participants			
Use Rainwater	Yes	0	0.0%
	No	33	100.0%
Roof Catchment Types	Asbestos	9	27.3%
	Corrugated Iron	23	69.7%
	Corrugated Iron/Asbestos Mix	1	3.0%
Surface Catchment Types	Paved	9	27.3%
	Tar	21	63.6%
	Paved/Tar Mix	1	3.0%
	Cement/Tar Mix	1	3.0%
	Paved/Cement/Tar Mix	1	3.0%
Sell Green Products	Yes	9	27.3%

Variables	Categories	Frequency	Percentage out of Total
	No	24	72.7%
3. Applying Green Practices	Yes	23	69.7%
	No	10	30.3%
4. Think They Can Benefit from Rain-and/or Stormwater Harvesting	Yes	24	72.7%
	No	9	27.3%
5. Water Saving Fixtures/Devices	Yes	13	39.4%
	No	20	60.6%
6. Irrigate?	Yes	5	15.1%
	No	28	84.9%
7. Time Controller?	Yes	0	0.0%
	No	33	100.0%
8. Number of Toilets per Building	1	14	42.4%
	2	12	36.4%
	3	2	6.1%
	4	2	6.1%
	6	1	3.0%
	GE 10	2	6.1%
9. Highest Water-use Category	Factory Floor Washing	1	3.0%
	Factory Washing	1	3.0%
	Hand Watering	2	6.1%
	Irrigation	1	3.0%
	Kitchen	2	6.1%
	Surfacing Washing	1	3.0%
	Toilet	23	69.7%
	Wash bay	1	3.0%
Surface Area Information to Determine Yield			
41. Roof Types	Asbestos	7	21.2%
	Corrugated Iron	25	75.8%
	Corrugated Iron/Asbestos Mix	1	3.0%
43. Surface Types	Paved	5	15.2%
	Tar	23	69.7%
	Paved/Tar Mix	1	3.0%
	Cement/Tar Mix	1	3.0%
	Paved/Cement/Tar Mix	1	3.0%
	Asbestos	2	6.1%

4.9.7 Survey Variable Results

As can be seen in Figure 28, 66% of the 50 businesses in the Kommetjie commercial business survey participated in the rain- and stormwater harvesting project. This percentage can also be referred to as the response rate:

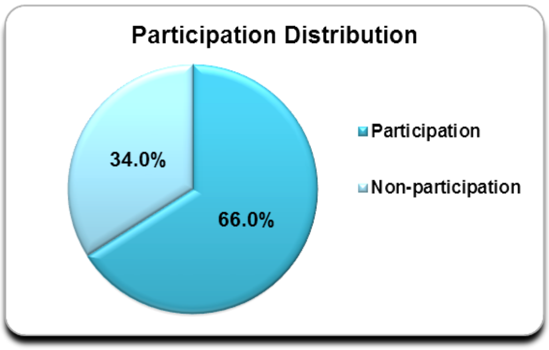

Figure 28: Commercial business participation distribution.

According to Figure 29, it is apparent that none of the businesses in the Kommetjie business area are currently harvesting/using rain- and/or stormwater:

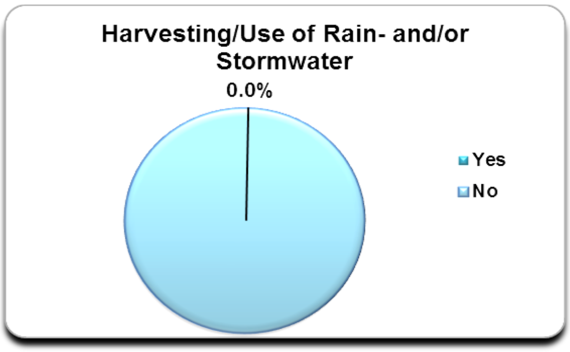

Figure 29: Percentage of participants harvesting/using rain- and/or stormwater.

In Figure 30, it can be seen that 27.3% of the businesses had asbestos as roof catchment type, and 69.7% had corrugated iron as roof catchment type, with 3% having a corrugated iron/asbestos mix roof catchment type:

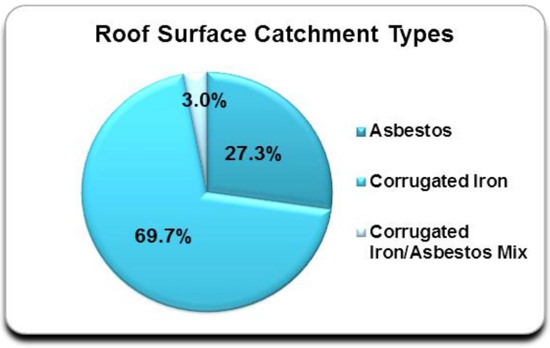

Figure 30: Roof surface catchment types.

Figure 31 indicates that 27.3% of the surface catchment areas were paved, 63.6% were tarred, and the other 9% were either a paved/tar mix, cement/tar mix, or paved/cement/tar mix:

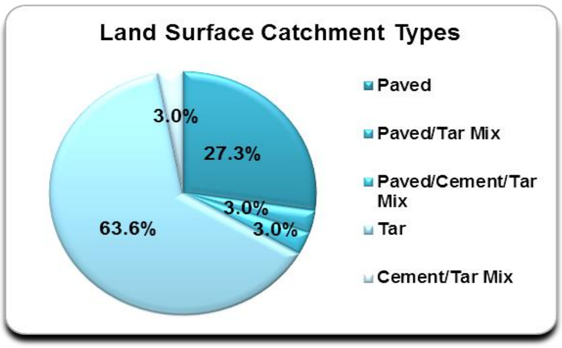

Figure 31: Land surface catchment types.

It can be seen in Figure 32 that 27.3% of the businesses sold some kind of green product/s. Typical green products included biodegradable insecticides and herbicides, recycled glass products and recycled paper products, amongst others:

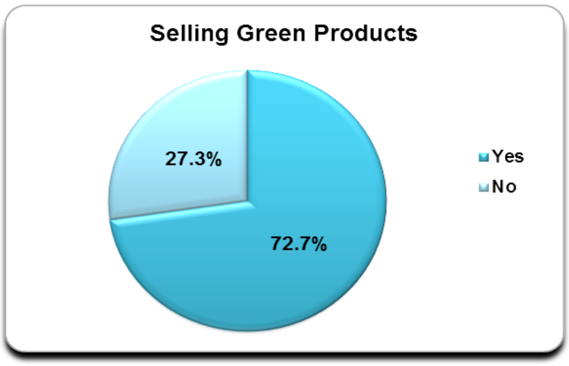

Figure 32: Businesses selling some kind of green product/s.

Figure 33 indicates that 69.7% of the businesses applied some kind of green practice/s. The most common practices found were waste recycling and the implementation of electricity saving products:

Figure 33: Percentage of respondents who applied green practices.

Although none of the businesses surveyed implemented or used rain- and/or stormwater harvesting, it can be seen in Figure 34 that 72.7% of the businesses thought that they could benefit by harvesting rain- and/or stormwater:

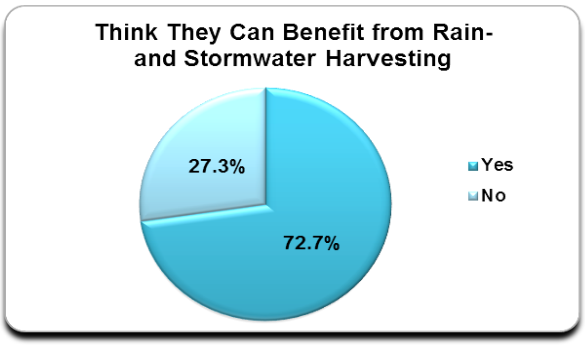

Figure 34: Percentage of respondents who think that they can benefit from rain- and stormwater harvesting.

It can be seen in Figure 35, that 39.4% of the businesses used/installed some kind of water saving fixtures or devices:

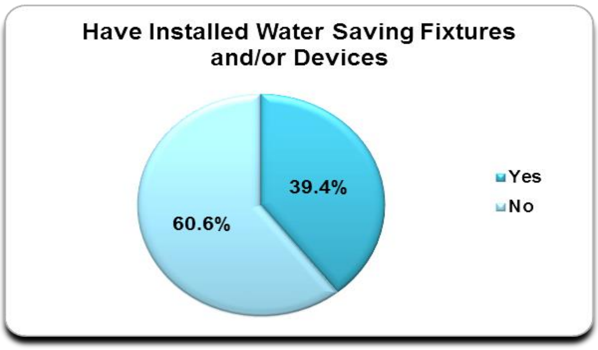

Figure 35: Percentage of participating businesses who had water saving fixtures/devices.

Only 15.1% of the businesses in the surveyed area were making use of irrigation, as can be seen in Figure 36. Irrigation was mostly implemented used for small, grassed patches and ornamental, landscaped beds near the front entrance areas:

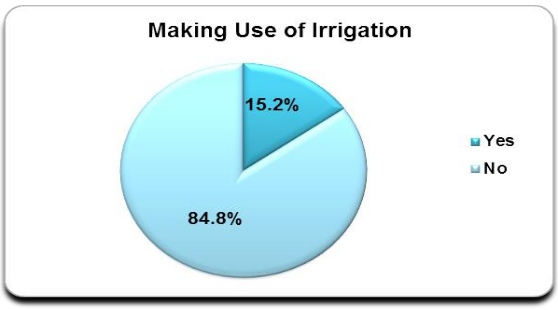

Figure 36: Percentage of businesses that are making use of irrigation.

None of the businesses applied irrigation time controlling, as can be seen in Figure 37:

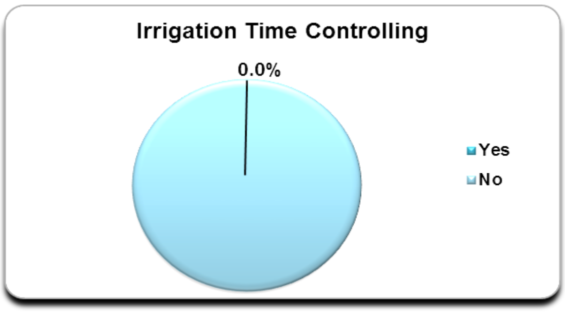

Figure 37: Percentage of businesses that are applying irrigation time controlling.

It can be seen in Figure 38, that most of the businesses had 1 (42.4%) or 2 (36.4%) toilets in their buildings:

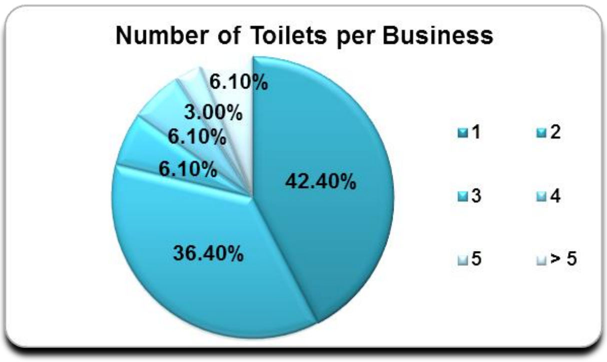

Figure 38: The average number of toilets per business.

After grouping some of the categories together, it can be seen that toilet flushing is the category that is used the most (69.7% of the businesses). Thus, nearly 70% of the businesses use the potable water for toilet flushing, as indicated in Figure 39:

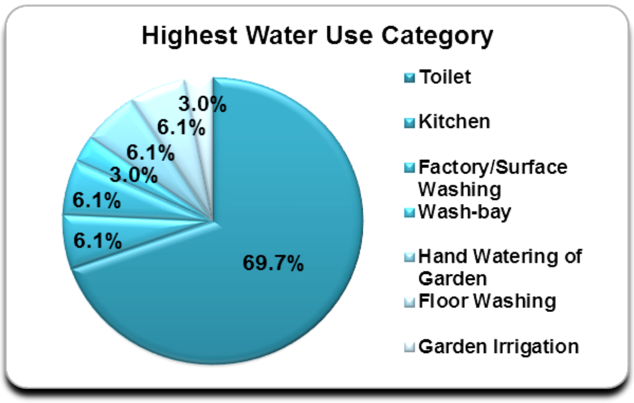

Figure 39: The highest water use category for the commercial buildings.

The statements were sorted, from the statements that the businesses mostly agreed with, to the statements that they least agreed with. The statements that the businesses agreed with the most, according to Figure 40, were the following:

- V09: Think they can benefit from rain- and/or stormwater harvesting (72.7% indicated 'yes');
- V08: Applied green practises (69.7% indicated 'yes');
- V10: Installed water saving fixtures/devices (30.3% indicated 'yes');
- V07: Sold green products. (27.3% indicated 'yes');
- V11: Are irrigating (9.1% indicated 'yes'); and
- V04: Currently harvesting/using rain- and/or stormwater (0.0% indicated 'yes').

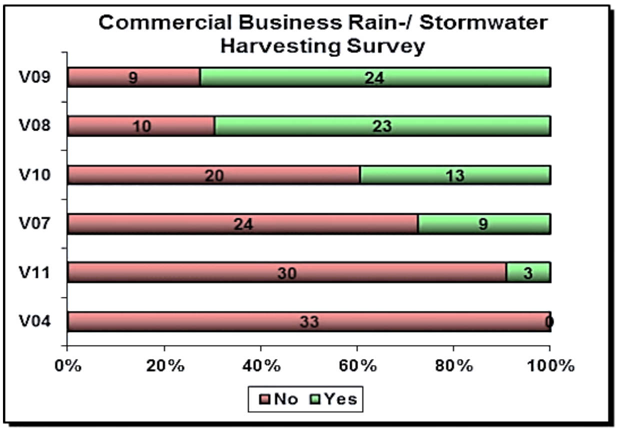

Figure 40: Commercial business rain- and stormwater harvesting survey results.

4.10 Hypothesis Testing

An SAS statistical software package was used, to determine the probability value (P-value) that measures the statistical significance when comparing variables with each other, and that also determines the association and relationship between the variables. The results will be regarded as significant if the P-values are smaller than 0.05, because this value presents an acceptable level on a 95% confidence interval ($p \leq 0.05$) (Cooper & Schindler, 2001).

The P-value was compared to the significance level ($\alpha = 0.05$), and on this basis the null hypothesis was either rejected or accepted. A P-value of less than the significance level meant the rejection of the null hypothesis, whereas a P-value greater or equal to the significance level meant that the null hypothesis was accepted.

The Wilcoxon rank test (Mann Whitney *U* test) and the Wilcoxon Sign Rank test (depending whether it is independent groups or paired data) were used, in order to determine whether the means were equal or not, and will be shown in Annexure C. Results will be regarded as significant if the P-values are smaller than 0.05, because this value is used as the cut-off point in most behavioural science research.

4.10.1 TEARS Pilot Study Hypothesis

The following hypotheses were tested:

- $H:_0$ There is no statistically significant difference between the pre-rainwater harvesting level of water usage in the pilot study building, and the post-rainwater harvesting level of water usage ($\mu_1 = \mu_2$) .
- $H:_1$ There is a statistically significant positive difference between the pre-rainwater harvesting level of water usage in the pilot study building, and the post-rainwater harvesting level of water usage (there is greater post than pre-rainwater harvesting level of water usage) ($\mu_1 \neq \mu_2$) .

- H:$_2$ There is a statistically significant negative difference between the pre-rainwater harvesting level of water usage in the pilot study building, and the post-rainwater harvesting level of water usage (there is greater pre than post-rainwater harvesting level of water usage) ($\mu_1 \neq \mu_2$).

Firstly, the municipal consumption was divided in two groups (pre- and post-rainwater harvesting), and then the average consumption amounts for the two groups (independent samples) were compared. The municipal consumption before the rainwater harvesting system was installed, and after the installation, was compared by using the non-parametric Wilcoxon Rank-Sum (Mann-Whitney *U*) tests for two independent samples (Figure 41):

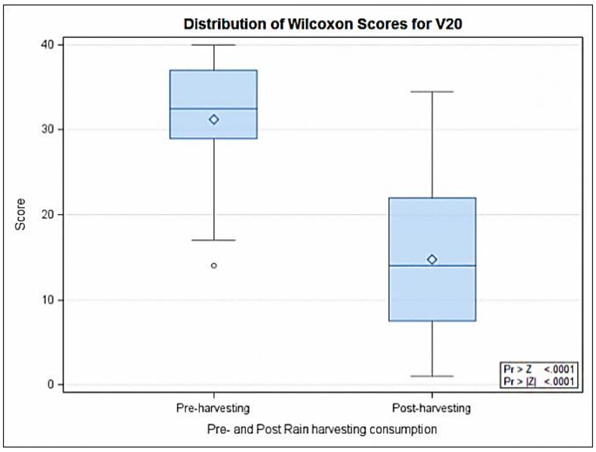

Figure 41: Non-parametric comparison between the pre- and post-system installation municipal consumption.

There was a statistically significant difference between the ‘pre’ and ‘post’ groups. The post-rainwater harvesting municipal water consumption was found to be statistically significant lower than the pre-rainwater harvesting municipal water consumption (Wilcoxon rank test statistic=436.500 and Z-value=14.0851, P-value=<0.0001).

It should be noted that the box plots were drawn to illustrate the differences based on the mean scores as calculated in the test and not the mean municipal consumption figures.

The hypotheses H:$_0$ and H_1 were therefore rejected, and H:$_2$ – “There is a statistically significant negative difference between the pre-rainwater harvesting level of water usage in the pilot study building, and the post-rainwater harvesting level of water usage (there is greater pre- than post-rainwater harvesting level of water usage) ($\mu_1 \neq \mu_2$)”, was accepted.

It can thus be said that since the rainwater harvesting system was installed, the municipal water consumption was statistically significantly lower than the consumption which was measured before the rainwater system installation.

4.10.2 Commercial Business Area Hypothesis

The following hypotheses were tested:

H:$_0$ There is no statistically significant difference between the level of average municipal water usage in the Kommetjie business district buildings, and the average theoretical harvested water yields at the buildings, for winter and summer ($\mu_1 = \mu_2$).

H:$_1$ There is a statistically significant positive difference between the level of average municipal water usage in the Kommetjie business district buildings, and the average theoretical harvested water yields at the buildings, for winter and summer ($\mu_1 \neq \mu_2$) (the yield is greater than the municipal usage).

H:$_2$ There is a statistically significant negative difference between the level of average municipal water usage in the Kommetjie business district buildings, and the average theoretical harvested water yields at the buildings, for winter and summer($\mu_1 \neq \mu_2$) (the yield is less than the municipal usage)

After calculating the mean consumption for each business during winter and summer, it was compared with the rain- and stormwater yields for winter and summer - which were calculated by using the average rainfall multiplied by the catchment surface area. The type of surface was also worked into the formula by means of the multiplication, with a runoff coefficient for the different roof or surface types. The calculated yield was then divided by 1 000 to receive the yield in Kl for comparison with the municipal consumption - which is also measured in Kl. The consumption was subtracted from the yield, and then the non-parametric Wilcoxon Sign Rank test was performed in order to test whether this difference differed from zero. If there was a statistically significant difference from zero, it could be assumed that the consumption differed from the yield.

The municipal winter and summer consumption for the 33 businesses was compared with the winter and summer calculated yield of rain- and stormwater harvested, as can be seen in figures 42 and 43:

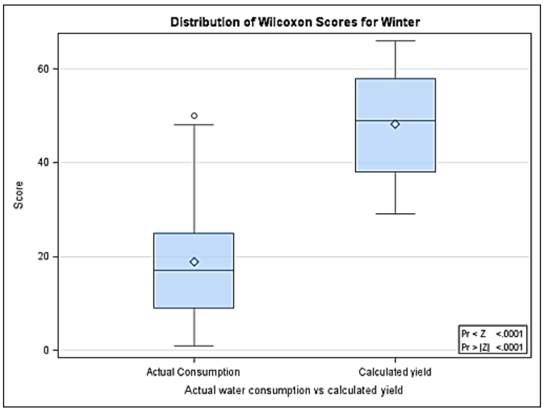

Figure 42: The winter municipal consumption compared with the winter rain- and stormwater harvesting yields.

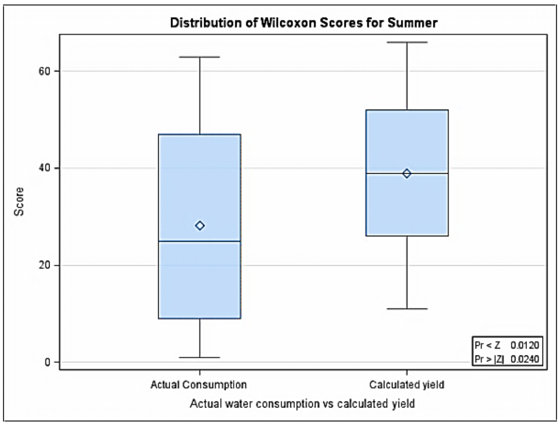

Figure 43: The summer municipal consumption compared with the summer rain- and stormwater yields.

There was a statistically significant difference between the actual municipal consumption and the theoretical rain- and stormwater yields for both winter and summer. The consumption of municipal water was statistically significant lower than the calculated yield of rain- and stormwater harvesting; thus, there will be a large amount of surplus water if rain- and stormwater harvesting systems are implemented. It should be noted that the calculated winter yield was statistically significantly higher than the calculated summer yield.

The hypotheses $H{:}_0$ and $H{:}_2$ were therefore rejected, and the hypothesis $H{:}_1$ - "There is a statistically significant positive difference between the level of average municipal water usage in the Kommetjie business district buildings, and the average theoretical harvested water yields at the buildings, for winter and summer ($\mu_1 \neq \mu_2$) (the yield is greater than the municipal usage)", were accepted.

It should be noted that the box plots were drawn to illustrate the differences, is based on the mean scores calculated in the test and not the means (average of consumption or average of yield). Although the Wilcoxon sign rank test was used - which is a paired test (dependent samples), the means scores were only shown in this case to illustrate the differences. What this means is that a paired test was used, but the graphs in this case showed independent samples.

4.11 Commercial Business Cost - Benefit Analysis and Future Projection

The potable water and financial savings results obtained through this research study has indicated that by implementing roof and land surface harvesting, an average monthly winter potable water saving of 293.55 Kl, and an average monthly summer potable water saving of 66.90 Kl, can be achieved. The average annual potable water saving that could be achieved if all the surplus water in the storage vessel were utilised, is 2 162.6 Kl - which amounts to an average annual financial saving of R 27 054.13 per building. By comparing this figure with the average installation costs of the installation of an above-and underground harvesting system as set out in Table 23, below, an average pay-back period of only 3.5 years could be achieved:

Table 23: The economic implications of installing an above-ground and below-ground rain- and stormwater harvesting system.

Average Cost of Potable Top-Up Rainwater Harvesting System and Under-Ground Stormwater Harvesting System.			
Material/Labour	**Amount**	**Price per Unit (R)**	**Amount (R)**
Flush units in the toilets	2	660	1320.00
Rain filters	4	2000	8 000.00
Above-ground storage tank - 5 000 L	1	4 000	4 000.00
Below-ground storage reservoir - 60 000 L	1	20 000	20 000
Pump and override	2	15 800	31 600
Float switch	1	360	360.00
Non-return valve	1	190	190.00
Outlet/inlet/piping and valves/overflow	1	470	470.00
Gutter pipe 110 mm and connectors	1	290	290.00
Electrical	1	380	380.00
Inlet filter	2	360	720.00
Pump Cover	1	230	230.00
Labour			8 000.00
Total Cost			**R 95 560.00**
Municipal Water Savings per Building			
Average Monthly Winter Water Saving According to Theoretical Calculations (Taken Over 6- Month Winter Period)	**293.55 Kl**		
Average Monthly Summer Water Saving According to Theoretical Calculations (Taken Over 6-Month Summer Period)	**66.90 Kl**		
Average Annual Water Saving According to Theoretical Calculations	**2 162.6 Kl**		
Current Cost of Municipal Water (Commercial)	**R 12.51 (excl. VAT)**		
Annual Financial Savings per Building	**R 27 054.13**		
Pay-back Period	**3.5 Years**		

Note: No maintenance or operating costs, i.e. electrical pumping costs, have been included in these calculations.

* Savings were calculated with the assumption that all the surplus water in the storage vessel is utilised.

The results also indicate that by implementing only roof harvesting, an average monthly winter potable water saving of 66.16 Kl, and an average monthly summer potable water saving of 15.08 Kl, can be achieved. The average annual potable water saving that could be achieved if all the surplus water in the storage vessel were utilised, is 487.44 Kl - which amounts to an average annual financial saving of R 6 097.87 per building. By comparing this figure with the average installation costs of the installation of an above-ground harvesting system as set out in Table 24, below, an average pay-back period of 5.8 years could be achieved:

Table 24: The economic implications of installing a potable top-up above-ground rainwater harvesting system.

Average Cost of Potable Top-Up Rainwater Harvesting System			
Material/Labour	**Amount**	**Price per Unit (R)**	**Amount (R)**
Flush units in the toilets	2	660	1320.00
Rain filters	4	2000	8 000.00
Above-ground storage tank - 5 000 L	1	4 000	4 000.00
Pump and override	1	15 800	15 800
Float switch	1	360	360.00
Non-return valve	1	190	190.00
Outlet/inlet/piping and valves/overflow	1	470	470.00
Gutter pipe 110 mm and connectors	1	290	290.00
Electrical	1	380	380.00
Inlet filter	1	360	360.00
Pump Cover	1	230	230.00
Labour			4 000.00
Total Cost			**R 35 410.00**
Municipal Water Savings per Building			
Average Monthly Winter Water Saving According to Theoretical Calculations (Taken Over 6- Month Winter Period)	**66.16 Kl**		
Average Monthly Summer Water Saving According to Theoretical Calculations (Taken Over 6- Month Summer Period)	**15.08 Kl**		
Average Annual Water Saving According to Theoretical Calculations	**487.44 Kl**		
Current Cost of Municipal Water (Commercial)	**R 12.51 (excl. VAT**		
Annual Financial Savings per Building	**R 6 097.87**		
Pay-back Period	**5.8 Years**		

Note: No maintenance or operating costs, i.e. electrical pumping costs, have been included in these calculations

* Savings were calculated with the assumption that all the surplus water in the storage vessel is utilised.

According to Table 25, it can be seen that; if rain- and stormwater harvesting is implemented, the municipal water demand can potentially be met by more than 100%. It can also be seen that if only roof rainwater harvesting is implemented, the winter municipal water demand can potentially be met by more than 100%, and nearly half of the summer municipal water demand can be met:

Table 25: The percentages of winter and summer municipal water demand which can be met by implementing both roof- and land surface harvesting, as well as roof harvesting only, at commercial buildings.

Harvesting Type	**Percentage Municipal Demand Met During Summer**	**Percentage Municipal Demand Met During Winter**
Roof-and Land Surface Harvesting	198%	967%
Roof Harvesting Only	44%	219%

A five- and ten year roof- and land-surface harvesting potable water and financial savings projection was performed on the results obtained during this research study, as can be seen in Table 26. The results indicate a five-year potable water and financial saving of 10 813 Kl and R 135 270.65 per building, 540 650 Kl and R 6 763 532.5 for 50 buildings, and 1 081 300 Kl and R 13 527 065 for 100 buildings.

The results also indicate a massive ten-year potable water and financial saving of 21 626 Kl and R 270 541.3 per building, 1 081 300 Kl and R 13 527 065 for 50 buildings, and 2 162 600 Kl and R 27 054 130 for 100 buildings, could potentially be achieved:

Table 26: The 5 - 10 Year Future Projection for Municipal Water and Financial Savings (Roof and Land Surface Harvesting).

Commercial Business - 5 Year Projection for Average Municipal Water and Financial Savings					
Average 5 Year Potable Water Saving per Building (Kl)	Average 5 Year Financial Saving per Building	Average 5 Year Potable Water Saving for 50 Buildings (Kl)	Average 5 Year Financial Saving for 50 Buildings	Average 5 Year Potable Water Saving for 100 Buildings (Kl)	Average 5 Year Financial Saving for 100 Buildings
10 813	R 135 270.65	540 650	R 6 763 532.5	1 081 300	R 13 527 065
Commercial Business - 10 Year Projection for Average Municipal Water and Financial Savings					
Average 10 Year Potable Water Saving per Building (Kl)	Average 10 Year Financial Saving per Building	Average 10 Year Potable Water Saving for 50 Buildings (Kl)	Average 10 Year Financial Saving for 50 Buildings	Average 10 Year Potable Water Saving for 100 Buildings (Kl)	Average 10 Year Financial Saving for 100 Buildings
21 626	R 270 541.3	1 081 300	R 13 527 065	2 162 600	R 27 054 130

* Savings were calculated with the assumption that all the surplus water in the storage vessel is utilised.

4.12 Research Challenges Experienced

The following challenges were experienced during this research study:

- At none of the surveyed commercial buildings was rain- and/or stormwater harvesting implemented, making assumptions on the water savings capability of different types of systems, and common challenges experienced with these different types of systems, very difficult.
- A suitable comparison building with similar water demand and size specifications as the TEARS study building, was not found within the study area, making comparison between a building with rainwater implementation against a building without rainwater implementation, impossible. The practical assessment section of this research study therefore only concentrated on comparing the water consumption information of the pre-rainwater harvesting system installation period against that of the post-rainwater harvesting system installation period of the same building.
- Although the commercial businesses in the survey area implemented some forms of green practices, none of them conformed to a typical green building status, and could be considered only as semi-green buildings; however, have the potential of being turned into green buildings with the correct municipal support, education and awareness.

5 Conclusions

The feasibility of rain- and/or stormwater harvesting for the commercial businesses is directly related to the land- and roof surface area sizes, the average amount of winter and summer rainfall in the area, the efficiency and size of the system installed, the preferred end-uses, and the municipal water demand of the preferred end-uses.

As for the results obtained through this research with regard to rain- and stormwater harvesting, the following analogies can be drawn from this research:

5.1 Roof Runoff Harvesting - TEARS Practical Pilot Case Study

If a theoretical calculation is done in order to establish the combined roof- and land surface harvesting potential at the TEARS pilot study site, a summer harvesting yield of 848 Kl, and a winter harvesting yield of 2 518 Kl, is obtained. This building is considered a high water consumption building, when compared with the average commercial building consumption figures in the Kommetjie area. Even though the building had a very high average municipal water consumption of 152.7 Kl as before the roof harvesting system installation (Table 15), the total municipal water consumption requirements could still potentially be met at above 100%, during winter and summer, if roof- and land surface harvesting was implemented, and by considering the high water consumer status of the TEARS building, the combined roof- and land surface harvesting at this building could be highly feasible.

The results obtained by the actual measurement of the roof harvesting volumes obtained during the pilot study period at the TEARS research site, indicate that the average monthly winter (14.2 Kl) and summer (9.0 Kl) harvested yields were not enough to meet the toilet flushing demand of 42.62 Kl if roof harvesting, only, is implemented, as shown in Table 15. During winter, an average of 33.3% of the toilet flushing demand could be met, and during summer an average of 21.3% of the toilet flushing demand could be met. An average annual municipal water saving of 139.2 Kl and financial saving of R 1 741.38 could be achieved.

It must, however, be noted that because the TEARS building is an animal shelter, a large number of people (an average of 15 people on any given day) are always present in the building - which explains the extraordinary high toilet flushing usage for this building. If the average toilet flushing demand of 5.4 Kl, as calculated for an average commercial building in the Kommetjie study area (Table 12), is considered, then the toilet flushing demand for an average commercial building could be potentially met above 100% during winter and summer.

According to the results obtained by the Wilcoxon Rank-sum test, a statistically significant negative difference between the pre-rainwater harvesting level of water usage in the pilot study building, and the post-rainwater harvesting level of water usage (there is greater pre- than post-rainwater harvesting level of municipal water usage) ($\mu_1 \neq \mu_2$) was shown, thereby resulting in the hypothesis $H:^2$ to be accepted.It can thus be said that since the rainwater harvesting system was installed at the TEARS building, the municipal water consumption was significantly reduced, compared to the municipal consumption figures before the system's installation.

It can be concluded that, although the results have shown that the toilet flushing demand could not be fully met with roof harvesting only, it must be considered that this building has an above-average toilet flushing demand. If roof rainwater harvesting should therefore be implemented at an average municipal consumption commercial building, the toilet flushing demand could potentially be fully met during winter and summer. If the combined roof- and land surface harvesting should be implemented at this high-consumption building, the total municipal water demand could be fully met, with significant municipal water saving, as well as financial savings, for the shelter.

It can also be concluded that aspects such as tank size, number of tanks, usage type, number of building occupants and roof size, have a direct impact on volumes of rainwater which can be harvested, as well as financial savings and system feasibility. Assumptions for the TEARS pilot study site are therefore only made in regard to the specific conditions relating to this study site, and may differ between buildings, according to different building and usage conditions. By no means can the same conclusions be drawn for simpler, more economical single use systems and other water usage types.

5.2 Land Surface Harvesting - Commercial Building Theoretical Assessment

By combining the use of an above-ground potable top-up roof harvesting system with a below-ground reservoir for irrigation and commercial washing usage, an annual rain- and stormwater yield of 2 162.60 Kl could be achieved as shown in Table 23. By comparing the average monthly summer yield of 66.90 Kl and the average monthly winter yield of 293.55 Kl with the average monthly summer and winter municipal consumption, it can be concluded that the harvested water can potentially totally replace the monthly municipal water usage during summer and winter. The cost-benefit analysis shows that an average financial saving of R 27 054.13 can be achieved, causing a buy-back period of as little as 3.5 years.

According to Table 24, it can be seen that if only roof rainwater harvesting is implemented, an annual rainwater yield of 487.44 Kl could be achieved. By comparing the average potential monthly winter yield of 66.16 Kl, and the average potential monthly summer yield of 15.08 Kl, with the average monthly summer and winter municipal water consumption, it can be seen that the winter municipal water demand could potentially be met at above 100%, and nearly half of the summer municipal water demand could be met. The cost-benefit analysis showed that an average financial saving of R 6 097.87 could be achieved by implementing roof rainwater harvesting, causing a buy-back period of as little as 5.8 years.

The Wilcoxon sign rank test indicated that the consumption of municipal water is statistically significant lower than the calculated yield of rain- and stormwater harvesting; thus there will be a large amount of surplus water available if rain- and stormwater harvesting systems are implemented. The hypotheses $H:_0$ and $H:_2$ were therefore rejected, and the hypothesis $H:_1$ was accepted.

It can therefore be concluded that the combined use of these systems for rain- and stormwater collection at commercial businesses, is highly financially viable, with exceptional municipal water savings as a result.

5.3 Theoretical Calculation Method Tested Against Actual Measured Results

It was found that the theoretical calculation method results, compared with the TEARS practically measured results, overestimated runoff, if average rainfall figures, which included exceptional high rainstorm events, were used in the calculations. If the average rainfall figures which excluded the exceptional high rainstorm events, were used, then a much more accurate result, compared with the TEARS result, would be achieved. This does not, however, mean that the theoretical method is overestimating if the total average rainfall figures are used, but merely that the tank size, tank overflow rates, water demand volumes, and so on, will influence the result. If the tank size is too small, then rainfall volumes during exceptionally high rainfall events will be lost through tank overflow, and the theoretical calculation that excludes exceptional high rainstorm events, should rather be used.

5.4 Rain- and Stormwater Harvesting - Commercial Building Survey

It can be concluded that two-thirds of the businesses sampled in the Kommetjie area participated in the rain- and stormwater harvesting project. None of the businesses at the time of the survey were harvesting/using rain- and/or stormwater. The roof catchment areas consisted mainly of corrugated iron, and the surface catchment areas consisted mainly of tar. Although most of the businesses did not sell green products, they did apply some kind of green practice/s. Although none of the businesses implemented or used rain- and/or stormwater, most of the business participants indicated that they think they could benefit by harvesting rain- and/or stormwater.

Less than half of the businesses surveyed had water saving fixtures or devices installed in their building, or made use of them. A small number of businesses indicated that they did have irrigation systems. None of the businesses applied irrigation time controlling. The businesses had mainly one or two toilets, and it seems that the category where the most water is used, was toilet flushing.

According to the survey results, it can be concluded that the commercial businesses in the Kommetjie area are implementing some green practices in order to be more environmentally friendly, but there was a zero perception level when it came to water saving awareness and alternative water resources.

In summary, the results obtained from this study show that if only roof rainwater harvesting is implemented, the winter municipal water demand can potentially be met at above 100%, and nearly half of the summer municipal water demand can be met. The results also indicate that by the combined implementation of above-ground and below-ground rain- and stormwater harvesting, the commercial buildings can be taken totally off the municipal water consumption grid during both winter and summer. The combined use of rain- and stormwater harvesting within a winter rainfall region is therefore an extremely viable option, with massive municipal and financial savings for the City of Cape Town and the commercial business consumer.

6 Recommendations

6.1 Unique measurement design

This study incorporated a unique measurement design implemented at the TEARS pilot study site, in order to practically assess the harvested rainwater yield to be used for toilet flushing purposes in the pilot study building. The design of this method is a ‘first’ and opens up the opportunity for further research focusing on direct measurement techniques, design and economical metering options.

The practical tank measurement of harvested rainwater during similar research studies has been very limited, due to the high financial costs associated with the insertion of electromagnetic flow meters capable of registering the low flows associated with rainwater harvesting. Due to this limitation, the practical measurement of harvested rainwater has been abandoned by many researchers - thereby leaving a gap in valuable information.

There have been many differing opinions regarding the feasibility of rainwater harvesting within a winter rainfall climate context. Theoretical studies are mostly focused on theoretical modelling, and conclusions for and against feasibility are made, leaving a certain degree of uncertainty as to whether rainwater harvesting can, indeed, be a viable alternative water option for a water-scarce city such as Cape Town.

The method designed for this pilot site study is a first step in the direction of direct rainwater research measurement, although the method designed for this study is only efficient for research studies investigating the potable top-up system which incorporates pumped flow pressures that make cheap mechanical measurement possible. In order for this method to produce results, the building needs to be occupied for a large part of the day, and the stored water should be used regularly, as the outflow volumes are critical in the calculation process.

6.2 Combined Roof - and Land Surface Harvesting for Industrial and Domestic Consumers

According to the results obtained during this study, it is recommended that roof- and land surface harvesting methods are combined, in order to offset the valuable potable water currently used for non-potable purposes such as toilet flushing, irrigation and other non-potable commercial business uses. Further research should be conducted on the viability of the combined use of rain- and stormwater harvesting methods for industrial and residential buildings.

Buildings with large roof- and land surface areas should be identified, and direct engagement with the property owners and consumers should be initiated, in order to encourage the use and installation of rain- and/or stormwater harvesting systems. Due to the large roof and land surface catchment sizes, as well as the high water consumption typical of industrial buildings, the potential for implementing combined rain- and stormwater harvesting is immense, and further research into its feasibility for these buildings should receive high priority.

6.3 Savings Calculation Spreadsheet Resource Tool

During this study, a commercial building rain- and stormwater harvesting yield and savings calculation spreadsheet was designed, to help commercial business consumers to assess their own yields and savings. This yield and savings calculation resource tool can be used by the consumer to assess the feasibility of roof harvesting, stormwater harvesting and roof- and stormwater harvesting, respectively, if implemented at their buildings. It is proposed that this resource be loaded on the municipal website for easy access and downloading by commercial business consumers.

6.4 Combining Rain- and/or Stormwater Harvesting and Greywater Re-use

According to Dixon, Butler and Fewkes (1999), up to 80% of toilet demand can be met by using grey- and rain- and/or stormwater with a 50 L storage tank. Ghisi and Oliveira (2007) tested properties where only greywater or rainwater systems, respectively, were installed against properties where the combined use of grey- and rainwater was implemented. They found that by combining the use of grey- and rainwater systems, a 6% to 9% higher potable water saving, when compared to a single system, could potentially be achieved.

The combined usage of rain- and stormwater harvesting initiatives with greywater recycling, is therefore highly recommended. At domestic properties where large areas for land catchment harvesting is typically non-existent, the combined implementation of roof harvesting and greywater recycling is strongly advised, and further research into this combined use and related savings is essential.

7 References

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Annexure A:

Descriptive Statistics: Frequency Tables

V (variable) = Variable number as generated by SAS statistical programme

The FREQ Procedure

F1	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	1	2.00	1	2.00
2	1	2.00	2	4.00
3	1	2.00	3	6.00
4	1	2.00	4	8.00
5	1	2.00	5	10.00
6	1	2.00	6	12.00
7	1	2.00	7	14.00
8	1	2.00	8	16.00
9	1	2.00	9	18.00
10	1	2.00	10	20.00
11	1	2.00	11	22.00
12	1	2.00	12	24.00
13	1	2.00	13	26.00
14	1	2.00	14	28.00
15	1	2.00	15	30.00
16	1	2.00	16	32.00
17	1	2.00	17	34.00
18	1	2.00	18	36.00
19	1	2.00	19	38.00
20	1	2.00	20	40.00
21	1	2.00	21	42.00
22	1	2.00	22	44.00
23	1	2.00	23	46.00
24	1	2.00	24	48.00
25	1	2.00	25	50.00
26	1	2.00	26	52.00
27	1	2.00	27	54.00
28	1	2.00	28	56.00
29	1	2.00	29	58.00
30	1	2.00	30	60.00
31	1	2.00	31	62.00
32	1	2.00	32	64.00
33	1	2.00	33	66.00
34	1	2.00	34	68.00
35	1	2.00	35	70.00
36	1	2.00	36	72.00
37	1	2.00	37	74.00
38	1	2.00	38	76.00
39	1	2.00	39	78.00
40	1	2.00	40	80.00
41	1	2.00	41	82.00
42	1	2.00	42	84.00
43	1	2.00	43	86.00
44	1	2.00	44	88.00
45	1	2.00	45	90.00
46	1	2.00	46	92.00
47	1	2.00	47	94.00
48	1	2.00	48	96.00
49	1	2.00	49	98.00
50	1	2.00	50	100.00

F2	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	2	12.50	2	12.50
2	1	6.25	3	18.75
4	2	12.50	5	31.25

5	1	6.25	6	37.50
7	1	6.25	7	43.75
9	1	6.25	8	50.00
11	6	37.50	14	87.50
12	1	6.25	15	93.75
14	1	6.25	16	100.00

Frequency Missing = 34

V01	Frequency	Percent	Cumulative Frequency	Cumulative Percent
AGM Kitchens FE	1	2.04	1	2.04
Ark Inflatables FE	1	2.04	2	4.08
Auto Clinic FE	1	2.04	3	6.12
Birchwood Timbers FE	1	2.04	4	8.16
Burglar Bar Studio	1	2.04	5	10.20
CCT Kommetjie Solid Waste	1	2.04	6	12.24
Cabinetworks FE	1	2.04	7	14.29
Compass Bakery Factory	1	2.04	8	16.33
Cooldandy	1	2.04	9	18.37
Creative Designs FE	1	2.04	10	20.41
DVC Printers	1	2.04	11	22.45
Dassenberg Nursery	1	2.04	12	24.49
Deck King FE	1	2.04	13	26.53
Digi-cut Wood	1	2.04	14	28.57
Directional Moling Services FE	1	2.04	15	30.61
Diva Health Foods	1	2.04	16	32.65
Flapping Fresh Deli	1	2.04	17	34.69
Fluvalve Marine FE	1	2.04	18	36.73
Glass Art	1	2.04	19	38.78
Glassfix	1	2.04	20	40.82
Harry Goemans Nursery (Lockhill Properties)	1	2.04	21	42.86
Heron Park	6	12.24	27	55.10
High Signs FE	1	2.04	28	57.14
KVS Sheet Metal Products FE	1	2.04	29	59.18
Kamicks Fishing Joint Ventures FE	1	2.04	30	61.22
Kelpak FE	1	2.04	31	63.27
Kline Engineering FE	1	2.04	32	65.31
Kommetjie Engineering FE	1	2.04	33	67.35
Konti Kitchens FE	1	2.04	34	69.39
Lumber City FE	1	2.04	35	71.43
Micklewood	1	2.04	36	73.47
Nu-style Kitchens FE	1	2.04	37	75.51
Rock Gardens FE	1	2.04	38	77.55
Rodgers Fruiteres	1	2.04	39	79.59
Slivers Biltong & Nut Factory	1	2.04	40	81.63
Stuart Steel Works	1	2.04	41	83.67
Super Decking FE	1	2.04	42	85.71
The Bean People FE	1	2.04	43	87.76
The Cover Studio	1	2.04	44	89.80
Valley Aluminium	1	2.04	45	91.84
Valley Glass FE	1	2.04	46	93.88
Valley Paints FE	1	2.04	47	95.92
Wall's Engineering FE	1	2.04	48	97.96
Woodgor Trading FE	1	2.04	49	100.00

Frequency Missing = 1

V02	Frequency	Percent	Cumulative Frequency	Cumulative Percent
14	1	6.67	1	6.67
18	1	6.67	2	13.33
24	2	13.33	4	26.67
25	1	6.67	5	33.33
32	1	6.67	6	40.00
36	1	6.67	7	46.67
41	1	6.67	8	53.33
42	2	13.33	10	66.67
43	1	6.67	11	73.33
44	1	6.67	12	80.00
50	1	6.67	13	86.67
53	1	6.67	14	93.33
54	1	6.67	15	100.00

Frequency Missing = 35

V03	Frequency	Percent	Cumulative Frequency	Cumulative Percent
No	17	34.00	17	34.00
Yes	33	66.00	50	100.00

V04	Frequency	Percent	Cumulative Frequency	Cumulative Percent
No	33	100.00	33	100.00

Frequency Missing = 17

V05	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Asbestos	18	36.00	18	36.00
Corrugated Iron	31	62.00	49	98.00
Main Office Asbestos/Other Corrugated Iron	1	2.00	50	100.00

V06	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Parking Inside/Tar	1	2.00	1	2.00
Cement/Tar Mix	1	2.00	2	4.00
Paved	17	34.00	19	38.00
Paving	1	2.00	20	40.00
Tar	29	58.00	49	98.00
Tar/Pave Mix	1	2.00	50	100.00

V07	Frequency
No	24
Yes (Bio-degradable plant bags, compost	1
Yes (Bio-friendly car products	1
Yes (Compost mulch)	1
Yes (Compost/organic worm farms)	1
Yes (Led free paints)	1
Yes (Plant bags, organic fertiliser, worm castings, eco-friendly pesticides)	1
Yes (Recycled brown paper bags)	1
Yes (Recycled glass products)	1
Yes (Recycled, bio-degradable paper)	1

V07	Percent
No	72.73
Yes (Bio-degradable plant bags, compost	3.03
Yes (Bio-friendly car products	3.03
Yes (Compost mulch)	3.03
Yes (Compost/organic worm farms)	3.03
Yes (Led free paints)	3.03
Yes (Plant bags, organic fertiliser, worm castings, eco-friendly pesticides)	3.03
Yes (Recycled brown paper bags)	3.03
Yes (Recycled glass products)	3.03
Yes (Recycled, bio-degradable paper)	3.03

V07	Cumulative Frequency
No	24
Yes (Bio-degradable plant bags, compost	25
Yes (Bio-friendly car products	26
Yes (Compost mulch)	27
Yes (Compost/organic worm farms)	28
Yes (Led free paints)	29
Yes (Plant bags, organic fertiliser, worm castings, eco-friendly pesticides)	30
Yes (Recycled brown paper bags)	31
Yes (Recycled glass products)	32
Yes (Recycled, bio-degradable paper)	33

V07	Cumulative Percent
No	72.73
Yes (Bio-degradable plant bags, compost	75.76
Yes (Bio-friendly car products	78.79
Yes (Compost mulch)	81.82
Yes (Compost/organic worm farms)	84.85
Yes (Led free paints)	87.88
Yes (Plant bags, organic fertiliser, worm castings, eco-friendly pesticides)	90.91
Yes (Recycled brown paper bags)	93.94
Yes (Recycled glass products)	96.97
Yes (Recycled, bio-degradable paper)	100.00

Frequency Missing = 17

V08	Frequency	Percent
No	10	30.30
Yes (Cardboard)	1	3.03
Yes (Glass, paper, plastic)	1	3.03
Yes (Metal recycling, energy saving light bulbs)	1	3.03
Yes (Paper recycling)	1	3.03
Yes (Paper, glass)	1	3.03
Yes (Paper, plastics, metal, waste food to worm factory)	1	3.03
Yes (Paper, glass, plastic, solar)	1	3.03
Yes (Plastic, paper, cardboard)	1	3.03
Yes (Plastic, glass, cardboard)	1	3.03
Yes (Recyclable pots, carrier bags, energy saving light bulbs)	1	3.03
Yes (Recycling paper)	1	3.03
Yes (Recycling, worm castings)	1	3.03
Yes (Waste paper, metal)	1	3.03
Yes (Waste recycling)	1	3.03
Yes (Waste recycling)	2	6.06
Yes (Waste)	3	9.09
Yes (Waste, solar, gas cooker)	1	3.03
Yes (Waste, cardboard)	1	3.03
Yes (Waste, glass)	1	3.03
Yes (Wood, Paper)	1	3.03

V08	Cumulative Frequency	Cumulative Percent
No	10	30.30
Yes (Cardboard)	11	33.33
Yes (Glass, paper, plastic)	12	36.36
Yes (Metal recycling, energy saving light bulbs)	13	39.39
Yes (Paper recycling)	14	42.42
Yes (Paper, glass)	15	45.45
Yes (Paper, plastics, metal, waste food to worm factory)	16	48.48
Yes (Paper, glass, plastic, solar)	17	51.52
Yes (Plastic, paper, cardboard)	18	54.55
Yes (Plastic, glass, cardboard)	19	57.58
Yes (Recyclable pots, carrier bags, energy saving light bulbs)	20	60.61
Yes (Recycling paper)	21	63.64
Yes (Recycling, worm castings)	22	66.67
Yes (Waste paper, metal)	23	69.70
Yes (Waste recycling)	24	72.73
Yes (Waste recycling)	26	78.79
Yes (Waste)	29	87.88
Yes (Waste, solar, gas cooker)	30	90.91
Yes (Waste, cardboard)	31	93.94
Yes (Waste, glass)	32	96.97
Yes (Wood, paper)	33	100.00

Frequency Missing = 17

V09	Frequency	Percent	Cumulative Frequency	Cumulative Percent
No	9	27.27	9	27.27
Yes	24	72.73	33	100.00

Frequency Missing = 17

V10	Frequency	Percent	Cumulative Frequency	Cumulative Percent
No	20	60.61	20	60.61
Yes	1	3.03	21	63.64
Yes (Aerators)	1	3.03	22	66.67
Yes (Dual flush toilet	3	9.09	25	75.76
Yes (Dual flush)	3	9.09	28	84.85
Yes (Dual flush)	2	6.06	30	90.91
Yes (Low flow	1	3.03	31	93.94
Yes (Waterless urinals)	2	6.06	33	100.00

Frequency Missing = 17

V11	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Garden Hand Watering	2	6.06	2	6.06
No	28	84.85	30	90.91
Yes	3	9.09	33	100.00

Frequency Missing = 17

V12	Frequency	Percent	Cumulative Frequency	Cumulative Percent
No	33	100.00	33	100.00

Frequency Missing = 17

V13	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	14	42.42	14	42.42
2	12	36.36	26	78.79
3	2	6.06	28	84.85
4	2	6.06	30	90.91
6	1	3.03	31	93.94
10	1	3.03	32	96.97
18	1	3.03	33	100.00

Frequency Missing = 17

V14	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Factory floor washing	1	3.03	1	3.03
Factory washing	1	3.03	2	6.06
Garden hand watering	2	6.06	4	12.12
Irrigation	1	3.03	5	15.15
Kitchen	2	6.06	7	21.21
Surface washing	1	3.03	8	24.24
Toilet	23	69.70	31	93.94
Wash-bay	1	3.03	32	96.97
Workshop floor washing	1	3.03	33	100.00

Frequency Missing = 17

TAY

V41	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Asbestos	7	21.21	7	21.21
Corrugated iron	25	75.76	32	96.97
Main office asbestos/other corrugated iron	1	3.03	33	100.00

V43	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Parking inside/tar	1	3.03	1	3.03
Asbestos	2	6.06	3	9.09
Cement/tar mix	1	3.03	4	12.12
Paved	5	15.15	9	27.27
Tar	23	69.70	32	96.97
Tar/paved mix	1	3.03	33	100.00

Annexure B:

Descriptive Statistics: Means, Standard Deviations, Median, Mode, Minimum, Maximum and Range

Variable	Label	N	Mean	Std Dev	Median	Mode	Minimum	Maximum	Range
V15	V15	32	3531.35	5978.12	1441.99	1799.42	590.9700000	30487.13	29896.16
V16	V16	32	816.0187500	666.0447455	643.5000000	356.0000000	266.0000000	3368.00	3102.00
V17	V17	32	2698.20	5884.15	740.8750000	.	195.6800000	29976.13	29780.45

Variable	Label	N	Mean	Std Dev	Median	Mode	Minimum	Maximum	Range
V27	V27	12	56.9750000	53.0331650	43.0000000	.	2.0000000	146.0000000	144.0000000
V28	V28	12	29114.23	27099.95	21973.00	.	1022.00	74606.00	73584.00
V29	V29	12	42.8583333	36.9890023	40.0000000	40.0000000	0.3000000	153.0000000	152.7000000

Variable	Label	N	Mean	Std Dev	Median	Mode	Minimum	Maximum	Range
V18	V18	32	59.8218750	51.6374066	40.0000000	28.0000000	0.3000000	183.0000000	182.7000000
V19	V19	26	55.9346154	59.4344812	39.7500000	44.0000000	2.0000000	214.0000000	212.0000000
V20	V20	40	83.9498750	110.6378627	40.8225000	24.0000000	0.3550000	574.0000000	573.6450000
V21	V21	26	55.9346154	59.4344812	39.7500000	44.0000000	2.0000000	214.0000000	212.0000000
V22	V22	18	12.5316667	7.4595764	9.9295000	.	3.8500000	30.5850000	26.7350000
V23	V23	18	165.9194444	98.7644474	131.4650000	.	50.9700000	404.9400000	353.9700000
V24	V24	19	12.3154211	7.3104280	9.4080000	.	3.8500000	30.5850000	26.7350000
V25	V25	19	154.0652632	91.4530244	117.6900000	.	48.1600000	382.6200000	334.4600000
V26	V26	25	30.0488837	6.0946432	28.7860000	.	22.5894643	47.5863200	24.9968557

Variable	Label	N	Mean	Std Dev	Median	Mode	Minimum	Maximum	Range
V37	V37	33	3554.95	5885.53	1491.33	1799.42	590.9700000	30487.13	29896.16
V38	V38	33	801.7454545	660.6630042	620.0000000	356.0000000	266.0000000	3368.00	3102.00
V39	V39	33	2736.59	5795.68	781.3300000	.	195.6800000	29976.13	29780.45
V40	V40	33	3538.34	5879.12	1491.33	1799.42	590.9700000	30487.13	29896.16
V42	V42	33	0.9166667	0.0620819	0.9500000	0.9500000	0.8000000	0.9500000	0.1500000
V44	V44	33	0.9212121	0.0484612	0.9500000	0.9500000	0.8000000	0.9500000	0.1500000
V45	V45	33	26.3112727	34.4372322	15.0000000	2.0000000	0	149.0000000	149.0000000
V46	V46	33	23.9826364	26.3561006	15.9030000	36.0000000	0	106.0000000	106.0000000
V47	V47	33	26.0543939	26.3417994	16.0000000	5.0000000	0	93.4500000	93.4500000
V48	V48	33	29.0793333	32.7193394	16.0000000	8.0000000	0	122.0000000	122.0000000
V49	V49	33	33.6432424	45.5541763	13.6690000	0	0	160.0000000	160.0000000
V50	V50	32	46.9734688	86.4664318	12.6700000	12.0000000	0	436.0000000	436.0000000
V51	V51	33	39.6819697	99.6853923	11.9620000	5.0000000	0	574.0000000	574.0000000
V52	V52	33	26.8783939	29.1201728	16.0000000	38.0000000	0	104.0000000	104.0000000

V53	V53	33	32.6854848	44.2679840	12.1130000	5.0000000	0	199.0000000	199.0000000
V54	V54	32	42.6155938	90.7165293	13.3000000	5.0000000	0	495.4460000	495.4460000
V55	V55	32	40.4601875	57.9959336	16.6320000	5.0000000	0	267.1420000	267.1420000
V56	V56	33	31.2694545	38.2192576	13.0000000	6.0000000	0	153.0000000	153.0000000
V57	V57	33	31.6032727	37.8317010	15.0000000	4.0000000	0	147.0000000	147.0000000
V58	V58	33	32.6972121	45.0143551	13.0000000	7.0000000	0	214.0000000	214.0000000
V59	V59	32	29.6123438	34.5595198	15.7465000	12.0000000	0	153.0000000	153.0000000
V60	V60	31	35.1378710	43.6348050	17.0000000	5.0000000	0	193.0000000	193.0000000
V61	V61	31	35.6602903	71.7297953	12.3470000	4.0000000	0	394.0000000	394.0000000
V62	V62	31	35.7587742	74.6992271	17.8550000	0	0	417.0000000	417.0000000
V63	V63	30	43.9552667	106.7809380	11.0000000	0	0	538.0000000	538.0000000
V64	V64	32	26.7051563	42.6652688	12.5000000	9.0000000	0	223.0000000	223.0000000
V65	V65	32	26.3916250	39.2232007	13.4765000	8.0000000	0	206.0000000	206.0000000
V66	V66	32	26.1804375	30.4740469	15.4765000	1.0000000	0	137.0000000	137.0000000
V67	V67	32	23.3549062	30.0803968	13.9000000	1.0000000	0	121.0000000	121.0000000
V68	V68	32	32.7290938	38.6421490	19.1730000	8.0000000	0	145.0000000	145.0000000
V69	V69	25	28.6418000	34.9188848	11.0000000	9.0000000	0	140.0000000	140.0000000
V70	V70	33	30.3540870	32.5226785	19.9230769	7.3076923	0	134.7692308	134.7692308
V71	V71	33	33.7730285	41.9801976	15.3333333	7.5833333	0	192.0000000	192.0000000
V72	V72	33	29.7053427	32.7205575	19.9230769	7.3076923	0	134.7692308	134.7692308
V73	V73	33	32.9630455	41.7728253	15.3333333	7.5833333	0	192.0000000	192.0000000
V74	V74	33	89.6923077	0	89.6923077	89.6923077	89.6923077	89.6923077	0
V75	V75	33	20.4416667	0	20.4416667	20.4416667	20.4416667	20.4416667	0
V76	V76	33	293548.86	500874.82	118663.64	.	50355.19	2597737.99	2547382.80
V77	V77	33	66902.37	114153.78	27044.49	.	11476.39	592047.36	580570.97

Annexure C:

Inferential Statistics: Wilcoxon Rank Test
(Comparing water consumption before and after rainwater harvesting system installation)

The NPAR1WAY Procedure
Analysis of Variance for Variable V20
Classified by Variable GRP

GRP	N	Mean
Pre-harvesting	14	168.642857
Post-harvesting	26	38.345962

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Among	1	154493.257138	154493.2571	18.1816	0.0001
Within	38	322895.472415	8497.2493		

Wilcoxon Scores (Rank Sums) for Variable V20
Classified by Variable GRP

GRP	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
Pre-harvesting	14	436.50	287.0	35.257387	31.178571
Post-harvesting	26	383.50	533.0	35.257387	14.750000

Wilcoxon Two-Sample Test

Statistic	436.5000
Normal Approximation	
Z	4.2261
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	<.0001
t Approximation	
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	0.0001

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	17.9797
DF	1
Pr > Chi-Square	<.0001

Inferential Statistics: Wilcoxon Sign Rank Test
(Comparing water consumption of Kommetjie with Main Municipal Meter consumption measurement)

The UNIVARIATE Procedure
Variable: DIFF

N	25	Sum Weights	25
Mean	-8.7109163	Sum Observations	-217.77291
Std Deviation	26.4836312	Variance	701.38272
Skewness	-3.5018337	Kurtosis	15.412886
Uncorrected SS	18730.1869	Corrected SS	16833.1853
Coeff Variation	-304.02807	Std Error Mean	5.29672624

Basic Statistical Measures

Location		Variability	
Mean	-8.71092	Std Deviation	26.48363
Median	-3.94622	Variance	701.38272
Mode	.	Range	149.52325
		Interquartile Range	15.90981

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	-1.64458	Pr > |t|	0.1131
Sign	M	-3.5	Pr >= |M|	0.2295
Signed Rank	S	-69.5	Pr >= |S|	0.0598

Quantiles (Definition 5)

Quantile	Estimate
100% Max	26.47121
99%	26.47121
95%	11.58632
90%	9.73107
75% Q3	2.96100
50% Median	-3.94622
25% Q1	-12.94881
10%	-24.62079
5%	-25.83154
1%	-123.05204
0% Min	-123.05204

Extreme Observations

------Lowest------		------Highest-----	
Value	Obs	Value	Obs
-123.0520	15	4.29819	24
-25.8315	7	4.78600	14
-24.6208	4	9.73107	10
-19.9775	2	11.58632	19
-14.3933	8	26.47121	12

Variable: V20 (V20)

N	25	Sum Weights	25
Mean	38.7598	Sum Observations	968.995
Std Deviation	26.1094951	Variance	681.705736
Skewness	3.61468986	Kurtosis	16.4890504
Uncorrected SS	53918.9901	Corrected SS	16360.9377
Coeff Variation	67.3623061	Std Error Mean	5.22189902

Basic Statistical Measures

Location		Variability	
Mean	38.75980	Std Deviation	26.10950
Median	36.00000	Variance	681.70574
Mode	24.00000	Range	152.64500
		Interquartile Range	13.38900

Note: The mode displayed is the smallest of 3 modes with a count of 2.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	7.422549	Pr > |t|	<.0001
Sign	M	12.5	Pr >= |M|	<.0001
Signed Rank	S	162.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	153.000
99%	153.000
95%	54.000
90%	48.421
75% Q3	41.389
50% Median	36.000
25% Q1	28.000
10%	24.000
5%	21.932
1%	0.355
0% Min	0.355

Extreme Observations

-----Lowest-----		-----Highest-----	
Value	Obs	Value	Obs
0.355	12	43.000	16
21.932	22	43.579	6
24.000	14	48.421	7
24.000	13	54.000	4
26.000	25	153.000	15

Variable: V26 (V26)

N	25	Sum Weights	25
Mean	30.0488837	Sum Observations	751.222091
Std Deviation	6.09464321	Variance	37.1446759
Skewness	1.14292686	Kurtosis	1.29822118
Uncorrected SS	23464.8574	Corrected SS	891.472221
Coeff Variation	20.2824281	Std Error Mean	1.21892864

Basic Statistical Measures

Location		Variability	
Mean	30.04888	Std Deviation	6.09464
Median	28.78600	Variance	37.14468
Mode	.	Range	24.99686
		Interquartile Range	9.21234

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	24.65188	Pr > |t|	<.0001
Sign	M	12.5	Pr >= |M|	<.0001
Signed Rank	S	162.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	47.5863
99%	47.5863
95%	39.7761
90%	37.1739
75% Q3	34.9006
50% Median	28.7860
25% Q1	25.6883
10%	23.5762
5%	23.0225
1%	22.5895
0% Min	22.5895

Extreme Observations

------Lowest-----		-----Highest-----	
Value	Obs	Value	Obs
22.5895	7	35.8182	16
23.0225	2	36.6988	11
23.5762	23	37.1739	18
23.6385	3	39.7761	10
25.5909	21	47.5863	19

Inferential Statistics: Spearman Correlation Coefficient
(Determine relationship between Kommetjie water consumption and main municipal meter consumption measurement)

The CORR Procedure

2 Variables: V20 V26

Simple Statistics

Variable	N	Mean	Std Dev	Median	Minimum	Maximum	Label
V20	25	38.75980	26.10950	36.00000	0.35500	153.00000	V20
V26	25	30.04888	6.09464	28.78600	22.58946	47.58632	V26

Pearson Correlation Coefficients, N = 25
Prob > |r| under H0: Rho=0

	V20	V26
V20	1.00000	0.05489
V20		0.7944
V26	0.05489	1.00000
V26	0.7944	

Spearman Correlation Coefficients, N = 25
Prob > |r| under H0: Rho=0

	V20	V26
V20	1.00000	0.09967
V20		0.6355
V26	0.09967	1.00000
V26	0.6355	

Inferential Statistics: Wilcoxon Sign Rank Test
(Comparing water consumption with calculated water yield)

```
                        The UNIVARIATE Procedure
                         Variable:  Diff_Winter
N                           33    Sum Weights                 33
Mean                263.194776    Sum Observations    8685.42761
Std Deviation       489.171469    Variance            239288.726
Skewness            3.65873745    Kurtosis             14.596657
Uncorrected SS      9943198.42    Corrected SS        7657239.24
Coeff Variation      185.85911    Std Error Mean      85.1538227

                      Basic Statistical Measures
         Location                    Variability
     Mean     263.1948     Std Deviation            489.17147
     Median    97.3278     Variance                    239289
     Mode            .     Range                         2509
                           Interquartile Range      165.21780

                      Tests for Location: Mu0=0
        Test           -Statistic-     -----p Value------
        Student's t    t  3.090816     Pr > |t|    0.0041
        Sign           M      15.5     Pr >= |M|   <.0001
        Signed Rank    S     279.5     Pr >= |S|   <.0001

                      Quantiles (Definition 5)
                      Quantile          Estimate
                      100% Max        2506.04568
                      99%             2506.04568
                      95%             1393.55178
                      90%              437.64605
                      75% Q3           215.57470
                      50% Median        97.32785
                      25% Q1            50.35689
                      10%               44.05939
                      5%                 7.91448
                      1%                -2.78475
                      0% Min            -2.78475

                         Extreme Observations
          ------Lowest------           ------Highest-----
              Value      Obs               Value      Obs
           -2.78475       31             346.175       11
            7.91448        4             437.646       16
           27.80499       13             941.107        8
           44.05939       18            1393.552       27
           44.25209       32            2506.046       29

                         Variable:  Diff_Summer
N                           33    Sum Weights                 33
Mean                33.1293421    Sum Observations    1093.26829
Std Deviation       102.307668    Variance            10466.8589
Skewness            2.86980817    Kurtosis            10.0548985
Uncorrected SS      371158.745    Corrected SS        334939.485
Coeff Variation     308.812858    Std Error Mean       17.809479

                      Basic Statistical Measures
         Location                    Variability

     Mean     33.12934     Std Deviation            102.30767
     Median   11.02013     Variance                     10467
     Mode           .      Range                    590.81151
                           Interquartile Range       22.65490

                      Tests for Location: Mu0=0
        Test           -Statistic-     -----p Value------
        Student's t    t  1.860208     Pr > |t|    0.0721
        Sign           M       9.5     Pr >= |M|   0.0013
        Signed Rank    S     147.5     Pr >= |S|   0.0064

                       Quantiles (Definition 5)
                       Quantile         Estimate
                       100% Max        460.21403
                       99%             460.21403
```

95%	281.48031
90%	67.96173
75% Q3	24.86065
50% Median	11.02013
25% Q1	2.20575
10%	-28.36202
5%	-51.47052
1%	-130.59749
0% Min	-130.59749

Extreme Observations

------Lowest------		------Highest-----	
Value	Obs	Value	Obs
-130.5975	17	61.6442	1
-51.4705	9	67.9617	11
-41.6121	24	206.6897	8
-28.3620	4	281.4803	27
-18.1454	13	460.2140	29

Inferential Statistics: Wilcoxon Sign Rank Test (Difference between winter and summer yield)

The UNIVARIATE Procedure
Variable: Diff_seasons

N	33	Sum Weights	33
Mean	226.646493	Sum Observations	7479.33425
Std Deviation	386.721039	Variance	149553.162
Skewness	3.66030056	Kurtosis	14.7347302
Uncorrected SS	6480866.05	Corrected SS	4785701.17
Coeff Variation	170.627409	Std Error Mean	67.3194919

Basic Statistical Measures

Location		Variability	
Mean	226.6465	Std Deviation	386.72104
Median	91.6192	Variance	149553
Mode	.	Range	1967
		Interquartile Range	153.76236

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	3.366729	Pr > |t|	0.0020
Sign	M	16.5	Pr >= |M|	<.0001
Signed Rank	S	280.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2005.6906
99%	2005.6906
95%	1107.1297
90%	423.6048
75% Q3	208.0145
50% Median	91.6192
25% Q1	54.2522
10%	39.5176
5%	38.8801
1%	38.8788
0% Min	38.8788

Extreme Observations

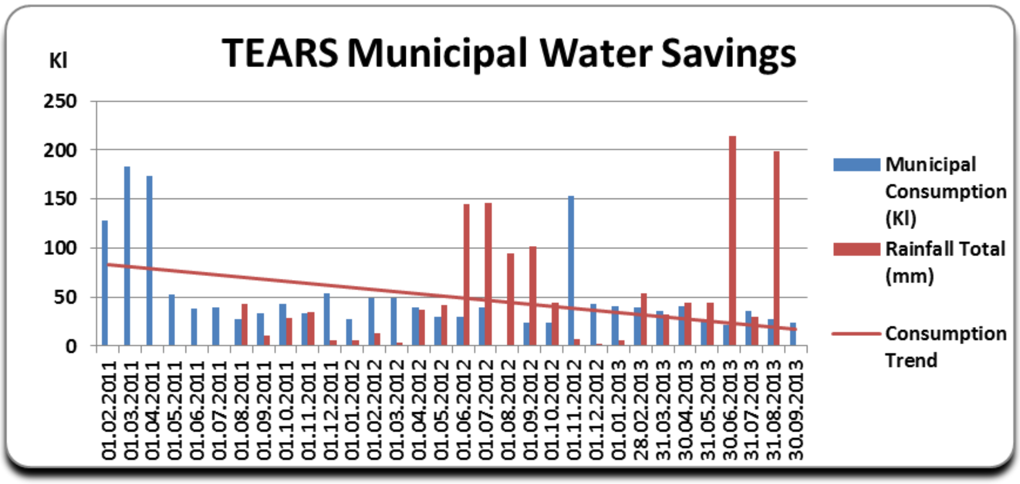
------Lowest-----		------Highest-----	
Value	Obs	Value	Obs
38.8788	10	293.526	1
38.8801	26	423.605	16
39.4702	7	734.084	8
39.5176	31	1107.130	27
39.5413	18	2005.691	29

Annexure D

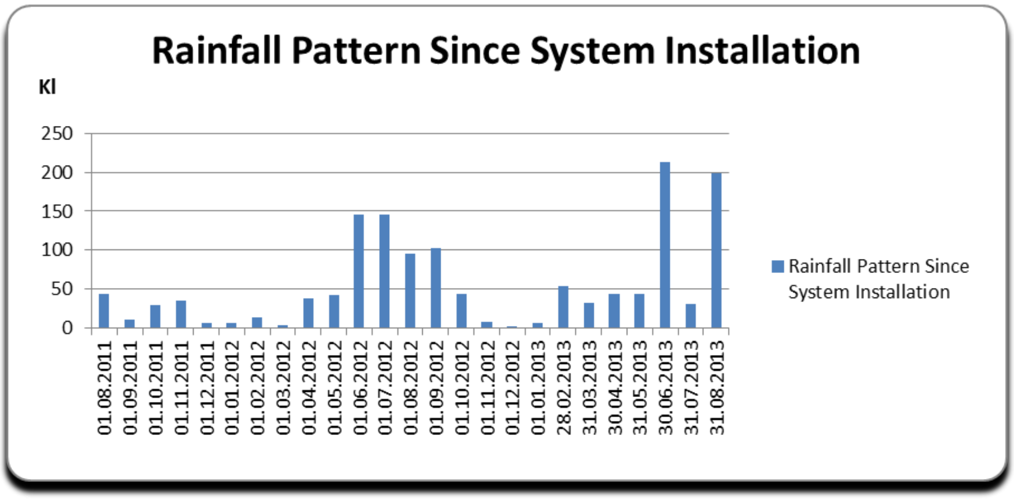
TEARS Results

Main Municipal Meter Historic and Current Consumptions		
Date	**Municipal Consumption (Kl)**	**Rainfall Total (mm)**
01.02.2011	128	
01.03.2011	183	
01.04.2011	174	
01.05.2011	153	
01.06.2011	138	
01.07.2011	140	
*01.08.2011	28	43
01.09.2011	34	10.2
01.10.2011	43	28.8
01.11.2011	33	34.4
01.12.2011	54	5.6
01.01.2012	28	6.1
01.02.2012	49	13.5
01.03.2012	49	3.2
01.04.2012	40	37.5
01.05.2012	30	42
01.06.2012	30	145
01.07.2012	40	146
01.08.2012	0.3	95
01.09.2012	24	102
01.10.2012	24	44
01.11.2012	153	7
01.12.2012	43	2
01.01.2013	41	6
28.02.2013	40	54
31.03.2013	36	32
30.04.2013	41	44
31.05.2013	28	44
30.06.2013	21	214
31.07.2013	36	30
31.08.2013	27	199

*Rainwater System Installation Date



Date	Rainfall Pattern Since System Installation
01.08.2011	43
01.09.2011	10.2
01.10.2011	28.8
01.11.2011	34.4
01.12.2011	5.6
01.01.2012	6.1
01.02.2012	13.5
01.03.2012	3.2
01.04.2012	37.5
01.05.2012	42
01.06.2012	145
01.07.2012	146
01.08.2012	95
01.09.2012	102
01.10.2012	44
01.11.2012	7
01.12.2012	2
01.01.2013	6
28.02.2013	54
31.03.2013	32
30.04.2013	44
31.05.2013	44
30.06.2013	214
31.07.2013	30
31.08.2013	199



TEARS Tank Meter Readings-Potable Inflow and Outflow-15mm Kent Meters					
Date	**Potable Inflow Reading**	**Outflow Reading**	**Difference (Potable Inflow)**	**Difference (Outflow)**	**Outflow - Potable Inflow= Rainwater Harvested (kl)**
01/02/2012	358.731	184.456			
12/03/2012	417.48	249.139	58.749	64.683	5.934
13/04/2012	457.825	298.892	40.345	49.753	9.408
11/05/2012	488.089	336.962	30.264	38.07	7.806
15/06/2012	518.599	385.385	30.51	48.423	17.913
17/07/2012	539.732	423.005	21.133	37.62	16.487
27/08/2012	570.131	480.629	30.399	57.624	27.225
30/09/2012	604.636	522.733	34.105	42.104	7.999
01/11/2012	637.048	562.785	32.412	40.052	7.64
01/12/2012	673.549	606.006	36.501	43.221	6.72
01/01/2013	707.852	644.159	34.303	38.153	3.85
01/02/2013	731.966	685.19	24.114	41.031	16.917
01/03/2013	766.372	727.392	34.406	42.202	7.796
01/04/2013	801.087	768.544	34.715	41.152	6.437
01/05/2013	834.189	813.947	33.102	45.403	12.301
01/06/2013	870.491	861.15	36.302	47.203	10.901
01/07/2013	901.884	902.994	31.393	41.844	10.451
01/08/2013	915.087	935.397	13.203	32.403	19.2
01/09/2013	926.191	977.086	11.104	41.689	30.585

Annexure E

Ethics Committee Approval Letter

UNISA university of south africa

2013-03-04

Ref. Nr.: 2013/CAES/024

To:
Student: N Viljoen **Student nr: 37272233**
Supervisor: Ms M Taylor
Department of Environmental Science
College of Agriculture and Environmental Sciences

Dear Ms Taylor and Ms Viljoen

Request for Ethical approval for the following research project:

The feasibility of rainwater and stormwater harvesting within a winter rainfall climate context: A commercial building focus

The application for ethical clearance in respect of the above mentioned research has been reviewed by the Research Ethics Review Committee of the College of Agriculture and Environmental Sciences, Unisa. Ethics clearance for the above mentioned project (Ref. Nr.: 2013/CAES/024) **is approved,** after careful consideration of all documentation submitted to the CAES Ethics committee.

The Ethics committee would like to remind the researcher that a Permission letter from the Kommetjie district is outstanding and should be forwarded to Ms Marthie van Wyk before data collection takes place.

Please be advised that the committee needs to be informed should any part of the research methodology as outlined in the Ethics application (Ref. Nr.: 2013/CAES/024), change in any way. In this instance a memo should be submitted to the Ethics Committee in which the changes are identified and fully explained.

We trust that sampling, data gathering and processing of the relevant data will be undertaken in a manner that is respectful of the rights and integrity of all participants, as stipulated in the UNISA Research Ethics Policy.

The Ethics Committee wishes you all the best with this research undertaking.

Kind regards,

Prof E Kempen,
CAES Ethics Review Committee Chair

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Annexure F

Survey Consent Form

TITLE OF RESEARCH PROJECT

The feasibility of rainwater and stormwater harvesting within a winter rainfall climate context: A Commercial Building Focus

Dear Mr/Mrs/Miss/Ms ________________________________ Date..…/..…/20...

NATURE AND PURPOSE OF THE STUDY

This study will attempt to assess the viability and feasibility of rainwater and stormwater harvesting systems, as well as the water savings efficiency of these systems, for green businesses in a winter rainfall area, by means of comparison, theoretical models and a perception survey.
The purpose of this survey is to ascertain the current trend in rain and stormwater harvesting interest and activities at businesses in Kommetjie, as well as the perception and attitudes relating to the efficiency and viability of this alternative water resource. The current perceptions and attitudes of respondents will also be used to assess the average knowledge of the topic and the need for more information.

RESEARCH PROCESS

1. Interviews and the completion of questionnaires will be conducted with business owners in Kommetjie, Cape Town.
2. The interviews and questionnaires will take approximately 5 minutes (five minutes each) of your time.
3. As part of a pre-survey stage approximately 10 respondents from businesses in the same area will be telephonically contacted to ascertain survey and questionnaire technicalities such as time taken to complete questionnaires as well as challenges with the questionnaire questions.
4. The main survey will target approximately 50 respondents from businesses in Kommetjie who will be provided with a questionnaire regarding rainwater harvesting interventions; if any; at their place of business.
5. The five minute interview will be conducted in order to enhance and support the questionnaire results.
6. Participation is voluntary and and no personal details is required.

CONFIDENTIALITY

The information you provide will be treated as highly confidential. Personal details are not required on the questionnaire form. If water account or any other related information is voluntarily released by participants during interviews it will be treated as highly confidential and any documents will be discarded after completion of this research study.

WITHDRAWAL CLAUSE

I understand that I may withdraw from this survey at any time. I therefore participate voluntarily until such time as I request otherwise.

POTENTIAL BENEFITS OF THE STUDY

In most urban areas, population is increasing rapidly and the issue of supplying adequate water to meet societal needs, and to ensure equity in access to water, is one of the most urgent and significant challenges faced by decision makers. South Africa has low levels of rainfall relative to the world average, with high variability and evaporation levels. All of these pose constraints on the amount of water available for use. A limited number of businesses are incorporating rainwater and stormwater harvesting at their place of business to further reduce potable water use, and information regarding the potential of these alternative water resources and related infrastructure should be made available to current and future green business owners and developers. If the outcomes of this study are in favour of rainwater and stormwater harvesting, programmes and frameworks are envisaged for the promotion of rainwater harvesting installations in current and future green commercial buildings in Cape Town.

INFORMATION (contact information of your supervisor)

If you have any questions concerning this study, you may contact the supervisors, Ms M Taylor at 011 471 2286 or Prof RM Hendrick at 011 471 2346 from the Department of Environmental Sciences, UNISA.

CONSENT

I, the undersigned, …………………………………………………………………. (full name) have read the above information relating to the project and have also heard the verbal version, and declare that I understand it. I have been afforded the opportunity to discuss relevant aspects of the project with the project leader, and hereby declare that I agree voluntarily to participate in the project.

I indemnify the university and any employee or student of the university against any liability that I may incur during the course of the project.

I further undertake to make no claim against the university in respect of damages to my person or reputation that may be incurred as a result of the project/trial or through the fault of other participants, unless resulting from negligence on the part of the university, its employees or students.

I have received a signed copy of this consent form.

Signature of participant: ....

Signed at ………………………………… on …………………………………

WITNESSES

1 ....

2 ....

Annexure G

Survey Questionnaire

Rainwater & Stormwater Harvesting Research - Survey Questionnaire

Declaration of Confidentiality

I am a MSc student of the University of South Africa (UNISA), and are conducting a research survey on the feasibility of rainwater and stormwater harvesting within a winter rainfall area. Could you please spare five minutes of your time to assist me with this survey. Your details and answers will be treated with high confidentiallity and will be discarded upon completion of this study.

Business Park: ____________________

Please tick ✓

Questions:

1. Do you make use of harvested rain and/or stormwater? If yes, please complete the questions below.	No	Yes				
2. What is the size of your rainwater/stormwater collection tank/container (Litres)?	100L - 1 000L	1 001L - 2 500L	2 501L - 3 500L	3 501L - 5 000L	5 001L - 10 000L	Other
3. Do you know your approximate roof/covered land surface area size in m^2?	$10m^2$ - $50m^2$	$51m^2$ - $100m^2$	$101m^2$ - $150m^2$	$151m^2$ - $200m^2$	$201m^2$ - $250m^2$	Other
4. What type of collection surface are you using?	Roof (Corrugated Iron)	Roof (Tiled)	Roof (Asbestos)	Hard Surfaces (Paved Area)	Hard Surfaces (Tarred)	Cemented
5. In your opinion, in which category is the most water used within your place of business?	Toilet	Kitchen	Bathroom	Irrigation	Other	
6. In your opinion, what level of water quality is needed for above mentioned categories, please assign a quality value to each? (1=Drinking Quality; 2=Indoor Usage But Non-Drinking Quality; 3=Outdoor Usage Only Non-Drinking Quality)	Toilet	Kitchen	Bathroom	Irrigation	Other	
7. Do you irrigate at your place of business, and if so, do you make use of an irrigation time controller?	Irrigate	Time Controller				
8. Are you using a pump to help distribute the water?	No	Yes				
9. Do you apply any environmentally friendly practises at your place of business, i.e. waste recycling, solar panels, etc.? If yes, please name them.	No	Yes	Environmental Friendly Practises: ____________________			
10. Do you sell any "green" (environmentally friendly) products? If yes, please name them.	No	Yes	Environmental Friendly Products: ____________________			
11. Do you have any water saving fixtures/appliances in your place of business, i.e. low flow shower heads, dual flush toilets, low water usage washing mashine, etc.	No	Yes				
12. According to your calculations or observations, how much rainwater are you harvesting on average (Litres)?	Summer	Winter				
13. On average, what is the financial savings you are achieving (Rand)?	Summer	Winter				
14. How many toilets do you have in your place of business?						
15. According to your opinion, was it worth it to install this system, i.e. does your financial water account savings make up for the installation costs, are you saving financially if you consider the electricity usage of your pump, etc.	No, please elaborate	Yes, please elaborate				
16. Do you think that you can benefit from rain-and/or stormwater harvesting at your place of business?	No, please elaborate	Yes, please elaborate				

Date : ____________________

Thank You for Participating

For more information please contact: Nina Viljoen, Email: nina.viljoen@capetown.gov.za