

**Investigating the cost and impact of water leakages in the Midrand region using the  
Economic Model for Leakage Management**

By

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## DECLARATION OF ORIGINALITY

I, Deshree Pillay declare that the thesis/dissertation, which I hereby submit for the degree Master of Science in Environment and Society at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE: 

DATE: 12<sup>th</sup> February 2020

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## ABBREVIATIONS

Average Annual Daily Demand	AADD
Acoustic Emissions	AE
Annual Real Losses	ARL
Burst and Background Estimate	BABE
Current Annual Real Losses	CARL
Central Business District	CBD
Cation exchange capacity	CEC
Congress of South African Trade Unions	COSATU
District Metered Areas	DMA
Department of Water Affairs	DWA
The Department of Water Affairs and Forestry	DWAF
Department of Water and Sanitation	DWS
Economic Model for Leakage Management	ECONOLEAK
Expected Minimum Night Flow	EMNF
Expected Night Flow	ENF
Fixed and Variable Area Discharge	FAVAD
24-Hour Zone Measurement	HZM
Integral Electronics Piezoelectric	IEPE
Integrated Forecast System	IFS
Infrastructure Leakage Index	ILI
International Water Association	IWA
Johannesburg Water	JWater
Local Economic Development	LED

Mean Annual Precipitation	MAP
Millennium Development Goals	MDG
Management Information System	MIS
Minimum Night Flows	MNF
National Research Council	NRC
Non-Revenue Water	NRW
Pressure Reducing Valves	PRV
Probability value	p-value
Polyvinyl Chloride	PVC
Republic of South Africa	RSA
South African Night Flow	SANFLOW
South African National Standard 241	SANS 241
System Applications Products	SAP
Sequential Convex Programming	SCP
Sustainable Development Goals	SDG
System Input Volume	SIV
Statistical Package for the Social Sciences	SPSS
Sulphate Reducing Bacteria	SRB
Sub-Saharan Africa	SSA
Target Minimum Real Losses	TMRL
Unavoidable Annual Real Losses	UARL
Unavoidable Background Leakage	UBL
Unaccounted-For-Water	UFW
United Kingdom	UK
United Nations Development Programme	UNDP

Water Conservation and Water Demand Management	WCWDM
Water Demand Management	WDM
World Health Organisation	WHO
Water Management Area	WMA
Water Research Commission	WRC
Water Supply System	WSS
Value Added Tax	VAT

## **METRICS**

Km	Kilometre
Km <sup>3</sup>	Cubic kilometers
m	Meter
MJ	Megajoule
MI	Megalitre
psi	Pounds per square inch
m <sup>3</sup>	Cubic meters
R	Rands

## **ADDENDUMS**

### **ADDENDUM 1: CALCULATIONS**

Calculations performed in the ECONOLEAK Model

### **ADDENDUM 2: PERMISSIONS FROM WATER SUPPLIER**

Addendum 2A: Signed permission letter from the custodian of data

Addendum 2B: Signed permission letter from the manager of Region A's depot

### **ADDENDUM 3: PERMISSIONS FROM RESIDENTS**

Addendum 3A: Permission from the representative in Pacific Gardens

Addendum 3B: Permission from the representative in Waterfall Estate

Addendum 3C: Permission from the representative in San Bernadino,

Addendum 3D: Permission from the representative in Carlswald Manor

Addendum 3E: Permission from the representative in Erand Gardens

Addendum 3F: Permission from the representative in Kyalami Estate

Addendum 3G: Permission from the representative in Tallyns

Addendum 3H: Permission from the representative in Cresentwood Country Estate.

### **ADDENDUM 4: ETHICAL CLEARANCE**

Ethics clearance from the Natural and Agricultural Sciences Ethics Committee, University of Pretoria

### **ADDENDUM 5: QUESTIONNAIRES**

Addendum 5A: Questionnaire administered to water suppliers

Addendum 5B: Questionnaire administered to residents

### **ADDENDUM 6: RESULTS FROM THE ECONOLEAK MODEL**

Excel sheet containing information pertaining to the ECONOLEAK Model

### **ADDENDUM 7: RESULTS FROM STATISTICAL ANALYSIS**

Addendum 7A: Results from frequencies

Addendum 7B: Results from cross tabulation

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## **Abstract**

Water leakages and subsequent water shortages is an occurrence that causes inconveniences to many people around the world. Expanding population groups have the potential to stimulate urban development rates which in turn leads to an increase in water demand. This places more pressure on water suppliers and the infrastructure involved in water distribution systems causing pipe bursts and water leakages to occur more frequently. Water resources are thus wasted, leading to costs associated with the impact of the pipe burst and water shortage for both water suppliers and consumers. This study focuses largely on the identification, causes, impacts and quantification of losses through water leakages and the subsequent cost associated with the leakage. The study area that was chosen is Vorna Valley, which is in the region of Midrand and falls within the Gauteng province. Midrand is rapidly expanding spatially and population rates are on the rise. To achieve the objectives of this study, residents, water suppliers and key informants were consulted through questionnaires and the results were statistically analysed. The Economic Model for Leakage Management, that is specifically aimed at determining when a water supplier should invest in active leakage control for a specific, zoned metered area, was applied. The model established the costs of leakages and pipe bursts and the appropriate interval for active leakage control by the municipality for the study area. Results from the Economic Model for Leakage Management suggests that an active leakage control interval of 6 months is best as the cost due to water loss is at its lowest. In the study region, 83,1% of residents experience burst pipes over 6 months. Findings of this study could benefit water suppliers when choosing the best mitigation method to apply during water leakages and water shortages.

## Chapter 1- Introduction

### 1.1 Introduction

The current status of water demand and supply in the Republic of South Africa (RSA) has become a very controversial issue that has led to numerous socio-economic problems (Oberholster, 2010). A combination of expanding economies, increasing developmental rates, changing climatic patterns, and population growth, has led to a high demand for water. However, water supply does not conform to the demand for water, making it difficult to meet demand requirements in the water supply sector (Castro *et al.*, 2018). Due to these demand requirements, it is likely that the RSA is overexploiting water resources and creating a deficit in water supply and demand, resulting in the need to reconcile the difference in water supply and withdrawals (Hedden, 2016). The Department of Water and Sanitation (DWS), has stated that there has been financial instability in the water supply sector as the country is facing an economic recession (DWS, 2018 ). This has led to great debt and reduced revenue in terms of water supply.

Water plays a very valuable role in society and is often required in the mining, agricultural and industrial sector. It is also used for domestic purposes and sanitation services. However, due to the overexploitation of water resources in the various sectors, funding may become necessary due to the financial instability associated with the resource. Furthermore, the financial value of water is influenced by various factors that constrain social and economic development while reducing the sustainability of the resource (DWS, 2018 ). These factors include a misunderstanding of the value of water in economic security for the sectors influenced by water supply, water demand exceeding water supply resulting in a funding gap, a degradation in the value of assets such as infrastructure, a lack of revenue and demand management systems and a reduction in quality of water (DWS, 2018 ).

With a specific focus on municipal water supply, the Integrated Forecast System (IFS) was used in RSA to predict the growth rate in terms of the population and their water demand requirements. It was estimated that 3.35 million water connections need to be piped to houses due to population growth (Hedden, 2016). The model predicts that municipal water demands alone will exceed 18.9 km<sup>3</sup> by 2035 resulting in serious inequalities associated with access to water in the RSA(Hedden, 2016). In 2007, 9.7 million (20%) of both developing and developed areas in the RSA did not have access to an adequate supply of water, while 16 million (22%) did not have access to sanitation services (Kahinda *et al.*, 2007). The Department of Water Affaris and Forestry (DWAFF) stated that the RSA also provides water to neighbouring

countries; Lesotho, Zimbabwe, Namibia, Mozambique, Swaziland and Botswana which places a large strain on water resources and can potentially impact municipal supply (DWAF, 1999).

In the RSA, many developing communities and households make use of communal taps, outside flush toilets and river water as alternatives to meet their demand for water (Bhagwan *et al.*, 2014). This is evident in, for example, the Alexandra Township, located in the City of Johannesburg. This township is infamous for its high population density and informal living conditions which leads to problems of water supply (Matowanyika, 2011). After 25 years of democracy, this township along with many other areas still experience problems of service delivery. In the country's current economic environment, it would be most beneficial to implement cost effective remedies for water shortages, supply and demand. However, much of the water supplied to the system has the potential of being lost during water leakages (Ncube *et al.*, 2016). Water leakages are often associated with poorly maintained bulk- and distribution infrastructure. Leakages occur when water escapes containment through a crack or a hole in the infrastructure. Water is also wasted through leaking taps and taps that are not entirely closed or broken. Water losses need to be identified within the water distribution system by employing leakage detection techniques in pipes in order to prevent further loss of water and the associated costs

Leakages need to be detected and quantified to ultimately implement mitigation measures such as metering and pressure management which will help future and current water management systems with leakage control (Lambert *et al.*, 2002). It is important to identify water losses through leakages as the water quality integrity is affected by the leakage and leads to further problems downstream in the system. For instance, contaminants residing outside the system network can simultaneously enter the distribution system while leakage is occurring and cause changes in the water quality. Contamination from outside sources can occur if the contaminant is present outside of the system network and a pathway is created for it to enter through a disturbance in the system network. An active agent such as pressure differences also needs to be present to promote the movement of the contaminant into the system. These types of disturbances are difficult to identify because water suppliers have little control over what happens outside of the distribution system (Wu *et al.*, 2014).

During water leakages, the system pressure drops excessively due to the demand in water supply and can decline to as low as atmospheric pressure. This not only impacts the immediate surroundings but also impacts the quality of groundwater outside of the pipeline in the case of pipelines running underground. Groundwater and soil enter the water distribution system due to the increasingly negative pressures in the network caused by breakages in the

pipeline. If a burst pipe is close to sewerage or harmful litter, potential leaching can occur which can pollute groundwater supplies leading to deterioration in water quality and the value of the water resource (Du Plessis *et al.*, 2018). Hydraulics of the soil characterises the existing relationship between pressure and leakage. Soils often cannot handle the high velocity and energy associated with water leakages along the hydraulic fracture or the crack in the pipe and begin to erode. This also compromises water quality integrity (van Zyl, 2014).

Water quality integrity must be maintained to prevent network contamination from occurring during leakages. This can be maintained through the collection of water samples within the network at various points within the system for microbial analysis. Microbial testing will also establish the impact on water quality after the leakage has occurred by identifying possible microbial constituents that may have entered the system (Luo *et al.*, 2015). Maintaining the system also ensures both the supplier and consumer is content with the water supply.

It is important to ensure that the consumer's complaints are dealt with accordingly as it serves as a vital source of water quality information. During water leakages, the consumer may notice certain occurrences such as odours expelled from the water or dirty water exiting the system. This information can prove to be valuable to the water supplier in the sense of pinpointing problem areas and consequently for the restoration of system integrity. South African National Standard 241 (SANS 241) risk assessments are conducted to assess whether a municipality is exceeding constituent concentrations. According to the Department of Water Affairs (DWA), risk assessments must be conducted annually during critical changes within the system such as during leakages (DWA, 2006). In conducting the analysis, possible acute health impacts are identified. Identification of health impacts helps reduce diseases in the population residing in municipalities that have been exacerbated by water leakages. The influence of aesthetic impacts and operational constraints are also identified during the risk assessment.

## **1.2 Problem statement**

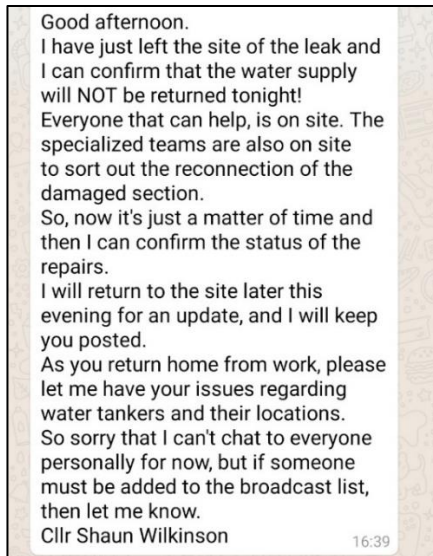
Due to the expansion of urban areas, water services provision has accelerated to ensure everyone has access to the services they require. With an increase in water services provision, the occurrence of infrastructure problems begin to occur. The maintenance of infrastructure can often be expensive and ensuring the appropriate operation of the infrastructure can also be time consuming. This was observed over a long period of time in the City of Johannesburg Municipality's infrastructure.

One of the most noticeable water use infrastructures in the area is the Johannesburg Grand Central Water Tower which was constructed in Midrand during the year of 1997, standing at 40m high with a capacity of 6 500 000L (Cox, 1997). Early in 2018, the main pipeline leading to the Grand Central reservoir burst, causing the reservoir levels to deplete, resulting in water shortages (Dube, 2018). Similar incidents have been experienced at the corner of Kruger and Dale Road in Midrand (JWater, 2015). Kyalami, Ivory Park, Noordwyk, Vorna Valley, Rabie Ridge, President Park, Ebony Park, Halfway House and Carlswald have experienced a similar situation at the beginning of 2018 which affected the main line supplying water to Midrand (Dube, 2018).

On the 30<sup>th</sup> of August 2019, more than 2000 residents were left without water in Pretoria when a major pipe had burst (Nomahlubi Jordaan, 2019). The magnitude of the problem was exacerbated when hospital patients and schools that desperately required water were left without. Although 30 water tankers were deployed at certain points in Arcadia, Clydesdale and Sunnyside, the problem was not addressed promptly. Residents received updates regarding the burst pipe and water shortages on a social media network, WhatsApp Group, that they were part of as seen in Figure 1 below. Updates on the burst pipe were further given through other social media networks. Ward councillors were consulted to ensure that communication with the community was continuous with regards to the repair of the pipe and provision of water supply. Inspections of the damaged pipe and physical water losses were carried out in the interim as the repair job was complicated and time consuming as seen in Figure 2 below.

The efficiency of a water distribution network largely affects drinking water supplies and end users. Physical water losses, also known as real water losses, are responsible for a reduction in the input volume of water supply to end users. Real water losses are those that encompass both background leakages and pipe bursts that occur in the water distribution network (Loucks *et al.*, 2017). Background leakages are minor leakages that occur through small cracks and holes in pipe joints. Real water losses are from leakages that occur on a very small scale in pipe joints and fittings as well as tanks that are used to store water (Martini *et al.*, 2015). Pipe bursts resulting in leaks generally result from fractures in the pipe which ultimately leads to larger holes in pipes and fractures in the pipe fitting. These leakages can occur during the normal functioning of any system. It is important to investigate the causes of, such leakages because they lead to secondary economic problems for example, communities may have to use extra money to buy water at the expense of other needs if water supplies are not restored promptly.

If the municipality inspected the pipeline regularly prior to the burst by using a cost-effective model such as the Economic Model for Leakage Management (ECONOLEAK) (Mckenzie, 2019), the water leakage and subsequent water shortages could have been prevented. The development of ECONOLEAK took place through the Water Research Commission (WRC) by Dr Ronnie McKenzie and Allan Lambert and is used to assist water suppliers in the management of their water distribution system (Lambert *et al.*, 2002).



**Figure 1.** WhatsApp Group message informing residents of updates on the burst pipe and water shortage (*taken in 2019*).

**Figure 2.** Burst pipe getting fixed in Pretoria (*taken in 2019*).

This study intends to provide insight into the cost implications in a selected study area in Midrand, South Africa where water is wasted through undetected leakages and re-occurring bursts which is a loss to the water supplier (provider) and an inconvenience to the consumer. The water loss through leakages and the associated cost will be assessed using ECONOLEAK in conjunction with questionnaires to establish the impact felt by residents in the study area. The costs involved need to be determined and reported to avoid the expense and maintain the expected water supply service.

### **1.3 Aims and objectives**

The overall aim of this study is to assess the various causes of burst pipes in the network, water leakages and subsequent water losses in selected wards within the Midrand region and ultimately make suggestions and recommendations to minimise water losses and propose strategies for effective water supply management.

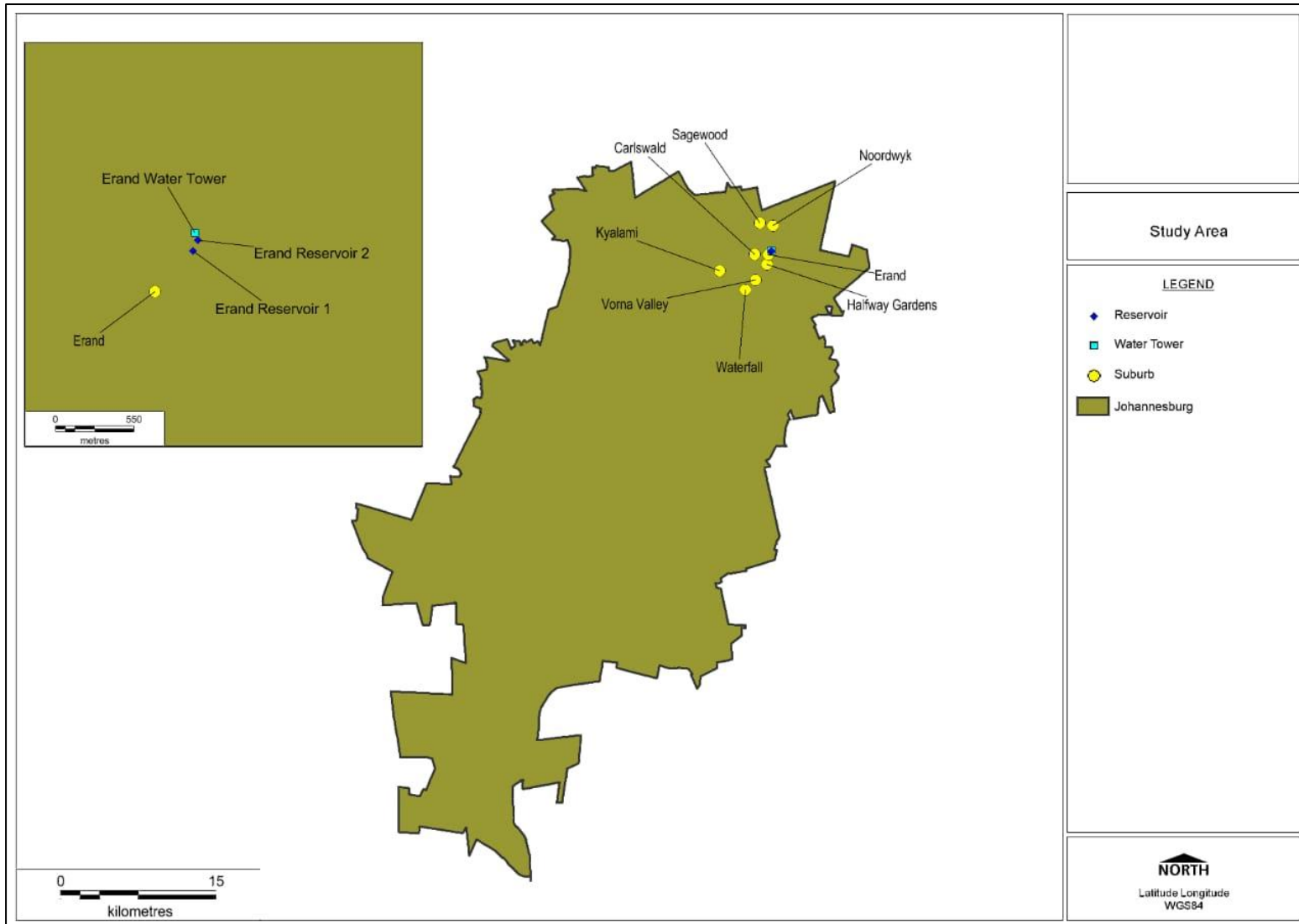
In order to achieve the overall aim of this study, further objectives have been devised and are as follows:

- a) To investigate the causes of water leakages and bursts in the study area of the Midrand region
- b) To investigate the costs associated with leak detection and intervention
- c) To quantify real and apparent losses in the network
- d) To propose recommendations for better management of the water in the distribution network

### **1.4 Study area**

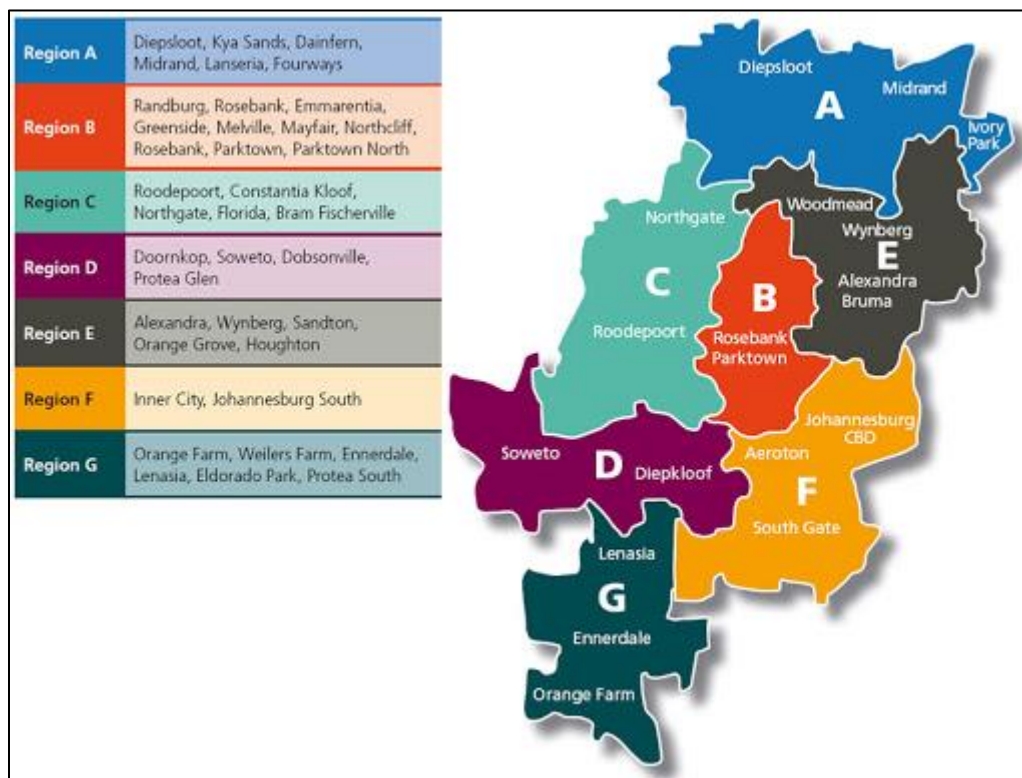
Midrand is located in the Gauteng Province, Republic of South Africa and is known for its optimal location halfway between Johannesburg and Gauteng. Over the past decade, Midrand has experienced a rapid rate of development and has shown great success in the role of Local Economic Development (LED) which places great emphasis on mitigating of poverty (Rogerson, 2003). Throughout the years of experimentation in LED and planning, municipal planners were able to use public procurement to develop infrastructure (Rogerson, 2003). The population of Midrand was estimated to be 87 387 during the last major census conducted in 2011, this number has since increased along with developmental expansion (StatisticsSA, 2018). Midrand is also known as Africa's first eco-city which is also why LED developers are interested in the city.

Refer to Figure 3 below for a map of the water distribution network selected for this study.



**Figure 3.** Water distribution network (Created using Map Info Pro, 2019).

The study area falls within Region A which includes Midrand. Johannesburg Water also supplies water to Region B, C, D, E and G of the Gauteng Province. In order to ensure that the distribution of water is efficient, various infrastructure was built by Johannesburg Water including 10 depots, 4 laboratories for water quality testing, 89 water reservoirs of which one is located in Vorna Valley, 28 Water Towers, 12 581 km water distribution pipes and 6-wastewater treatment works. Johannesburg Water also takes responsibility for ensuring the maintenance and upgrading of its infrastructure assets. Johannesburg Water distributes water to 4.5 million people across Gauteng which include industrial, domestic and commercial sectors. A 1574 MI per day is distributed to consumers and is of acceptable standards. Johannesburg Water provides jobs to approximately 2500 people (JWater, 2018). The regions supplied by Johannesburg Water can be seen in Figure 4 below.



**Figure 4.** Johannesburg Water supply regions (PSHB, 2020)

#### 1.4.1 Geology

Midrand falls within the Transvaal Supergroup which is a stratigraphic unit that consists of the Eastern Transvaal Basin, Western Griqualand Basin and the Southern Botswana Kanye Basin (Dippenaar, 2014). The prominent rock type of Midrand is granite which forms part of the bedrock. There is a large circular body of granite that is known as the Archaean Lanseria Gneiss of the Johannesburg Granite Dome in which Midrand is a part of. These granite domes are the basement on which sedimentary cover rocks are deposited.

Region A's Johannesburg Water Depot lies on the Halfway House Granite gneiss which includes trondhjemite, gneissic biotite tonalite, pegmatite and migmatite gneiss from the Swazian Age (Kruidenier, 2016).

#### **1.4.2 Climate**

In terms of the regional climate, the site is located in number 0513 of the Weather Bureau. There were two weather stations in use at the time of the last climatic analysis. These are numbered 0513385 and 0513150. The rainfall data collected from these stations range from 1912 to 1929 for 0513150 and 1976 to 1989 for 0513385. Rainfall patterns depict summer rainfall from October to March in the form of thunderstorms with high velocity winds and lightning. Approximately 83% of rainfall occurs during this period.

The time between May and September covers the winter months which are extremely dry. During the period of 1912 to 1929, the Mean Annual Precipitation (MAP) was 768mm/a (Kruidenier, 2016). This decreased to 693mm for the period between 1976 to 1989. In terms of evaporation, the closest evaporation station is the one found in Irene (A2E025). This evaporation station covered the years of 1978 to 1979 and recorded mean annual evaporation (MAE) of 1346mm for the Pan A value. The mean annual runoff (MAR) was calculated using the Hydro Zone F and was between 10mm to 20mm annually (Kruidenier, 2016).

#### **1.4.3 Topography**

The study region has an average gradient of 3<sup>0</sup> with a gentle slope from north to the north west and an inclination of approximately 2-6% (Kruidenier, 2016).

#### **1.4.4 Soils, land capability and land use**

According to SANBI BGIS, Vorna Valley has red, yellow and/or greyish soils with low to medium base status and an association of Classes 1 to 4: undifferentiated structureless soils (SANBIBGIS, 2018-2019 ). According to (Fey, 2010) soils of red or yellow colour is characteristic of the B horizon and are known as oxidic soils with an orthic A horizon that can be used for agricultural purposes (Fey, 2010).

Apedal soils have a low Cation exchange capacity (CEC) and are generally less than 11 cmol<sub>c</sub> kg<sup>-1</sup> and associated with kaolinitic clay. These soils are well aerated and have free

drainage allowing water to seep to lower layers. Erosion is less prevalent in oxidic soils with a reduced dispersibility between the aggregates. In areas of higher rainfall, the acidity of the soil becomes a large problem due to seepage into the soil and can subsequently cause damage to pipes. Acidity in the subsoil is widespread in summer rainfall regions (Fey, 2010). Due to the centrality of Midrand to both Johannesburg and Pretoria, much of the land has been used for urban development which has changed the land use from vacant land to developed land and reduced the land capability and soil fertility.

#### **1.4.5 Vegetation and animal life**

The study area is situated within the Egoli Granite Grassland threatened ecosystem (SANBI BGIS, 2018). The Egoli Granite Grassland is characteristic of bullfrogs and has a high density population of bird life (Adegun, 2018).

#### **1.4.6 Surface and groundwater**

Vorna Valley and Halfway Gardens fall within the City of Johannesburg Municipality which is within the Republic of South Africa Municipal boundaries. Vorna Valley is part of the A21C quaternary catchment area and part of the Crocodile West and Marico Water Management Area (WMA). Groundwater in the vicinity of the study site is expected to occur within fractured granite with a depth assumed to be deeper than 6 m. The perched water table is found at a shallower depth, 1 m below the surface (Dippenaar, 2014). Johannesburg Water SOC Ltd supplies water to the study area.

#### **1.4.7 Regional socio-economic aspects**

During the 2010 census, the number of households in Midrand was found to be approximately 100 000 households. This number was expected to increase to at least 115 000 in 2015 indicating a 2% increase (Prinsloo, 2010). In terms of housing, there are mainly multiple and single units found in the Midrand region. Urban planners have noted that Midrand has displayed a vast growth in residential capacity to accommodate the growth in market supply. However, due to an insufficient supply of electricity, the industrial growth of Midrand is hindered and a greater provision is made for office space.

The formal working sector consisted predominantly of domestic workers, factory workers and workers that had little to no skills at all (Humphries *et al.*, 1999). It became a cycle of low-level employment and poor services that restricted the growth of areas in Midrand. Most of the meetings of focus groups dealt with the issue of alleviating poverty and providing houses

for the poor. Much of the population in Midrand lived in informal settlements and were not able to improve their lifestyle due to the lack of employment opportunities (Hussein, 1999). With the lack of employment came many environmental problems that were difficult to mitigate due to a lack of funds. These environmental problems include the leakage of pipes that transported water into the region which led to the wastage of much needed water (Van Vuuren, 2015).

These problems surfaced much more frequently in areas that were generally poorer and plagued with diseases. Healthcare was not prominent in these areas and was seen as a luxury. In 2002 it was acknowledged that the Midrand region is growing at an extremely rapid rate even though the growth was not enough to ensure that there was a significant reduction in poverty. Residents had to live with very low salaries as well as the little resources found in the regions that they stayed in. In order to alleviate the disparity in socio-economic terms, it was necessary to place a large focus on the local economy and promote entrepreneurship and infrastructure development. Poverty was experienced in clusters between the well-developed and affluent areas and is to be alleviated through the creation of more jobs and variety in these jobs (Sugrue, 2000).

### **Water supply**

The Vaal River is the main source of water in the Gauteng province. Since runoff from the river is not constant, the Vaal Dam was built in 1938 to ensure the supply of water. The Department of Water and Sanitation and Environmental Affairs manage the dam and ensure the efficient usage of the dam. The dam was built with a capacity of 2575 million cubic meters of water with a depth of 22.5 meters which makes the dam the fourth largest in South Africa. Johannesburg Water draws water from the dam for purification and distribution. The water is transported from the dam through canals and pipelines to the various Rand Water purification plants. The water is then treated according to SANS 241 as well as standards set out by the World Health Organisation (WHO). Once the water is of acceptable quality it is pumped through underground pipelines from the purification plants through pump stations where it is then stored in the Johannesburg Water reservoirs. Underground pipelines transport the water from reservoirs to the consumer (Mohamed *et al.*, 2017). Johannesburg Water buys water from Rand Water at R10 per cubic meter as Rand Water is a Water Board (Shibambu, 2019).

In Figure 5 below, the Erand Reservoir 1 and 2 can be seen as well as the Erand Water Tower. Erand Reservoir 1 supplies water to Carlswald, Kyalami, Vorna Valley and Waterfall. Erand Reservoir 2 supplies water to Noordwyk, Sagewood and Erand. The Erand Water

Tower supplies water to Erand and Halfway Gardens. Details of location, capacity in megalitres and storage can be viewed in Table 1. The coordinates of the reservoir are 25°58'50.93"S and 28°7'9.72"E. The reservoirs were constructed with concrete and are cleaned every 5 years by emptying the reservoir and closing the inlet and outlet. If short term maintenance is required, it is done at night as water usage is generally lower.

**Table 1.** Johannesburg water reservoirs and towers that supply Midrand with water

Number	Reservoir	Location	Capacity in megalitre	Storage hours	Areas supplied
1	Erand Reservoir 1	New Rd and sixth Rd, Erand	25 MI	24 hrs	Carlswald, Kyalami, Vorna Valley, Waterfall
2	Erand Reservoir 2	New Rd and sixth Rd, Erand	9 MI	30 hrs	Noordwyk, Sagewood, Erand
3	Erand Tower	New Rd and sixth Rd, Erand	0.5 MI	6 hrs	Erand, Halfway Gardens



**Figure 5.** Midrand Reservoirs (Google Earth Pro, 2018).

## Chapter 2- Literature review

There are few topics that have demanded as much attention in the Republic of South Africa's public debate, in recent years and months, as the challenge of water supply (WHO *et al.*, 2015). The urban population of the Republic of South Africa has risen from 5 million people in 1951 to more than 13 million people in 1980 and was estimated to be 57,398,421 people in 2018 (Statistics SA, 2018). Coupled with urban expansion is social, economic, political and environmental problems that are becoming more apparent. Thus, with much of the South African population migrating to urban environments, the effect of rapid urbanisation on elements of the water distribution network should assume importance within the South African water supply fraternity.

Urbanisation is inadvertently responsible for a tremendous demand for water which in turn places immense pressure on water suppliers and the water distribution network (Xu *et al.*, 2014). As a result, a great deal of water is lost to the consumer due to water leakages. Considering RSA's urbanisation rates, the low frequency of rainfall events and lack of proper water management, it is evident that water leakages pose a huge problem for water suppliers. The well-being of residents becomes a primary concern as there are many problems that accompany water leakages such as economic loss and health complications. There are health risks associated with water leakages and people at risk of ill health are both directly and indirectly affected due to the poor health care system of South Africa (Ogutu *et al.*, 2016). Furthermore, the damaged or degraded infrastructure, which results in burst pipes, contributes to high costs for the necessary remediation.

The quantification of real and apparent water losses as well as the costs associated with leakage detection are thus vital and necessary in the design and planning of infrastructure and management.

Water resources such as ecosystems or ecosystem components have a larger set of values and functions that are not known to most and are often necessary to conserve. Ecosystem services regulate ecosystem processes such as water purification and the management of waste (BISE, 2020). Ecosystem services in relation to water resources assist biodiversity maintenance resulting in provisional (provision of water supply for usage) and cultural benefits (education and research or tourism) (Kotze *et al.*, 2007). With the South African landscape being so rapidly modified, water resources are increasingly threatened. It is thus important to ensure water wastage of any form does not occur. The combination of these problems makes this study highly relevant considering South Africa's ever-increasing

rate of urbanisation, recurrence of water losses through leakages and increasing degradation of the environment. Bulk water infrastructure connects the water resource to a municipal area or a scheme. In future, much more attention will have to be directed towards solving bulk water infrastructure problems to ensure the impact does not affect the surrounding ecosystem. Man's very existence and well-being will depend on how well he can positively co-exist, interact and maintain the surrounding biotic and abiotic environment.

Realistic and reliable water resource planning is driven by a set of adequate and complete information. The role of water leakage models thus provides deterministic and stochastic solutions that simulate identification processes in the water distribution network (Hoffman DJ, 2016).

## **2.1 The potential causes of water leakages and bursts**

The causes of water leakages and bursts can be broadly defined under two categories: a loss in physical integrity and a loss in hydraulic integrity. These issues are discussed below.

### **2.1.1 Losses in the physical integrity of the water distribution system**

The physical integrity of the system is defined as the ability of the system to function correctly. This includes the coherent functioning of the components found in the system which ensures that the physical barrier between the internal system and external environment is intact (Mays, 2000). The physical integrity of the system relies on the capability of the water distribution system to handle stresses both internally and externally. The water inside the network also needs to remain within the network. If the system fails and contact between the external and internal environment occurs, the physical integrity of the system is affected. In order to ensure the water supplied is of reputable and safe quality, a barrier needs to be installed to prevent contact between the supply of water and the external environment. A breakdown of the various infrastructure components of a system, stresses and the materials found within the system, that are potential threats, are shown in Table 2 below.

**Table 2.** Infrastructure components, materials and threats to infrastructure (Source: Mays, 2000)

<b>Component</b>	<b>External threats to the component</b>	<b>Common materials used</b>
Network pipes	Soil, groundwater, sewage contamination, surface run-off, human activity, animals, plants and pathogens.	Cast iron, ductile iron, steel, asbestos cement, Polyvinyl chloride (PVC) and polyethylene.
Plumbing pipes	Human activity, sewage and non-potable water	Copper, iron, brass, steel, rubber, plastics
Fittings (meters, valves, hydrants, etc.)	Soil, groundwater, sewage contamination, surface run-off, human activity, animals, plants and pathogens.	Cast iron, brass, steel, rubber, plastics.
External coatings and wraps for pipes and fittings	Supporting role in that it preserves the pipe integrity from external threats	Zinc (galvanising), polyethylene, bitumen coating, bitumen wrapping, cement-mortar
Internal linings for pipes and fittings	Supporting role in that it preserves the pipe integrity from internal threats	Zinc (galvanising), epoxy, urethanes, bitumen, cement-mortar, plastic inserts
Storage facility walls, roof covers and vent hatches	Air contamination, rain, algae, surface runoff, human activity, animals, birds and insects	Concrete, steel, cast iron, bitumen, epoxy, and plastics.
Backflow prevention devices	Non-potable water	Brass, ductile iron, plastics
Gaskets and joints	Soil, groundwater, sewage contamination, surface run-off, human activity, animals, plants and pathogens.	Rubber, leadite, bitumen, plastics.

Water distribution systems, as defined by the National Research Council (NRC) is a transportation structure containing pumps that move water through the system and are able to control water pressure through valves as well as regulate flow direction and fluctuation (NRC, 2007). Water distribution systems consist of many components that work systematically to transport water. The complex combination of components includes pumps, reservoirs, valves, meters hydrants, backflow stoppers and pipes to ensure that the conveyance of water is maintained (Folkman, 2018). The age of the system and additions to the system, such as replaced components, can cause the physical integrity of the system to change over time. There are often severe consequences associated with a loss in the physical integrity of the system. The three main consequences identified by Mays (2000) are;

- 1) system malfunctioning due to the components not operating optimally,
- 2) the loss of water through leakages occurring in infrastructure and lastly,
- 3) the risk of contamination by either chemical, physical or biological contaminants.

Construction flaws and design factors are the first factors causing degradation of physical integrity. Flaws such as cracks in the steel are often not visible and pass undetected during the construction process.

Physical factors leading to the deterioration of physical integrity also include excessive loads within the system. If a load or the force within the system exceeds the ability of the system to withstand it, failure of the system occurs. Externally, buildings, traffic or soil loads place pressure on the pipelines which can lead to breaches in the pipelines. Internal pressure fluctuations include a change in momentum of the water flow caused by either bends or junction between the fittings (Folkman, 2018). Chemical factors also influence the physical degradation of the system.

The three main types of corrosion that affect the water distribution system are galvanic, electrolytic and microbiological corrosion (Zhang *et al.*, 2014). The latter type of corrosion experienced by pipes is, driven by microbiological factors (Zakowski *et al.*, 2016). Certain microorganisms found in the soil may become a problem during anoxic or low oxygen level conditions that lead to anaerobic microbiological activity. Corrosion leads to the weakening of the infrastructure and the eventual failure of components which often creates a hole or small fracture in the infrastructure. The primary group of bacteria causing this is known as Sulphate Reducing Bacteria (SRB), The activity of SRBs is enhanced near micro-crack tips which promote localised microbiological corrosion and infrastructural damage (Wu *et al.*, 2014).

### 2.1.2 Possible reasons for losses in hydraulic integrity of a water distribution system

The hydraulic integrity of a system determines the amount of water that can flow through the water distribution system. It is influenced by the following:

- Pressure
- Water demand
- The state of the infrastructure of the distributions system
- Leakages and pipe bursts

Hydraulic integrity in conjunction with the physical integrity of a system is important for the functioning of the system, preventing bursts and the provision of water supplies. Hydraulic integrity deals with meeting all demands placed on the system by users. These include domestic, industrial and commercial demands. Hydraulic integrity is achieved when, the appropriate pressures and velocities are present in the system (Mays, 2000). One of the most important indicators for hydraulic integrity is pressure. Design guidelines stipulate that the maximum and minimum pressure in the water distribution system should be between 24m and 90m respectively (Mays, 2000). To ensure hydraulic integrity, pressures measured in the system should comply to these guidelines. If the pressure is within the 90m range it is too high and will be indicative of poor hydraulic conductivity (Mays, 2000). When the demand for water is at its highest, the pressure within the system usually is at its lowest due to the excessive energy loss and higher flow rates. The typical pressure under these conditions is usually around 24m (Mays, 2000).

Water demand does not remain constant and fluctuates according to the Average Annual Daily Demand (AADD). The AADD tends to increase over time due to factors such as economic growth, urbanisation and increased leakages found within the system (Gurung *et al.*, 2015). Other factors that affect the AADD are the seasonal or diurnal patterns that cause fluctuations. Summer temperatures are higher than those of winter and therefore, causes an increase in the demand for water and an increase in the AADD (Mini *et al.*, 2015). Random fluctuations are influenced primarily by user behaviour and are unpredictable such as in the instance of fires that have to be extinguished. During fire mitigation, there is an increased demand for water leading to pressure fluctuations within the water distribution system. It is anticipated that at some point in the lifetime of the system, the demand will exceed the capacity of the system. Low pressures may exist during periods of high demand such as during extremely dry or hot weather or seasonal conditions like an influx of tourists to areas during holidays. During high demand periods pipe burts could become more commont and result in water loss.

A potential cause of a loss in hydraulic integrity is a reduction in system capacity due to pipes deteriorating over time with age (Folkman, 2018). Once a pipe deteriorates it becomes susceptible to bursts. When a pipe burst occurs, the system capacity is lowered because the optimal amount of water supply drops. The burst will need to be fixed to reinstate system functioning.

The hydraulic capacity of the system is also affected due to a build-up of deposits on the internal pipe surfaces as well as an increase in the roughness of the wall. Iron pipes undergo corrosion and the by-product forms deposits on the internal surfaces of the pipes that could promote the reduction of the internal pipe diameter. Bursts are more likely to occur in older pipes that have a reduced system capacity due to the increase in leakage flow rates. The hydraulic capacity of a system is also reduced during periods of maintenance when certain components are not in operation.

Negative pressures occur when the demand exceeds the supply within the system which causes the system pressure to drop below the atmospheric pressure. The negative pressures within the system will cause contaminated water to move from the external environment to the internal environment when a crack or hole is present (Kumpel *et al.*, 2016). Water is contaminated externally through chemicals, sewage and groundwater causing flooded septic tanks. The sediment intrusion during leakages can also cause discolouration of the water. The continuous negative pressures during the water leakage damage pipelines and may cause the pipelines to crack. The diameter in the pipes may become larger and cause the entire pipe to collapse. Therefore, the hydraulic integrity needs to be maintained.

Another reason for maintaining the hydraulic integrity and thereby consumer safety is to ensure that the time between the water entering the network to delivery to the consumer is short. This is because longer times of transportation equates to an increase in the rates of chlorine depletion. Chlorine and other disinfectants are essential in keeping the water supply safe for consumption,

In order to mitigate a reduction in hydraulic integrity, for example in Georgia, a guideline document was developed which used the surrounding environment as a means to identify leakages and do repairs. The Georgian guideline document was developed as underground leaks are more difficult to identify and are not always visible or easily accessible (Lahlou, 2005). However, there are certain characteristics in the surrounding environment which can aid the identification of underground leakages that support teams can apply to check and confirm underground leakages. These characteristics include;

- a reduction in pressure or volume in the water distribution network,
- cracked pavements, the appearance of sink holes
- an increase in water use or,
- identification through biological means, for example, the formation of moss in dry areas (Martini *et al.*, 2015).

Leakages above ground can be identified through the inspection of the water system, comparison of water records from previous years, performing trend analysis and undertaking routine infrastructure inspections. Identifying leakages rapidly can ensure an increase in operational efficiency and a decrease in operational costs. The risk of contamination will also be reduced along with the reduction of infrastructure and property damage. In order to get to the leakage promptly or to monitor the distribution network, distribution maps must be updated and remote sensor technologies can be used to identify the exact point of burst (Lahlou, 2005).

### **2.1.3 Non-Revenue Water**

Non-Revenue Water (NRW) is the water that is lost from the distribution system that does not reach the end user and is not paid for-in other words there is no revenue generated from NRW necessary for maintenance or refurbishment of the system (Seago *et al.*, 2007). NRW is grouped into 8 categories of non-revenue water components as seen below (Seago *et al.*, 2007);

- Billed consumption that is not paid for (non-recovered revenue, a new category added to SA water balance);
- Unbilled metered consumption (authorised consumption);
- Unbilled unmetered consumption (authorised consumption);
- Unauthorised consumption (apparent losses);
- Customer meter inaccuracies (apparent losses);
- Leakage on transmission and distribution mains (real losses);
- Leakage on overflows at storage tanks (real losses); and
- Leakage on service connections up to the point of customer meter (real losses).

The contribution of leakages to total water losses in the City of Harare, Zimbabwe has been investigated by Makaya *et al* (2014) and it was found that operational and mitigation costs were significantly reduced when the time of identifying the leakage was reduced. This resulted in a decrease in total water loss (Makaya *et al.*, 2014). Another study undertaken in

the Harare Municipality, Zimbabwe, investigated water and sanitation infrastructure to determine if replacements or refurbishing were required. The study also investigated the possible reasons behind water leakages in the study area. The reasons listed were; aging infrastructure problems, soil movements, disruptions due to lack of understanding of the system, pressure related leakages and most prominently low awareness of Non-Revenue Water (Ndunguru *et al.*, 2016).

Table 3 below provides a summary of the NRW in RSA and describes the System Input Volumes (SIV) which is the annual volume put into the part of a water supply system that relates to water balance calculation (Mohamed, 2019), the water losses that include physical losses through either overflow or leakages and the apparent losses occurring through unauthorised water consumption or meter inaccuracies and is not paid for by the user. The litres per capita per day of NRW and the Infrastructure Leakage Index (ILI) are also included. The ILI is a non-dimensional index which provides an indication of how immense the leakage occurring in an area is compared to the theoretical minimum level of leakage that can be achieved (Lambert *et al.*, 2002). It is estimated that 41% of the total 4000 million m<sup>3</sup> of water used by municipalities in the Republic of South Africa is considered as NRW (Reddick, 2018). The associated cost lost in revenue due to the collective NRW is estimated to be R6.3 billion annually. The NRW in the Western Cape alone is 21% as can be seen in Table 3 below.

**Table 3.** Overview of non-revenue water in the Republic of South Africa (Source: Reddick, 2018)

Province	Population	System Input Volume (m <sup>3</sup> /annum)	Non- revenue water (m <sup>3</sup> /annum)	% Non-revenue water	% Water Loss	Litres per capita per day	Infrastructure Leakage Index
<b>Eastern Cape</b>	4 477 918	332 151 376	158 647 165	47.80%	45.00%	200	4.8
<b>Free State</b>	2 723 028	207 835 805	106 908 574	51.40%	46.60%	209	4.8
<b>Gauteng</b>	12 978 281	1 473 100 700	528 839 540	35.90%	27.40%	305	5.8
<b>Limpopo</b>	4 225 967	281 235 907	155 016 679	55.10%	55.10%	182	5
<b>Kwazulu-Natal</b>	8 491 508	697 751 184	327 444 107	46.90%	43.00%	225	6.2
<b>North West</b>	3 039 995	206 496 825	105 577 898	51.10%	51.10%	186	4.7
<b>Northern Cape</b>	1 085 944	94 205 305	45 418 308	48.20%	45.50%	238	7.1
<b>Western Cape</b>	6 108 993	482 695 411	102 720 237	21.30%	16.70%	201	2.4
<b>Mpumalanga</b>	3 622 506	270 990 713	129 852 490	47.90%	43.90%	205	4.3
<b>National</b>	46 754 140	4 046 463 225	1 659 588 711	41.00%	35.90%	233	5.3

#### 2.1.4 Pressure within the water distribution network

Pressure management is one way to identify and mitigate leakages within the system and help reduce NRW due to leakages (Lambert, 2002). Worldwide water supply systems provide water to users at the critical point of pressure which is the lowest pressure in the system. These systems are designed to withstand pressure fluctuations and flow requirements in times of peak demand at a specific time of day (McKenzie, 2014). Systems are thus designed to provide appropriate supply volumes and pressure in a short period in the year while the rest of the time the systems are operating at higher pressures than are actually needed. Pressures are influenced by topography or the distance from the point of water supply. This results in parts of the supply system operating at pressures higher than required to ensure sufficient pressure at a critical point (McKenzie, 2014). To reduce leakages by using pressure management it is necessary to reduce the water pressure without causing a compromise in the level of service provided to consumers. If the pressure within the system can be reduced during low demand periods then water leakage in the system will be reduced. This can be done through fixed outlet valves or electronic and hydraulic controllers (McKenzie, 2014).

To track the pressure values within the system, data recording devices are installed that track both flows and pressure values to identify irregularities. The South African Night Flow (SANFLOW) analysis model was implemented in District Metered Areas (DMAs) in the City of Harare (Eugene, 2017). The SANFLOW model was developed through the Water Research Commission by McKenzie to aid water suppliers in determining unaccounted water leakages when using Minimum Night Flows (MNF) (Lambert *et al.*, 2002). Information for the study was derived from the local municipality, Harare Water Board and the City of Harare's local council. MNF consists of normal legitimate night use, background losses and burst pipes. The model is based on the following input parameters (McKenzie, 1999);

- Night-flow reference;
- Date of measurement;
- Average zone night pressure;
- Measured minimum night flow;
- Length of mains;
- Number of connections;
- Number of properties;
- Population in zone

The model estimates the Expected Night Flow (ENF) through the subtraction of the Expected Minimum Night Flow (EMNF) from the MNF. The result gives the estimation of water leakage for the DMA. Results have shown that 33% of the 36% of total water lost is through leakages due to poor NRW management.

## **2.2 The consequences of water leakages and shortages**

One of the most prominent consequences of water leakages is the effect it has on water quality integrity. Due to the immense influence water quality integrity has on the different users of water, it has a greater potential to cause harm during water leakages. Water quality integrity refers to the quality of the water in the distribution system and the ability to meet acceptable water quality standards for use by the public (WHO, 2004). The quality of the source of water that feeds into the water distribution system influences the water quality in the system. For example, water sourced from boreholes, pipelines or reservoirs are of different microbial and chemical quality and may negatively affect the quality of water transported to the consumers.

In developing countries, water quality is essential as water transported through the distribution system is often the only source of clean water available (Jha *et al.*, 2015). Substances that are not often found in water, for example hazardous waste materials from sewage or septic systems, are found in high concentrations during water leakages as the pipe burst is an easy path of entry for the substance (Rush, 2019). During water leakages, a larger range of substances enters the water distribution network. These substances are often harmful to those who ingest it and can cause gastrointestinal and reproductive problems (Rush, 2019). Contaminants could alter the water quality and reduce the aesthetics to unacceptable standards. Although the water may be safe to drink in certain instances, the quality may be reduced aesthetically. (Faust *et al.*, 2018). The reduction in aesthetical standards can come in the form of odours, change of colour in the water and unpleasant tastes upon consumption. People may not be able to afford a higher standard of water quality as this is their only source of water. It is thus vital to mitigate water shortages in an efficient manner to reduce the possibility of a reduction in water quality integrity and subsequent health impacts.

One of the consequences of water leakages is water shortages that may result in civil unrest. The water distribution system is shut off during times of leakages by water suppliers to prevent pressure transients and to help fix the leakage. Once the leakage is fixed, the water supply is restored. However, in some South African cities, the water is not restored, and the people of that region decide to protest as an act of disapproval. Protests can be violent and cause further infrastructural damage.

Earlier on in 2018, the Congress of South African Trade Unions (COSATU) reported that they would strike in Cape Town, RSA due to water shortages and subsequent water restrictions. Cape Town had put harsh fines in place to ensure the wastage of water does not occur. The punishment put in place was a fine or penalty for those who use more than 6 000 litres of water a month (Vallie, 2018). It was imperative that the little water being supplied was not lost due to water leakages. COSATU represented the citizens that suffered during the time of no water. The citizens felt that due to mismanagement of infrastructure and water resources, they had to pay from their own personal capacity to solve the matter. A prominent issue that was raised was that the water shortages were felt more by the poor than the rich as they already had limited access to clean water. This was when citizens took to the streets to protest for an adequate supply of water (Vallie, 2018).

The loss of water through water shortages and leakages have not only affected the residents in the area but also the existing local enterprises. There are certain local enterprises that depend entirely on water usage and cannot operate during water shortages and water leakages. Examples of these enterprises include car washes, laundromat services and hair salons. The impacts of water shortages are amplified during times of drought and more than one sector is affected.

Although water shortages have left many enterprises and sectors battling to generate income, it has also taught enterprises to cope in instances of water shortages. The businesses that can function during water leakages and subsequent water shortages and persist through periods of drought have now built resilience which has placed them in a stronger position of operation. Water disruptions are common and water scarcity is a contentious issue that RSA faces due to aridity. However, water shortages are not the only problem faced. Electricity outages and the strikes caused due to poor service delivery disrupt the operation of businesses making it difficult to generate income in such conditions (Parker, 2018).

Water shortages during operational hours pose a major health risk to the employees and business owners are often forced to send the employees home. Management measures undertaken by companies include the design of infrastructure that is risk adverse such as leakage resistance pipes. Certain companies have water storage tanks and can use stored water during water shortages. The companies analysed were only able to plan appropriately when they were informed by the water supplier of the planned disruptions which emphasises the importance of an early warning system during water shortages. Certain companies have invested in resource management systems to ensure operations continue as normal and

protocol is followed during resource disruption. Resource management systems include simulation models and optimization methods that are used to support analyses of water resource problems. The design and management of facilities relating to water storage and leakages are assessed by models used to deduce the best resource management option available to the business.

A study was undertaken by the University of Cape Town, to understand why some firms could not operate during water service delivery disruptions while some could. The authors found that in order to adapt to service disruptions, these businesses have begun to reconfigure resources. For example, if a business does receive a water shortage alert, they are able to change the working hours to avoid the time of leakage (Kotler, 2011). This could also reduce the load on the water distribution system. The load on the power grid could also be reduced because water released from the reservoir is necessary to drive turbines, spinning it, which in turn activates a generator to produce electricity. If there are leakages in the pipes transporting water to the turbine, the process of producing electricity could be hampered. In turn, electricity is used to pump water to households. If there is no electricity available for the pumps to operate then water shortages may occur.

## **2.3 Role of the Economic Model for Leakage Management during pipe bursts and water shortages**

### **2.3.1 Background**

Pipe bursts and leakages in the water distribution system have led water utilities into research and technology that involves the reduction of water loss. Subsequently, various techniques for leakage detection and location were developed. The two broad categories of leakage detection are hardware based methods which can include acoustic detection methods (listening rods), leak correlators, leak noise loggers and non-acoustic detection methods (gas injection), radar technology capable of penetrating the ground and infrared photography (Li *et al.*, 2015). Software based methods use data that has been collected by real-time pressures or flow sensors as well as statistical data analysis tools and artificial intelligence. These include numerical modelling methods, such as inverse transient analysis, time domain analysis and frequency domain analysis, non-numerical modelling methods (artificial neural networks) and Bayesian inference systems (Li *et al.*, 2015).

Water leakage, ever increasing water demand and management problems that occur in developing countries make it increasingly difficult for water suppliers to operate (JWater, 2018). Developing countries such as the RSA have many other challenges to deal with and

poor water leakage management contributes to the challenges faced. The Water Research Commission in RSA has thus designed software programmes to aid in the process of water leakage identification and mitigation. The models developed aim to help mitigate water leakages are; SANFLOW, ECONOLEAK, AQUALITE (water balance method) and PRESMAC (pressure management model) (Makaya, 2016). This software among others is not only aimed at helping RSA water utilities but can be implemented in the rest of Africa and the world.

The ECONOLEAK Model is based on the Burst and Background Estimate (BABE) procedures that were developed in the United Kingdom (UK). These procedures were developed as an approach to understanding the management of leakages in water distribution systems (Mckenzie, 2019). BABE was one of the first of its kind developed to address the problem of leakages and the associated cost of mitigation internationally. Water suppliers and leakage management specialists were involved in the development of the model that has since been improved and more recent variations are available (Lambert *et al.*, 2002). The variations of the UK based BABE model include the SANFLOW, ECONOLEAK, AQUALITE and PRESMAC models. The ECONOLEAK model provides a template that is easily understood and creates a graph that effectively summarises all water supply and leakage information. The curve also indicates the costs associated with each intervention method. The information expressed by the model in an excel sheet format can help municipalities audit their water supply and use this information for compliance (Reddick, 2018).

Customers are uninformed and unaware of the extent of water losses in the country. They are also unaware and uninformed about the financial costs associated with these losses. The ECONOLEAK model has the potential to provide the necessary information on the water distribution system that enables the user to determine where water is lost in infrastructure components within the distribution system and the cost associated with the water loss. This is done using (Mckenzie, 2019);

- Basic System Data (length of mains, number of connections, pressure etc);
- Water Loss Data (real and apparent losses);
- Duration of reported bursts;
- Number and leakage rates for Reported and Unreported bursts;
- Marginal cost of water;
- Costs for leak detection and repair

A detailed description of how ECONOLEAK is implemented can be found in Chapter 3.

ECONOLEAK provides information on water losses, including NRW, and could, therefore, contribute to water conservation and water demand problems. The implementation of Water Conservation and Water Demand Management (WCWDM) strategies that have been developed to meet the national goals of basic water supply for all South Africans and the sustainable use of water resources would also contribute greatly to resolving water demand problems (DWAF, 1999).

These problems, if left unsolved, can result in decreased revenue, higher cost implications at a municipal level and increased capital expenditure (Reddick, 2018). WCWDM models create additional opportunities other than cost savings such as job creation. Consultants, planners, designers and engineers can be employed to work systems that reduce water loss. Once awareness around water leakages are raised, companies that assemble and manufacture components to reduce water losses will also have an opportunity for further investment by providing equipment, for example, water meters, calibration instruments and leakage detectors and consequently, pressure management, monitoring and system repair could be achieved.

Water loss and the prevention of leakages in the supply network can be alleviated by the methods discussed in this study such as the replacement of old infrastructure or pressure management. However, one of the larger problems faced in the water supply network in terms of management is to assess which measures will be the most cost effective and time efficient. Particular attention was paid to the Western Cape, South Africa, during the year of 2017 and 2018. In 2017, due to severe drought, the province was left without very little water for months and strict water restrictions were implemented (Naidoo, 2017). During this time, it was vital that no water leakages occurred, as the Western Cape could not afford more water loss because they had no water reserves.

The GreenCape market produced an intelligence report in 2017, following the water shortages, which estimated that 37% of the water in RSA is lost through leakages (Reddick, 2018). The report is aimed at investors interested in the RSA urban water sector. Due to the severity of the situation, opportunities were also created for water metering and monitoring. This is where ECONOLEAK can be implemented. The model includes options for sound financial calculations aimed at finding the best solution for water suppliers, enhances communication between the water supplier and the municipality by presenting the leakage and water supply information in a simplified format. Meters can also be installed that monitor

the pattern of leakages and inform the municipality of pipe bursts (Reddick, 2018). Many residential estates and the commercial sector have implemented sub metering as a method of billing to make the billing process more efficient. This means that the supply authority (water service provider) meters remain in place. However, this is not a permanent solution to effective water supply and financial costing.

The private sector needs a tool to improve water management in times of water shortages. The ECONOLEAK model is a tool with the potential to aid the determination of whether a water supplier should invest in a certain water leakage detection method and control for a specified area or not (Lambert *et al.*, 2002). There are currently other avenues of decentralised water systems being investigated and implemented in RSA such as harvesting rainwater and groundwater during times of water shortages or droughts. In the Western Cape, fines and water restrictions have been enforced to conserve water and prevent unnecessary water loss. Businesses and the industrial sector were placed under significant pressure to reduce excessive water consumption (Reddick, 2018). For water suppliers to avoid further excessive wastage of water they need to know the best water conservation method as well as leakage reduction method or if inaccurate billing is taking place.

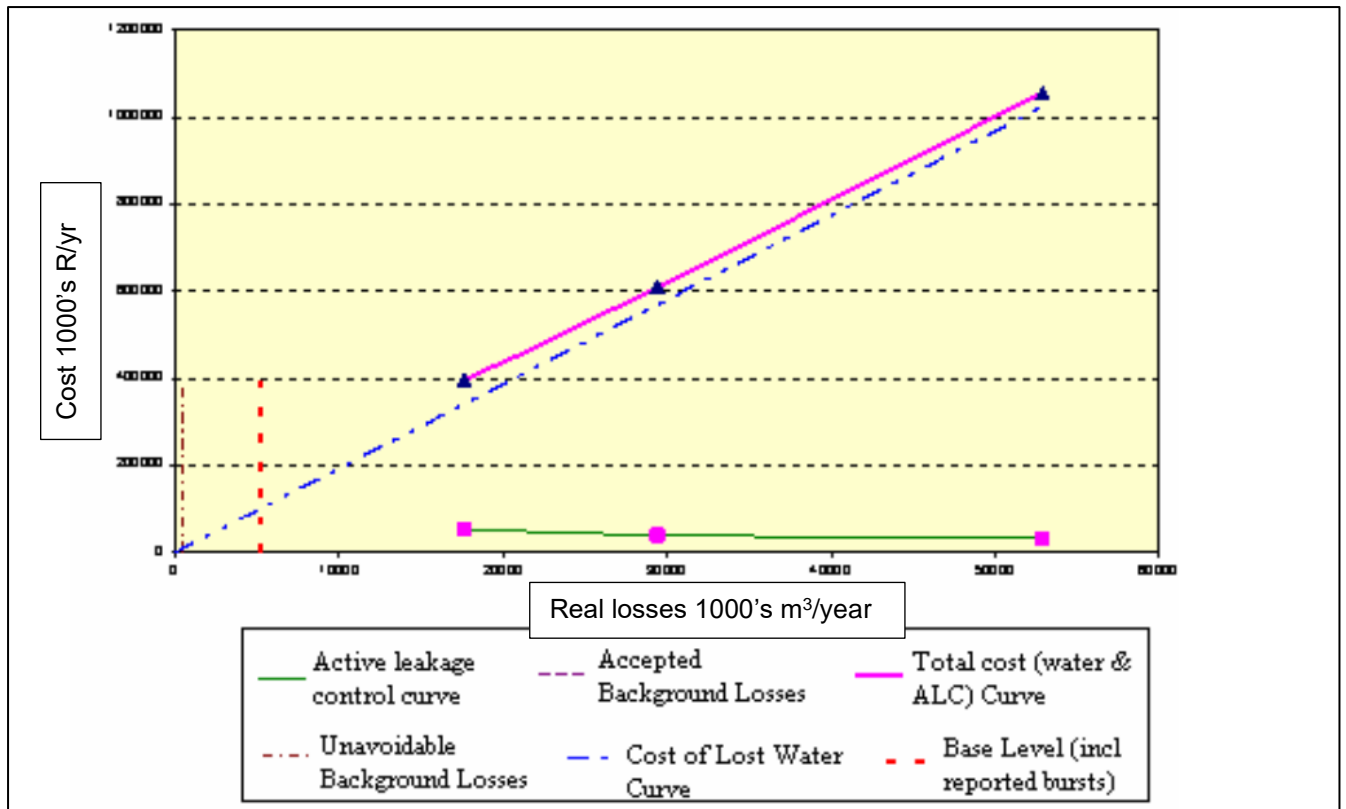
In certain cases, inaccurate billing can lead to businesses paying more for water uses than if they were correctly billed. Residents and businesses are encouraged to install their own meters to ensure the municipal water readings are correct. If the ECONOLEAK model is implemented and provided to the residents, more transparency will be created between the supply and demand chain (Reddick, 2018). The ECONOLEAK model requires the water supplier or user to collect factual data from the system regarding the leakage in the network. If the water supplier does not collect such data or does not have access to such data, awareness can be raised encouraging the collection of the data. It leads to further information requirements and the need to gather data in the event of leakages and system failure. The model can enable the supplier to identify when active leakage control is necessary. For instance, water utilities in the Republic of South Africa require certain water users to provide them with their water usage on an annual basis to keep track of water usage and the associated cost.

Leakage management software such as those developed for the WRC as mentioned above can be used. In addition to ECONOLEAK, BENCHLEAK can be used to calculate inter alia the ILI from data covering the total length of the mains, the number of service connections, the average operating pressure over the period in question, the system input volume and the components of authorised consumption. BENCHLEAK can calculate and compare

performance in managing water losses in a standard format (McKenzie, 1999). However, when it comes to investing in water supply infrastructure, there are various other factors that need to be considered. Appropriate water infrastructure planning and management require reasonable water demand forecasts for the future years, knowledge of hydraulic behaviour, degradation of infrastructure, the need of network expansion and the available budget which is included in ECONOLEAK. To maximise the use and efficiency of water supply infrastructure, regular maintenance and the prevention of water leakages must transpire.

In the Blantyre water supply area, the ECONOLEAK model was used to calculate the Infrastructure Leakage Index and the found it to be 18.4. This meant that there was an excessive need for rehabilitation of the system as the ILI was more than 8 in a developing country (Chiipanthenga, 2008). The burst frequency can be used to describe the infrastructure condition and reliability. Systems with high burst frequencies should be replaced. The study proposed that N1 components can be used to aid decisions for pipeline replacement. The N1 component will measure the sensitivity of burst frequency to pressure. The decision to replace the pipeline was determined by comparing the internationally derived N1 values ranging from 0.5 to 1.5 to those derived locally (Folkman, 2018).

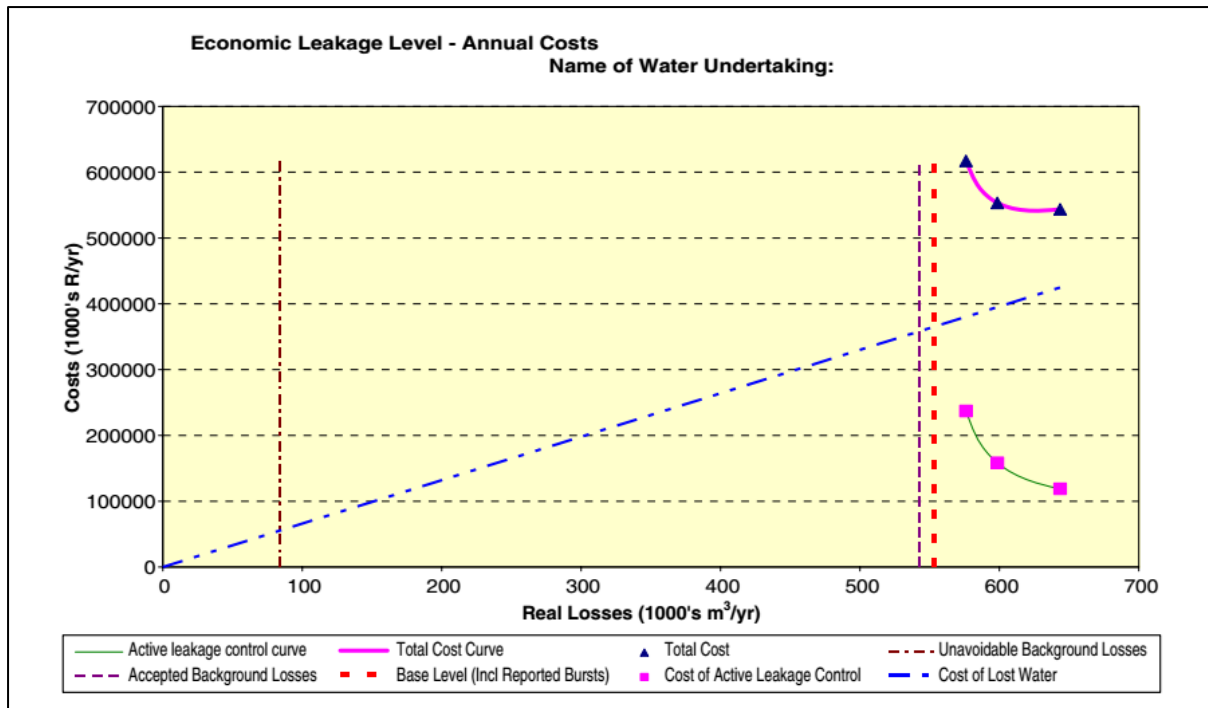
The results as seen in Figure 6 below show that the total cost for Active Leakage Control increases with real losses in the system. The minimum point of leakage, which is the economic level of leakage has already been exceeded. The curve for lost water runs almost parallel to the total cost and forms a large part of the total cost curve (Figure 26). It was concluded that the economic level of leakage is exceeded, and Active Leakage Control is required. It is further noted that previous studies relating to infrastructure condition assessment in the Blantyre region found that at least 46 km of the total pipeline needs to be replaced based on burst frequency which confirms the findings of the ECONOLEAK Model's calculated ILI index and final ACL curve. The best interval for intervention as seen in Figure 6 below was the 6-month intervention period.



**Figure 6.** Results of an ECONOLEAK model on analysis for the Blantyre water supply area (Chiipanthenga, 2008)

Tabesh *et al* (2009) also used the ECONOLEAK Model along with the SANFLOW Model to develop an integrated leakage model to evaluate Non-Revenue Water losses (Tabesh *et al.*, 2009). The daily and yearly leakage values were assessed and were given as 4,638 m<sup>3</sup> and 1,693,010 m<sup>3</sup> by the model respectively. The ILI calculated was 14.95 which meant that the network conditions that were assessed are unacceptably poor with low economic efficiency. Figure 7 below shows that the best intervention period for active leakage control is the 24-month intervention interval as it is the cheapest. However, this does not correlate to the current conditions of the water distribution system. Although the cost of active leakage control is the lowest at the 24-month intervention interval, the cost of lost water increases rapidly which may inevitably lead to a higher cost of fixing leakages at the 24-month intervention period as compared to the 6-month intervention period. Short term cost cutting may lead to long term problems.

A model such as the ECONOLEAK Model will therefore prove to be useful in determining the frequency required for active leakage control as well as the associated cost.



**Figure 7.** Economic level of leakage (*Tabesh et al, 2009*).

## 2.4 The costs associated with leak detection and intervention

The costs associated with water leakage detection and mitigation vary depending on the state of the infrastructure and level of maintenance of the water distribution system. The cost of leakage detection for water suppliers vary depending on the location of the leak, type of leak and type of leakage detection but generally include the following costs (*Lambert et al., 2002*);

- Administration and set up costs;
- Manpower inspection costs;
- Supervision costs;
- Mains repair costs;
- Connection repair costs

Costs are, for example, associated with the loss of drinking water and in terms of water scarcity and public health risks. Indirect costs are associated with medical treatment necessary when people's health is affected as a result of the intrusion of contaminants into drinking water at leakage points and when water of dubious quality is used for drinking because it is the only water available.

Further risks include the structural integrity of buildings when water from burst pipes seep into the foundations of buildings. Roads are another example where costly damage and potholes may occur due to the contraction and expansion of ground water in the soil due to temperature changes that have entered below the surface level. Water leakages heighten the potential infiltration of the soil in to ground water resources and consequently, increases the chances of pothole formation. In cases of underground piping where leakages occur, the leaked water is already close to the ground water level. Once the ground water contracts, the surface of the road above the ground water contracts too resulting in voids in the surface directly under the road. Water then gets trapped in these voids as the cycle of expansion and contraction continues leading to the prolonged weakening of the road surface. As heavy cars and trucks drive over the weakened areas of the road, parts of the road deteriorate causing the displacement of material to eventually form a pothole. Potholes are expensive to fill and result in extra charges incurred by the municipality along with that of detecting the leakage and fixing the burst pipe (Madli *et al.*, 2015).

Preserving buried infrastructure within the urban landscape is important for the maintenance of modern living as it can result in the breakdown of utility service provisions (pipelines) (Royal *et al.*, 2011). Leakage detection and pipeline replacement through open-cut methods are disruptive to the functioning of society and damage the road beneath which the pipelines resides. A study was undertaken in the UK that estimated that street works cost the UK £7 billion in lost revenues annually; comprising £5.5 billion in social costs and £1.5 billion in direct damages (Royal *et al.*, 2011). Open cut methods involve a lot of work and hence cost.

A study was carried out in Cape Town, South Africa to determine the approximate costs of lost water. The leakage intervention costs in this instance involved the cost of driving to the site to identify and mitigate the leakage if reported. In areas with poorer infrastructure such as Khayelitsha and Mitchells Plain, pressure reduction is used to combat leakages on a larger scale. The resultant water savings were immediate amounting to almost 40% of the original supply (Meyeridricks, 2016).

Table 4 below was compiled using the stepped Cape Town water tariffs at the time of the study. It gives an indication of how much water will be wasted and how much would it cost.

**Table 4.** Leakage costs in Cape Town (Meyeridricks, 2016)

Leak Hole diameter (mm)	At 7 Bar pressure (litres wasted per month)	Stepped Tariff*
1	50 000 litres	R1900
2	205 000 litres	R7850
3	460 000 litres	R17600
4	820 000 litres	R31400
5	1 280 000 litres	R49000

\* Stepped Cape Town Water Tariff

In South Africa, a leakage detection company provided the estimated costs of leakage detection in the following regions and grouped the cost as follows (Logix, 2020 );

1. Domestic house on a standard stand in Pretoria or Tshwane Municipal area  
Any unit on his own to be tested inside a complex will be charged the same as a domestic home depending on location.

R1500,00 + Value Added Tax (VAT) R225.00 = R1725.00

2. Complexes/ Factories / Municipal

R10 800.00 per day with a minimum charge of R2700.00 if the leak is found within a two hour period and R5400.00 for up to 4 hours.

Houses further away must work in travel cost at R6.50 per km while overnight stays average around R1300.00 per person per night.

The size of complex, pipe layout and knowledge of same will determine the total amount of time (day's) needed to complete the work.

These are just the costs of one company in South Africa and will defer depending on the company.

#### **2.4.1 Models used in leak detection and intervention for potential cost reduction**

There are two broad classes of leak detection systems, one being dynamic leak detection where the presence of leakages are verified by leak detection devices and personnel going to the suspected areas (El-Zahab *et al.*, 2019). The second class of leak detection systems is

the static leak detection system which provides early leak detection with minimal input required by personnel (El-Zahab *et al.*, 2019). Research in the field of leak detection has led to models and systems being developed that could assist the occurrence of leakages and the associated cost. These models and systems will be addressed below.

One of the methods analysed in a study undertaken by Poulakis *et al* (2003) aimed to use a Bayesian probabilistic framework methodology to detect leakages in the water pipe networks (Poulakis *et al.*, 2003). He implemented a time-efficient and cost-effective methodology that detects multiple leakages in water pipe networks together at the same time rather than screening individual leakages (Poulakis *et al.*, 2003). This methodology requires more computation but decreases the cost associated with detecting individual leakages based on information obtained from the water supplier. A hydraulic formula was applied to the entire water distribution network in the study area. A set of equations was required to solve the water network leakage problem which also included mass conservation equations applied to certain junctions and nodes. Energy conservation equations were applied at loops and pseudo-loops in terms of the pathway of the network. The scheme used in the study was the Newton iteration scheme (Poulakis *et al.*, 2003).

It was assumed that the point of leakage includes the outflow at the leakage point and will cause changes in the flow characteristics depending on the severity of the burst pipe. Results showed that if the model is error free and all input parameters for equations are accurate, the model can identify the exact point of damage of multiple leakages at once. The approach taken can form part of integrated software programmes to assist the water supplier in the decision-making process. The study revealed that the location of leakages can be identified using the Bayesian system identification methodology if measurement errors do not exceed a certain threshold value. The model is only able to perform an accurate measurement if the system is free from errors such as mistakes in data entered manually. Errors in the system are inevitable which brings into question the validity of the model under erroneous conditions. The model also requires a series of intricate and complicated computations which may not always be viable to work with as a water supplier. Although the methodology is useful, the ECONOLEAK Model would better suit water suppliers due to its simplicity of use.

A study conducted by (Wu *et al.*, 2009) aimed at devising a cost-effective strategy for leakage detection. This was found to be challenging to apply to all water utilities and therefore a model-based solution was proposed. This optimisation strategy was applied to leakage detection within water distribution systems. Within these water distribution systems, leakage hotspots were identified by the researcher through field visits and are assumed to exist within

specific model nodes (Wu *et al.*, 2009). The leakage detection was also based on a pressure management system as it was represented by the pressure- dependent demand. The pressure-dependent demand was simulated as part of the emitter flows for the selected model nodes. Leakage detection methods included the formation of leakage node locations to identify their associated emitter coefficients (Wu *et al.*, 2009).

In identifying the emitter coefficients, differences between the predicted result from the model and field observations for flow and pressure were minimised. The optimisation-based model calibration tool was thus used with a new add-on for leakage detection which assisted engineers in identifying leakage hotspots. The researchers were also able to combine the task with varied field data and hydraulic model calibration. Results revealed that the model can be used to predict leakage hotspots, reduce physical measurement and model calibration limitations to ensure enhanced accuracy. Xu *et al.* (2014) argued in another study that leakage identification and control could ensure sustainable development through the preservation of water resources (Xu *et al.*, 2014). Results have found that there is a general lack of pipe break prediction tools. The model used in this study incurred a high cost which is not feasible for most water suppliers. A model that uses a lower cost of leakage detection methods would be more appropriate.

In the City of Usti, Labem and Teplice, North of Bohemia, an investigation was carried out regarding the minimisation and cost of leakages in the city system. The study area is a District Metered Area for which a Water Supply System (WSS) master plan was used as a source of data for the mathematical model used. Svitak *et al.* (2011) used a leakage monitor to implement complex data to determine the financial implication of leakages (Svitak *et al.*, 2011). The model analyses the data, to identify leakages at the time chosen by the researcher for a specific DMA. The output data summarises all inflow and outflows of the system to evaluate the leakage and consumption.

The WSS data included in the master plan are the various invoices saved by the water suppliers for self-consumption. These values can be entered manually into the Model Leakage Monitor or be calculated while the analysis runs automatically. The economic loss associated with leakages is calculated by using the balance between the costs that can be saved on water leakages and the cost to mitigate the leakage. The price associated with the water leakage and the level of leakage occurring after mitigation measures is also considered in the calculation. Investment plans and infrastructure rehabilitation plans were suggested as alternative methods of preventing leakages and the associated cost. Results of the study show that the Leakage Monitor can reduce leakage by 30% and reduce more than half of the cost

allocated in the WSS master plan for leakages. The WSS approach was proven to be helpful in reducing leakage and can be implemented by water suppliers. However, one needs to be careful with the manual entry into the leakage monitor as human error can be introduced which will corrupt the analysis.

The overall aim of a study conducted by Martini *et al* (2015) was to develop an automatic device that can aid early detection of water leakages and include the identification of unreported bursts (Martini *et al.*, 2015). The methods currently used for leakage detection adopt technologies such as district meters to discover the presence of losses within the water distribution system. The equipment used to observe the phenomena are accelerometers and hydrophones. Martini *et al* (2015) focused their research on detecting leakages in the entire service connection as opposed to pinpointing the exact location, meaning more than one leakage can be detected at a time (Martini *et al.*, 2015). Results of the study revealed that signal filtering was a profitable solution to enhance the algorithm being used. The algorithm was not tested in a larger study area with a larger database of real leakages such as that of Johannesburg Water's Region A supply area. It is therefore unclear whether the algorithm will be appropriate for Region A's water distribution network and must be tested first before usage.

Anastasopoulos *et al* (2009) developed another method which uses acoustic surveys capable of detecting leakage (Anastasopoulos *et al.*, 2009). Active bursts usually emit sounds that propagate along with the pipeline network under the ground. Noise loggers can be installed to detect these changes within the pipeline network. Acoustic Emission (AE) was used by mounting an AE sensor in a pressurised pipeline at 600-1000m sections. The AE sensor was able to detect turbulence in the flow during a leakage. The use of AE systems along with specialised software identified the point of leakage. Results of the study show that the AE signal attenuation is higher on small diameter pipes (4-6") due to the larger distance between pipes, this can be mitigated by decreasing the distance between sensors on pipes. One of the problems mentioned in the study is the risk of external noise such as vehicular movement over the pipelines or large bangs from pumping stations. This can be mitigated through filtration of the system.

Investigations on the automatic detection of leakages in water distribution networks by means of vibration monitoring were performed in Italy by (Martini *et al.*, 2014). Vibration monitoring tools were used to detect leakages in the water distribution network. The multiutility nature of the proposed tool ensures that leakages are detected early in cases of unreported bursts running from the mains to the customer's meters. Vibration signals were measured when real leakages occurred for the duration of the study and a prototypal algorithm was used.

The algorithm incorporates standard deviation performed on signals received by the vibration monitor. Vibrations were detected using the commercial Integral Electronics Piezoelectric (IEPE) accelerometer that uses a signal conditioner to power the sensor and gain the required signal. The IEPE is an electromechanical device used to measure acceleration forces within the water distribution network. The signal was then acquired and recorded by a GigalogF datalogger.

External sources of power supply are not required by the system as a battery is able to power the entire system. Due to the algorithm being based on simple standard deviation procedures much cost is saved in detecting leakages (Martini *et al.*, 2014). Leakages were detected by the use of a band-pass filter that was installed in the system. Signal filtering was used to enhance the sensitivity of the algorithm to leakages in the network. The algorithm was also able to include the different influencers on measurements such as environmental perturbations. Results of the study show that the algorithm and measuring device were economically viable to implement amongst other electronics (Martini *et al.*, 2014)

A study was carried out in Surat City, India, due to the immensity of problems faced in the water supply system. Popawala, (2014) aimed his paper at water management and high level water loss to ensure water resource sustainability, water supply efficiency and minimisation of costs in the water supply network (Popawala, 2014). The ILI of the study area was analysed, and data was sourced from the hydraulic engineer in the area who filled out the BENCHLEAK model template. The data was then verified by the creators of the model and results were generated by the model. The BENCHLEAK model considered three main water loss components, namely; the real losses, apparent losses and total losses. The apparent losses were associated with errors in the metal used, unauthorised use of water as well as administration errors (Xin *et al.*, 2014).

The ILI data was prepared, using the calculations used to set up a water balance by water services providers, (Seago *et al.*, 2007) and the result was evaluated against the water balance performance indicator developed by the International Water Association (IWA). The collection of the entire data set took 4-5 weeks to complete. Once complete, the data was verified and inserted into the model. The types of data required included the length of mains, number of service connections, average operating pressure when the system is pressurised and the percentage of time the system is pressurised. The model split the authorised consumption into five components. Authorised consumption is the volume of metered or unmetered water taken by registered customers, the water supplier and others who are authorised to do so by the water supplier, for residential, commercial and industrial purposes

(Lambert, 2002). The five components were given as a percentage of the total Unavoidable Annual Real Losses (UARL) and consist of;

- household use,
- standpipe,
- firefighting,
- non-household use and
- water exported.

Once the authorised consumption and ILI were calculated the exact volumes of water lost were available and the results indicated that the more cost effective option was to mitigate (Popawala, 2014).

A study conducted in Ghana implemented the BABE methodology in accordance with the BENCHLEAK model to reduce the money spent on water leakages (Amoatey *et al.*, 2014). The study required information such as the number of bursts, physical leaks, total water loss and overflows. From the period of 2010 to 2011, it was shown that around 40% of water supplied to the network by the water supplier in the study area was lost (Hirvi *et al.*, 2015). Ghana has not yet implemented smart metering systems. The night flow analyser could not be used either as it was not available for night logging.

Other smart metering systems were used as estimates for the model and the rest of the data was obtained manually by the researcher from water suppliers. Variations in leakage estimates were observed. Low leakage rates were due to relatively new infrastructure in the area such as pipelines and reservoirs which were built in 2008. High leakages were attributed to meter inaccuracies, unreported water losses, theft and billing inaccuracies. Results show that water suppliers should actively identify, locate and mitigate bursts in a shorter amount of time. In order to do this, they need to investigate the causes of unreported and apparent losses as this was where the greatest amount of water was lost (Amoatey *et al.*, 2014).

Johannesburg Water has a turnaround time of 48 hours for fixing a reported burst pipe or water shortage with an average of 90% of all logged calls attended to within the first 48 hours (Shibambu, 2019 ). If the burst pipe or water shortage is left for longer than 48 hours the cost of lost water subsequently increases which is why Johannesburg Water aims to fix the burst quickly and restore water. Once a leakage is reported, a reference number is allocated to it at the Depot and all further calls associated with the same leakage are placed

under the same reference number. This results in lower amounts of water being lost through leakages.

## **2.5 Quantification of real and apparent losses in a network**

Water losses constitute the total water losses that the supply network can incur. This includes apparent or commercial losses as well as physical or real losses. Real losses consist of;

- Leakage on transmission and distribution mains
- Leakage and overflows at storage tanks
- Leakage at service connections up to the point of the customer's meter

The apparent losses consist of;

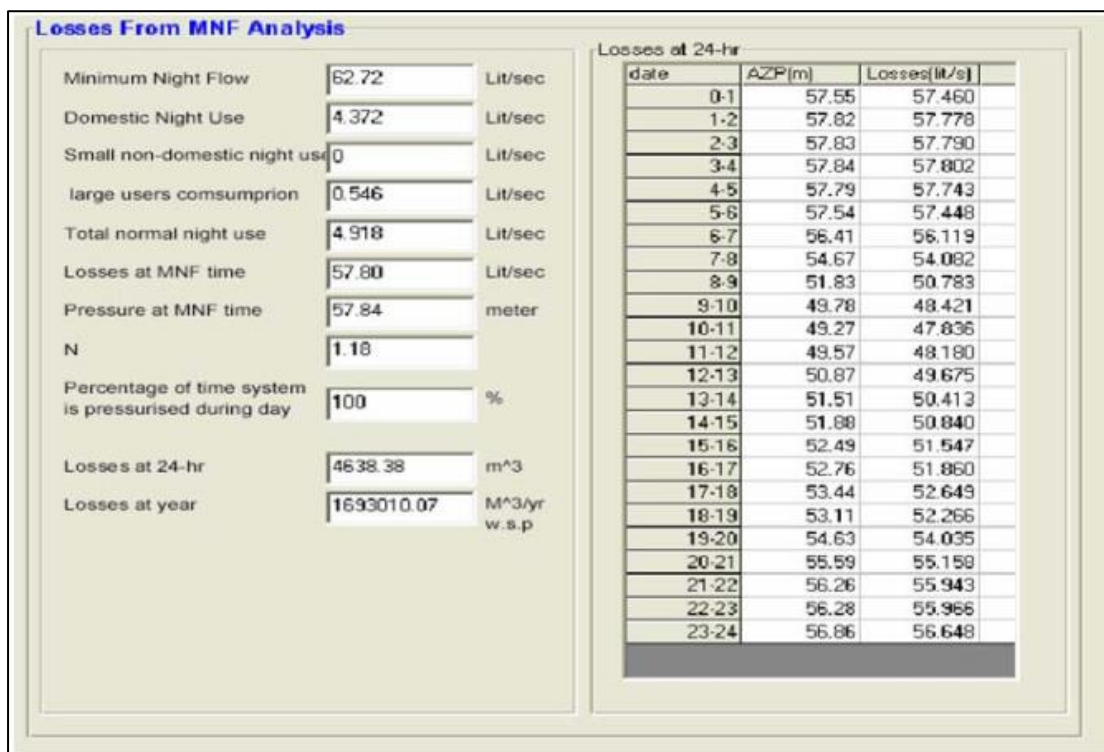
- Unauthorised consumption
- Customer meter inaccuracies and
- inaccurate billing

Apparent losses are also known as commercial losses and consist of the authorised consumption (illegal use of water or theft) and all technical plus administrative inaccuracies associated with billing and metering (McKenzie *et al.*, 2012). An estimate of the apparent loss can be derived from local knowledge of the system and analysis of administrative and technical customer meter systems. Real losses or physical leakage constitute the physical leakages that occur in pressurised systems up to the point of measurement of customer use (McKenzie *et al.*, 2012)

Real losses from the distribution network include losses from overflows, bursts and storage areas which assist the quantification of the cost of lost water. In the instance of apparent losses, quantification becomes a major problem as these are non-physical losses. Apparent losses can result from numerous problems such as data errors, billing and meter reading inaccuracies or theft. This water is hard to account for, measure or pay for as the exact amount is not known. Apparent losses disrupt consumer consumption patterns as not all the data required is known (Xin *et al.*, 2014). Several studies investigated the negative impacts of the real and apparent losses that occur in distributions systems of water services providers.

A hydraulic simulation model, as seen in Figure 8 below, to determine the leakages in pipes and nodes is given by (Tabesh, Yekta *et al.* 2009). Non-Revenue Water and losses

within a system network can be identified by using the minimum night flows as well as the annual water balance (Tabesh *et al.*, 2009). To analyse the NRW, the quantification of real and apparent losses in the network needs to take place. Real and estimated data is used along with information on all reported and unreported bursts, background leakage and indices of leakages obtained from water suppliers. The dependence of leakage on pressure is one of the main aspects highlighted in the paper. In one instance, a pressure dependent system is analysed in terms of hydraulic behaviour while pressure independent of local pressure is also determined. A computer code used to evaluate all the components involved in the loss of water was developed by the team for the study.



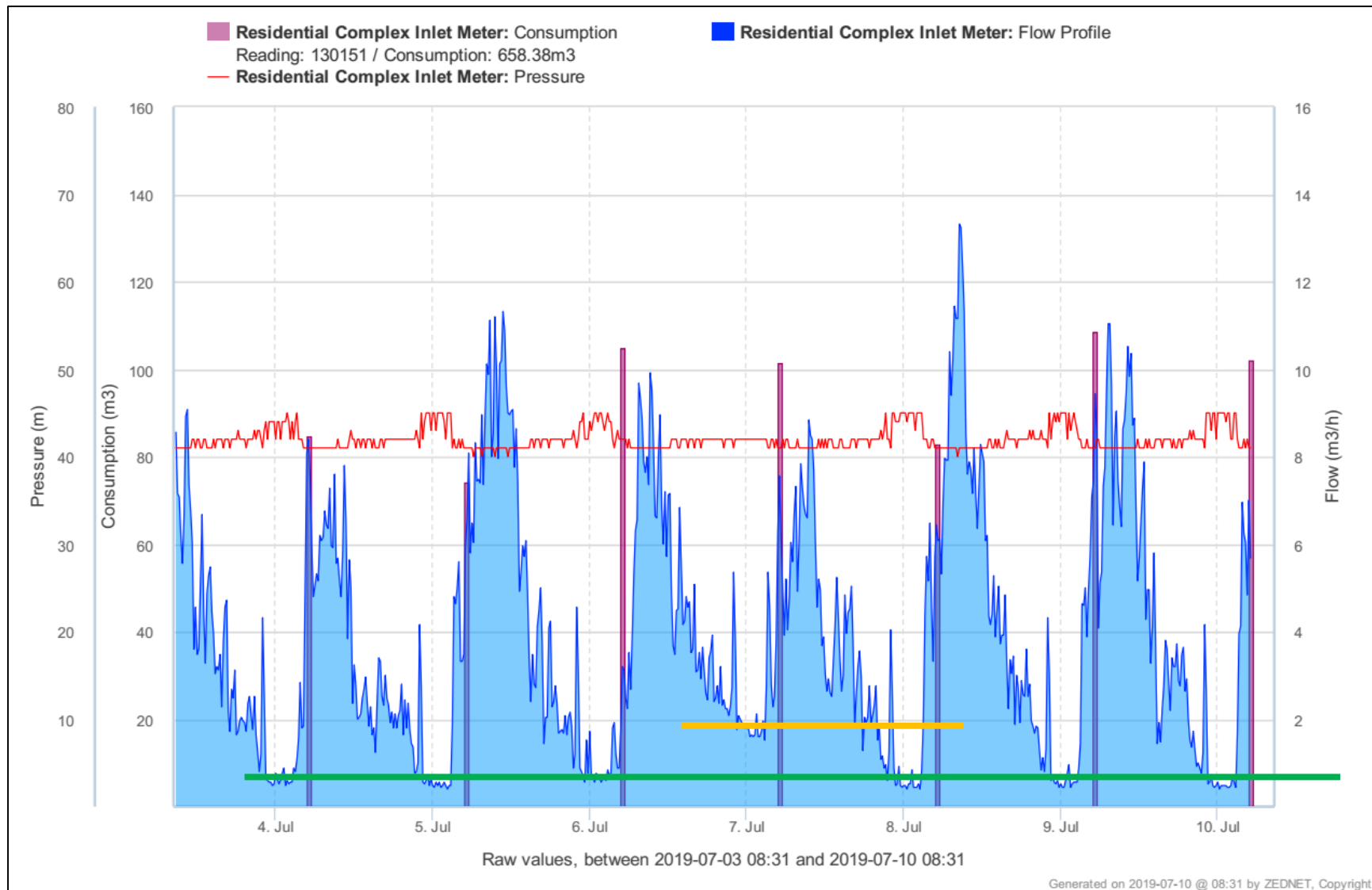
**Figure 8.** Results of leakage calculation by Minimum Night Flow method (Tabesh *et al.*, 2009).

To make the interpretation of results easier to analyse by end users, the results can be exported to a GIS model to create a network map. The attribute data contains information and factors that have been identified as having an impact on the network. NRW and real losses were identified through the annual water balance method. Estimated values were the only values available for analyses of the apparent losses through this method. The Minimum Night Flow uses average pressures and inflow data in the chosen DMA. Once obtained, the hydraulic leakage model can calculate the flow at the MNF to output the leakage rates on a monthly and daily rate. Once all data is obtained, the BABE and Fixed and Variable Area Discharge (FAVAD) concepts are applied. The FAVAD concept explains how water systems

react differently to pressure depending on the type of leakage present. The volume of water lost through leakage is dependent on the type and size of the hole or crack or broken joint. The size of a corrosion hole, for example, will stay fixed during the day's pressure fluctuation even though more water will exit the hole as pressures increase. However, in the case of a leaking joint the size of the opening may increase as the pressure increases due to the opening and closing of the joint with changing pressure (Lambert *et al.*, 2002). The FAVAD concept therefore reflects the area of leakage paths that need to be fixed. Data for model input can be obtained through field visits over a period or by using data that are collected by municipalities and equations can be used to calculate the rate of leakage from the reported burst (Tabesh *et al.*, 2009):

In an interview that took place on the 5<sup>th</sup> of July 2019 with Dr Ronnie McKenzie, the cocreator of the ECONOLEAK Model, various techniques for leakage detection were analysed. He suggested that one of the most practical methods used by himself and by his company is to monitor Minimum Night Flows. This is done by installing a flow meter or pressure logger on your water meter or the municipal water meter. Log flows and pressures are then monitored 7 days a week at 15-minute intervals. The logging results can be downloaded onto Zednet and used daily. Zednet is web based and uses a data acquisition and display system. Meter readings can then be electronically compared to your municipal account to check if there is correlation or discrepancies. The following logging results can be analysed; Minimum Night Flows, average flows, possible leaks, daily demand patterns and any irregularities that are found in the system. Recommendations, continuous monitoring and remedial action are then provided by the company that installed the loggers and a short report on the findings can be found on Zednet.

Currently, at WRP Consulting in Pretoria, Gauteng, a logger has been installed on the residential complex inlet meter. The flow profile, consumption and pressure are measured by the logger and is displayed daily on the system. In Figure 9 below, a graph has been generated for the logger installed at WRP Consulting. The graph works on a 7-day cycle where consumption is the highest during the daytime hours at the office block and lowest at night when everyone leaves the office block. The green line seen in Figure 9 below is the Minimum Night Flow.



**Figure 9.** Graph showing logging results on a residential complex inlet meter at WRP Consulting, Pretoria (*Graph generated in 2019 on Zednet*).

From the 4<sup>th</sup> of July 2019 to the 6<sup>th</sup> of July 2019, the MNF is constant as represented by the green line. On the 6<sup>th</sup> of July to the 7<sup>th</sup> of July 2019, the MNF has increased as represented by the yellow line. During this time, a leakage has developed which caused the MNF to increase. On the 7<sup>th</sup> of July 2019, the leakage was fixed and the MNF returned to its normal value as seen from the 8<sup>th</sup> of July to the 10<sup>th</sup> of July 2019. The 7<sup>th</sup> of July 2019 was a Sunday and the leakage was hence fixed over the weekend. The cause of the leakage was a damaged pipe in the bathroom (Mckenzie, 2019). The leakage was identified immediately by analysing the graph in Figure 9 which was generated by the Zednet System with the data from the logger at the office residential block. During this leakage, the flow profile increased from 1.8 m<sup>3</sup>/hour to 2.24m<sup>3</sup>/hour resulting in a greater wastage of water. As the leak was fixed immediately, the cost associated with the leakage was not high. This leakage was easier to identify as it occurred in the bathroom and was reported. However, other leakages such as those in underground pipes are difficult to identify. Figure 10 below is the data logger at WRP Consulting offices that was used to generate the graph seen in Figure 9 above.



**Figure 10.** Logger installed at WRP Consulting (*Photo taken at WRP Consulting in Pretoria, 5<sup>th</sup> July 2019*).

One of the approaches applied by Anand (2015) in the city of Mumbai against water leakages was analysing water audits, the politics associated with infrastructure and the perceptions associated with water loss (Anand, 2015). The author investigated the controversies surrounding water leakages (Anand, 2015). These controversies included the source of unaccounted for water and losses such as theft. The role of water engineers and municipal managers in quantifying losses was analysed. Water losses were detected through the interpretation of water audits. This requires

a lot of time as maintenance workers must inspect the infrastructure manually to identify exactly where the apparent loss is occurring. Anand (2015) states that there are many municipal managers and engineers that work hard to fix the leakages they are aware of but make no effort to find out about the apparent water losses that they are not aware of. This has led to existing controversies (Anand, 2015). Through various interviews, it was found that much of the water supplied is lost through apparent losses. The methodology employed can be implemented in this study, although it is time consuming insight may be provided into the cause of losses by analysing water audits.

Often, managers are aware of the apparent losses but are not actively identifying and mitigating the problem. As apparent losses are not easily detectable, it is hypothesised that it does not affect the local government's political image, therefore no attention is paid to the quantification of the loss. Ignorance takes precedence when no effort is made to account for apparent losses while real losses are addressed. This results in large sums of money wasted through unaccounted water losses. In Limpopo, the Republic of South Africa, questionnaires were distributed regarding water shortages. The study was undertaken by Hoffman (2016). The author analysed the data from the questionnaires and identified water leakages and pipe bursts as one of the main contributors to water supply shortages.

The districts Patzcuaro and Quiroga of Mexico have been experiencing increased demand in municipal services due to the rapid increase in population causing water shortages and in particular shortages of drinking water. The Water and Sewerage Agency in Mexico who is responsible for the distribution of drinking water to the population consequently had to identify other sources of water. One possible option is to increase the efficiency of water supply. One way to ensure water supply efficiency is by using hydrometric districts. The hydrometric district assists in the tracking of water volumes that are supplied and delivered (Xin *et al.*, 2014). Results of the study have shown that hydrometric districts assist in the tracking of apparent losses and the reduction of incorrectly registered users. However, when people do not register their water uses, a problem of tracking water supply and loss arises. A second option for this district is the extraction from wells. However, the extraction of water from wells comes at the cost of a reduction in the aquifers of the area. Mexico has begun extracting water from wells to ensure the demands of the population are met.

Rios *et al* applied an economical method to aid the registration of water users to help the eventual quantification of real water losses in the network (Ríos *et al.*, 2014). The first step was to gather all information that has already been recorded on the water supply system of the cities chosen. These included all the registered users, the distribution network and historical records of pressure management. Data was sourced from historical records and the Water and Sewerage Agency.

However, the flow had to be manually measured by use of electromagnetic meters. Water consumption per day was then calculated using the number of shots recorded, the overcrowding index (4.3hab/shot) and the envelope (230 l/person/day) (Ríos *et al.*, 2014).

The comparison of the flow entering the system in each city with the volume consumed in the city by each user gave the number of physical losses in the cities analysed. To identify apparent losses, ArcMap was used to integrate photographic equipment, Global Positioning System (GPS) locators and the front of each property. This was converted into a shapefile and used as a graphical interface. Results showed a 68% difference between users that are registered and those that are not (Ríos *et al.*, 2014).

In a study conducted in Egypt, the BABE methodology was used to determine the use of pressure control in the system to reduce leakages. In Egypt, one of the main contributors to total water loss was leakages that are undetected (Samir *et al.*, 2017). Bursts that are seen by consumers are more easily mitigated as they are reported and repaired quickly. Those that are smaller such as cracks in piping are more difficult to detect and can continue without being repaired for long periods of time. The study area chosen by Samir *et al.* (2017) was in Arama, Egypt which is a District Metered Area (Samir *et al.*, 2017).

Leakage scenarios were simulated to prevent extensive field work, the programme used to simulate the leakage scenarios was WaterCAD which uses hydraulic modelling. The study aimed to use WaterCAD as a tool to plot leakage as a function of pressure within the system. Pressure Reducing Valves (PRV) were inserted into the model at strategic points to observe how the leakage values fluctuate. Different PRV locations and diameters were used in different water leakage scenarios. Results revealed that by implementing pressure management in District Metered Areas, leakages can be reduced by 37%. PRV can significantly reduce the amount of water lost through real and apparent losses (Samir *et al.*, 2017).

Sub-divided DMA are easier to analyse for causes and points of leakage when selecting the best leakage management system to adopt (Galdiero *et al.*, 2016). DMAs are created by a process that entails closing off internal boundary valves in order to isolate or cut-off portions of the network so that each portion has a single inflow. During times of low flow consumption, such as at night, leakages can be identified. In the United Kingdom, DMA was used which reduced leakages over the past 25 years by 30% (Wright *et al.*, 2015). To facilitate the reduction of water leakages in the system, PRV is used. This is done through the installation of valves at each DMA to reduce the pressure and hence the leakage. Wright *et al.* (2015) investigated pressure management and resilience in a water distribution system through the use of PRV (Wright *et al.*, 2015). Sequential

Convex Programming (SCP) was used to control PRV in the system for the different topology to find the best optimization method. Results show that the reliable convergence method is the best optimization method and results in pressure reductions of 3.7% within the DMA.

In the City of Zomba, Malawi, Non-Revenue Water and Unaccounted for Water (UFW) are a major problem for water suppliers and cause excessive drinking water production rates. Hoko *et al* (2017) investigated unaccounted water loss in the study and found that real losses were higher than apparent losses (Hoko *et al.*, 2017). The period over which the study was conducted was from 1999 till 2008. Water use and water balance records were collected for this period. Water production values were obtained from treatment plants and water consumption patterns obtained from customer bills that were based on meter readings. UFW was separated into real and apparent losses to ensure that efficient leakage strategies were implemented correctly. To determine MNF, flow loggers were installed in pipelines and provided information on real losses based on pressure readings. To calculate apparent losses, the difference between UFW and real losses were analysed.

Meter inaccuracies, billing errors and old infrastructure were the reasons behind the UFW in the study conducted. Pressure management through Pressure Reducing Valves, meter repair and upgrading infrastructure were put forward as active water loss control options (Hoko *et al.*, 2017). Figure 11 below depicts a typical PRV that is used in South Africa.



**Figure 11.** Pressure Reducing Valve (Photo was taken at WRP Consulting in Pretoria, 5<sup>th</sup> July 2019).

After careful consideration of literature, the use of a model in a District Metered Area was most plausible for the study area. The model will quantify the real and apparent losses using information collected by the water supplier. This study will thus use the ECONOLEAK Model which takes into consideration the quantification of losses within the water distribution network. The advantages of using a model to quantify water losses range from being time efficient and accurate in calculating several variables involved in water losses such as pressure. Another avenue of water loss quantification researched was the use of computer codes in the network. However, the use of computer codes is often difficult to interpret by water suppliers. Questionnaires can also be

distributed to establish water losses in the system. However, they may not be accurate and may contain human error. It is thus more suitable to use meters and attain records from water suppliers.

In an interview that took place with Johannesburg Water on the 1<sup>st</sup> of July 2019, it was mentioned that the quantification of unreported losses in the system is difficult. This is due to an increasing number of illegal connections and damages in underground pipes. According to Johannesburg Water, leakages in the distribution mains have reduced over time from 414 in 2016 to 250 in 2019. Unfortunately, in 2016 there were 372 illegal connections which have increased to an estimated 485 in 2019 (Shibambu, 2019 ). The official figures did not include illegal connections. Physical losses are easier to identify as they are within sight and can be repaired easily whereas unreported losses require active leakage control. Johannesburg Water must, therefore, send out teams to areas where they have had a high number of leakages or where pipes are old to monitor the infrastructure and check for unreported bursts. The System Applications Products (SAP) is used by Johannesburg Water and generates the time and place that needs to be checked using the monitoring information entered into the system (Shibambu, 2019 ).

## **2.6 Relevance of present study within the sub-Saharan Africa context**

The importance of water security is seen as a world-wide problem as given in the Global Risk Report where the crisis has been placed among the ranks of natural disasters and the impacts of climate change (Forum, 2017). In sub-Saharan Africa (SSA) water supply is considered a pressing issue. These issues include the problem of ineffective governance, poverty and water distribution management. The problem of water scarcity has been researched widely in rural areas. Historically, rural areas have felt the impact more severely. However, water scarcity is extending into urban areas due to the reduction in available freshwater resources.

It is not only the urban and rural residential areas that are affected by the water problems experienced in SSA but also the agricultural and industrial sector. Much of the revenue generated is from the agricultural and industrial sectors which largely depend on water as an input. The repercussions of the agricultural and industrial sector not functioning at full capacity include a loss in food and a potential reduction in produce for trade. There is a subsequent shortage of information regarding the various strategies that can be used to ensure the appropriate distribution of water resources in urban and informal settlements along with the various sectors. Researchers are contributing to adjust research methods to include inequalities in access to water and put forward strategies that ensure the appropriate distribution of water (Dos Santos *et al.*, 2017).

Urban dynamics of water supply in SSA as explained by Dos Santos *et al* (2017) is largely influenced by the rapid expansion in population numbers. Africa has increased in population size over the past two decades surpassing most other regions (Brikké *et al.*, 2016). Population numbers experienced in SSA are expected to triple to 1,1 billion from 346 million in future (Desa, 2014). In order to allow population growth, the expansion of metropolitan areas must occur in an outward fashion. Much of the existing urban areas in Africa have been due to spontaneous growth and occur in unplanned settlements. The rapid rate of development has led to infrastructural inadequacies and a shortage in the provision of water resources. This proves to be a challenge for the existing infrastructure and places pressure on institutions to respond to the problem. One way of managing the problem of access to water is to ensure water governance strategies consider the trade-off between water as a commodity and water as a basic need. Therefore, the role of local authorities in the water crisis is important for the management of water resources. Problems such as water leakages and restrictions should be placed at the forefront of management.

In South Africa water restrictions have been applied nationwide in attempts to mitigate the impending water crisis. The Republic of South Africa is located in a semi-arid region (Mawela, 2008). The water availability in RSA will thus always be at risk of depletion. It is therefore imperative that we conserve all water resources in our country for example by conserving water resources and to ensure water supply is distributed optimally and that there are no water losses from the supply network. The study of water supply and water loss thus becomes one of critical importance (Oyebande, 2001). Of concern is that the amount and quality of clean water supplied is not distributed uniformly in South Africa on both a spatial and temporal scale (Oyebande, 2001). The application of results and recommendations of this study could help in creating effective mitigation measures and dealing directly with the issue of water supply suited for a specific land use setting, in this case residential.

Expanding urban development is evident worldwide as more people relocate from rural areas to urban areas in search of jobs and better livelihoods. The increase in urban developmental rates causes a rise in municipal, recreational and industrial land use. This puts pressure on the resources within the environment such as the water supply network which in turn can affect the quality of water. Section 24 of the South African Bill of Rights highlights the right to a clean and healthy environment as well as the responsibility of preserving the environment (The Constitution of the Republic of South Africa, 1996). This includes the adequate supply of clean water to everyone in the country. However, due to limited infrastructure and resources, clean water supplies are only provided to limited areas in the country which jeopardizes a basic human right and causes further municipal problems.

Water shortages are also directly related to the power supply in RSA because pumping stations come to a halt during a power outage. For example, late in the year of 2018, there was a large power outage in the City of Johannesburg municipality which was a result of a fire at the Eikenhof electricity substation. At the time of the incident, water shortages were a large concern for the municipality (Nomahlubi Jordaan, 2018). The substation that was on fire affected a large portion of Johannesburg and Rand Water supply, distribution and provision system. The affected suburbs did not have any water for a number of days. This was not the first major shortage of water to occur within the Johannesburg region. In the year of 2017, there was a major pipeline that burst in Linbro Park under an unstable landfill in Alexandra. This caused water shortages in the township and the surrounding area for over three days. The mayor of Johannesburg at the time, Herman Mashaba, stated that one of the reasons for the massive loss of water due to leakages is an “infrastructure and administrative backlog.” Nico De Jager, the Member of Mayoral Committee for Environment also echoed the problem of water shortages. He also commented that electricity supply infrastructure plays a large role in the water supply as the city is currently in the process of renovation. Renovations within the city such as the refurbishment of Johannesburg Water networks caused the water shortages.

The problem of water leakages is so immense that De Jager said “R900-million” will be spent on projects in the city which includes the renovation and refurbishment of existing infrastructure and the construction of new infrastructure. The city council estimates that by the end of the financial year of 2018, less than 6000 burst pipes will be reported with new infrastructure in place (Nomahlubi Jordaan, 2018). The city is now spending more money on refurbishments than ever spent before. The current backlog in administration and infrastructure is estimated to be R12 billion. The reduction of water shortages and improvement in water quality was one of the main aims of the financial year given the state of governance in the municipality.

Water quality refers to the chemical, physical and microbial constituents of a water body or a water sample. Water quality also determines whether water is appropriate for different uses such as human consumption, irrigation and domestic activities (Holmes, 1995). During bursts in the network, the water quality could be affected as a result of intrusion of contaminants into the distribution system. Factors such as pH, faecal coliforms, total dissolved and suspended solids determine whether the water is suitable for human consumption without posing a detrimental threat to wellbeing (Zone, 2008). Poor water quality due to an unmaintained water supply or sewerage system can cause fatal diseases for example cholera (Hunter, 2003). This further emphasises the importance of ensuring water supply networks are maintained and that water supplied comply to the national water guidelines and standards.

This study adheres to Goal 6 of the Sustainable Development Goals (SDG) pertaining to “Clean Water and Sanitation.” Water scarcity problems are not only experienced in South Africa, as more than 40% of the world’s population are affected by water quality and quantity problems (Kates *et al.*, 2005). This number is expected to increase in conjunction with the rise of global temperatures. The United Nations Development Programme (UNDP), estimated in 2011 that out of 41 water-stressed countries, 10 were very close to the depletion of all freshwater that was renewable. Alternative sources of water must be found to ensure that total depletion of usable water does not occur. This often requires extensive research with associated costs (UNDP, 2018). It is further estimated that by the year 2050 arid countries such as RSA will be affected by the recurrence of water shortages (UNDP, 2018). One of the SDG targets states that by the year 2030, everyone should have access to safe and affordable drinking water. This requires the appropriate infrastructure and sanitation facilities as well as the protection and maintenance of water resources and supply networks (UNDP, 2018). It also requires that the users are informed and willing to save water wherever possible. This study could support the identification of water loss problems in the water supply network and provide information regarding the associated cost of mitigation measures and in so doing help raise awareness amongst water suppliers and the importance of infrastructure maintenance.

Similarly, this study is in line with Goal 6 of the Millennium Development Goals (MDG) pertaining to the eradication and combatting of “HIV/AIDS, malaria and other diseases. The RSA Government is responsible for planning and implementation of strategies, policies and programmes to help combat the spread of diseases such as malaria. However, to implement these plans on a municipal level can prove to be challenging (Chopra *et al.*, 2009) in terms of governance. Implementation of such plans often requires support from more than one government sector making cohesion, co-operation and implementation of strategies exceptionally difficult. Health problems in RSA are complex as they often include various socioeconomic factors that require civil society, the private sector and government to work coherently to solve the problem. This study can help municipal water suppliers to ensure their water supply network has fewer prolonged burst pipes and the associated risk of contamination.

In September 2018, leaflets were provided to the residents of Midrand. These leaflets were distributed throughout Midrand by being placed within the local newspaper, the Midrand Reporter. The leaflets contained information of high importance from Johannesburg Water regarding water restrictions. In 2018, the Department of Water and Sanitation requested that the City of Johannesburg Municipality reduce their water use by at least 15% with immediate effect. The request was made as water levels in the Vaal River system had dropped drastically. The cause for this was an on-going drought experienced in the region and warmer weather conditions that could

have been caused by global warming (JWater, 2018). In response interventions have been put in place to reduce the -water usage in the City of Johannesburg Municipality. In terms of Section 44(3) of the Water Services By-laws implemented in the Johannesburg Municipality, consumers were compelled to stop watering gardens between 06:00 and 18:00. Use of irrigation systems (only hand-held hoses or buckets of water were allowed during watering times), filling of swimming pools, using hosepipes to wash cars or to clean paved areas and driveways were illegal.

If residents were non-compliant to the above-mentioned conditions, fines were issued. There were strict water demand restriction tariffs enforced. These water restrictions were implemented by reducing outflows from the Midrand reservoir. To avoid impacting residents and the usage of water, the reduction of outflows only took place during off peak times which were from 20h00 p.m. to 04h00 a.m. This only occurred daily in selected areas (JWater, 2018). Johannesburg Water included water saving techniques in the leaflet for the residents of the municipality. These tips are simple and easy to implement by residents and include fixing all leaking taps immediately. Fixing all leaking taps as well as not leaving taps dripping will ensure that further wastage of water does not occur, and water restriction fines are not incurred. The re-use of water and storage of drinking water was also encouraged. Refer to Figure 12 below for the leaflet that was distributed in the Midrand Reporter.



**Figure 12.** Water Restriction Leaflet distributed by the Midrand Reporter (*Taken from the Midrand Reporter, 2018*).

## Chapter 3- Methodology

This chapter aims to define and explain the research approach in the context of this dissertation and shows how the objectives of the research are addressed. In doing so, the techniques used to collect, analyse and interpret the data are discussed. It must be noted that a scientific methodology portrays a system of findings, methods and concepts which have been widely accepted by a number of scientists in order to explain the complexity of real world problems (Weber, 2017). Through concepts and constructs, people can categorise and classify the experiential world. This study leans towards environment and society, hence significant attention is placed on the man-land- water interaction.

### 3.1 Data and source of data

This study requires quantitative research methods that deal primarily with the input of numbers into a model. It is a measurable and systematic way to investigate water leakages and the relationship with economic loss. The input variables are measurable and will assist in the prediction of the desired result (Brannen, 2017). The implementation of the ECONOLEAK model requires the user to collect the basic information on the water supply system from water suppliers. To implement the ECONOLEAK model, the following data requirements must be met for the water supply system that is under study. These involve basic system data as seen in Addendum 6, the duration of all reported bursts and the water loss data associated with bursts which includes real and apparent losses, the rates of leakages and the number of leakages for all reported and unreported cases of burst pipes, the marginal cost of water for the economic loss section of the model and the costs associated with the detection and repair of leakages (Lambert *et al.*, 2002).

A correlation exists when a variable either decreases or increases in response to the other variable's behaviour. In the case of the ECONOLEAK model, a graphic curve is the final visual output. On this curve the relationship between the following can be observed; the unavoidable background losses, the base level of background losses, the base level of real losses including reported bursts, the cost of lost water, the cost of active leakage control and the total intervention costs. The numbers required are reflections of the measurements taken based on the aim and objectives of the study. The relationship between the quantitative data is presented in the form of a graph to easily interpret the data.

Objective 1 was to investigate the causes of water leakages and bursts in the Midrand region. To achieve this objective, part 1 and 2 of the model were used. The data derived are collected during

construction, repair, maintenance and various records taken by the water supplier, in this case, Johannesburg Water that supplies water to the study region. The data required is quantitative and is seen in Table 14 below. Unavoidable Annual Real Losses for both the system and basic parameters require background, reported bursts and unreported bursts data for the transmission mains, distribution mains, connections and service pipes in litres/km/day per meter pressure. Lastly, in part 1, is the Infrastructure Leakage Index. The ILI requires the following data in m<sup>3</sup>/year of water supplied to the system, authorised consumption, current total annual water losses, apparent losses in % of the total losses, current annual real losses and UARL.

Information required included the duration and rates of reported bursts and unreported bursts at 50-meter standard pressure. This information is necessary for the transmission mains, distribution mains, connections and service pipes and requires the awareness and location, repair, total days and losses in m<sup>3</sup>/hour. The number of bursts occurring in the year is required for part 2 of the model, for the transmission mains (per km mains/year), distribution mains (per km mains/year), connections (per 1000 connection/year) and service pipes (per 1000 connection//year). The frequency and number of bursts are calculated for each component. The losses from reported bursts and unreported bursts include the number of bursts per year, the duration in days, the rate at 50-meter standard pressure, in m<sup>3</sup>/hr, the average losses in m<sup>3</sup>/day for the transmission mains, distribution mains, connections and service pipes.

Objective 2 was to investigate the costs associated with leak detection and intervention which is addressed by part 3 of the model. Part 3 requires data to calculate the marginal cost of water. The cost of bulk supply, power and chemicals is required for water from both own sources and imported sources along with the highest values recorded. The costs associated with leakage detection is required next and can be found in Addendum 6.

Objective 3 of the study was to determine all bursts associated with the quantification of real and apparent losses in the network. Objective 3 was addressed by part 4 of the model. The unavoidable background losses for leakages and N1 (the leakage exponent) values are calculated. International research has shown that different types of leakage paths have different values of N1, which can range from 0.5 to 2.5 (Lambert *et al.*, 2002). Values of N1 derived from tests on small sectors of distribution systems are usually in the range of 0.5 to 1.5. As N1 is an exponent there is no unit in this case. In this instance, the service reservoirs (% of capacity /day), transmission and distribution mains, connections and service pipes are calculated in l/km/hr at 50m standard pressure.

Base level data for annual real losses are required for the unavoidable background losses, factor for base level losses, total base background losses and losses from reported bursts. Water losses for a number of interventions per year are required for part 4. Storage reservoirs, transmission mains, distribution mains, connections and service pipes water loss data are required in m<sup>3</sup>/year and Rands/year. The total intervention costs at regular intervals can then be calculated by the researcher and inserted into the model. Part 5 of the model incorporates all the data in the model to prepare it for the creation of the final graph and is discussed below as part of the analysis of data. Objective 4 makes suggestions and recommendations to minimise water loss and damages to infrastructure and to propose strategies for effective water supply management. This was achieved by using the graph produced by part 5, literature and questionnaires regarding water leakage intervention.

### **3.2 Data analysis**

The approach taken by ECONOLEAK estimates the volume of water that is lost through leakages in the system of interest. The model works in three main Active Leakage Control situations namely, every 6, 12 or 24 months (Lambert *et al.*, 2002). Once the leakage has occurred, the model then includes intervention strategies which ensure that the leak is detected rapidly and repaired adequately to prevent future leakages.

The value of the water lost is estimated in each of the three scenarios that are chosen and the net cost or the net benefit is then calculated by using the difference in value between the water that is saved and the cost of water leakage intervention. Each calculation involved has been split into various excel sheets with each of the main economic assessments on a separate sheet to make the model more user friendly. The calculations involved require reliable data which should ideally be obtained directly from water suppliers. In cases where unreported bursts have occurred, representative information derived from the likelihood of the occurrence of burst pipes of mains and connections should be collected (Lambert *et al.*, 2002). There is also default values that are provided for instances where water suppliers do not have all the required data.

In Figure 13 below, a summary of the model input parameters is shown. The first part of the model requires simplistic data such as basic system data and the details of the water supplier completing the model. Water utility data is also required as part of the general system data. The model assesses the UARL = Unavoidable annual real losses (litres/day) which are derived in equation (2) below (Lambert *et al.*, 2002).

The ILI is calculated next and requires the amount of water supplied to the system, the apparent losses as a percentage of the total losses and the consumption that has been authorised (Lambert *et al.*, 2002). The water supplied in the form of bulk supply in litres, as well as the authorised consumption, can be obtained directly from the meter or billing records kept by water suppliers. The apparent loss is more subjective and can be indicated by either a stable Management Information System (MIS) system and is in the order of 10% to 20% which reflects as little to no theft or wastage of water. The MIS aids the process of data categorisation making the analysis of apparent losses easier. Quantifying the level of theft can be complicated which is why a percentage reflection is easier to use by the water supplier. This percentage can be closely approximated based on the actual percentage of service delivery and the level of water used by people who have not purchased it through legal means.

Certain areas have a higher amount of total apparent losses which can vary from 50-100% indicating that theft is most likely to occur in these regions (Lambert *et al.*, 2002). Part 2 of the model involves the process of calculating the actual loss of water through bursts and includes the following steps; defining the duration, standard pressure and rates of reported bursts, the number and leakage rates approximated for unreported bursts which can be difficult to detect, the number of reported and unreported bursts on an annual rate basis, the estimated losses from reported bursts at local pressure levels and the estimated losses from unreported bursts depending on the levels of Active Leakage Control. The location, repair time and awareness of the reported bursts influence the time at which the leaks are detected, and intervention occurs. This is included in part 3 of the model which demonstrates that the longer leaks are left unrepaired, the higher the cost of repair. Therefore, the greater volumes of water lost, the greater the financial implications for water suppliers and residents.

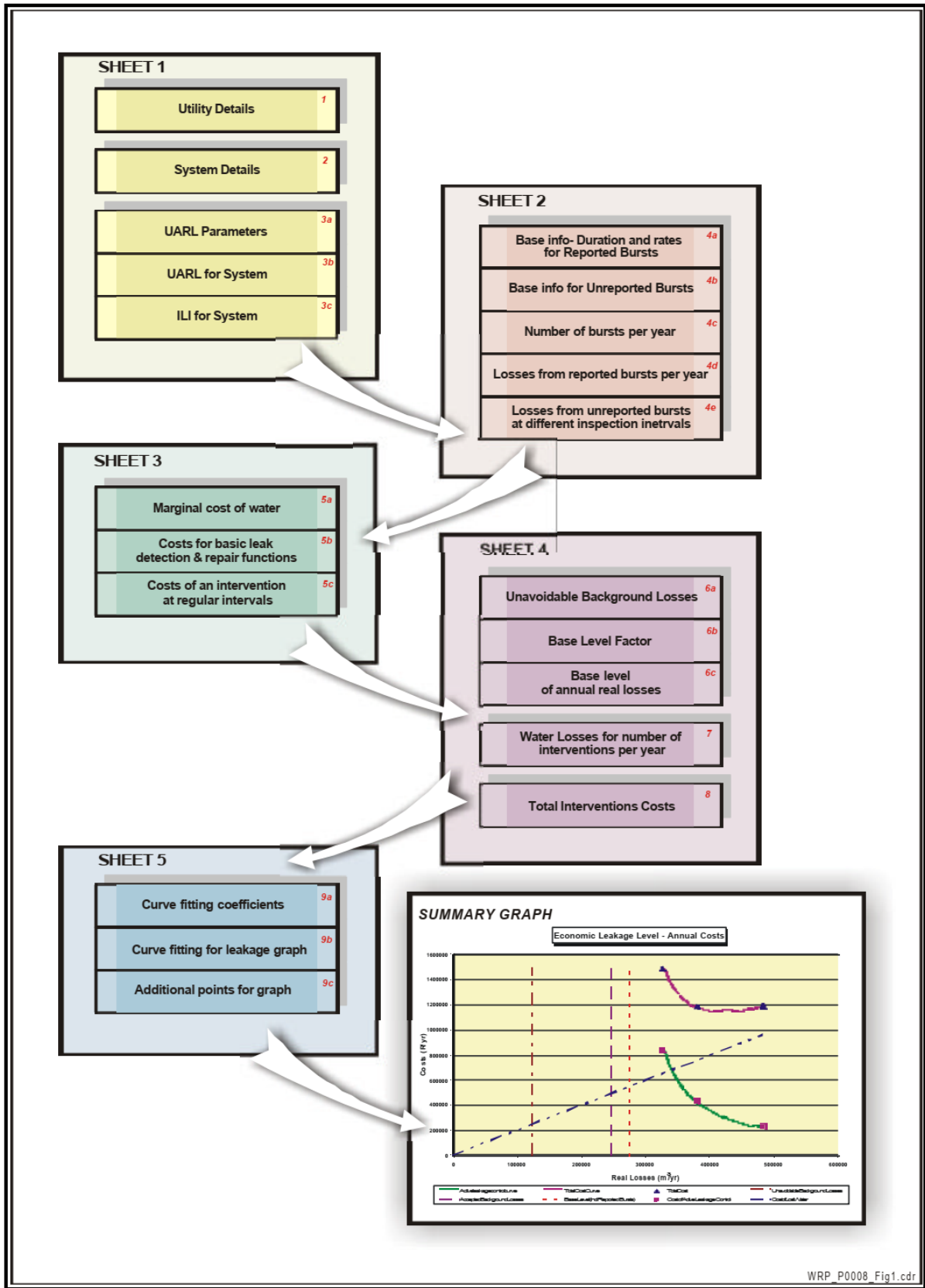


Figure 13. Overview of the ECONOLEAK Model (Lambert et al, 2002).

In order to define the number of reported and unreported cases of burst pipes annually, the number of reported and unreported cases that are known by water suppliers are multiplied by the length of the pipe in meters used to transport water as well as the number of connections involved. To involve the bursts at the local pressure, the values from the previous calculations are used to estimate the losses from the reported bursts. The model uses standard pressure at 50m. The losses thus have to be corrected for the local pressure as the model is based on parameters that are standardised (Lambert *et al.*, 2002). In order to estimate water losses from unreported cases of burst pipes, the duration over which leaks run will depend on the frequency of active leakage control. If a supplier checks the system for leakages that are unreported annually then the average duration of the leak will be 12 months and is also based on the same 12 and 24-month Active Leakage Control scenarios.

The pressure correction can be seen in equation (1) below (Lambert *et al.*, 2002).

$$FlowP_2 = FlowP_1 \times P_{CF}$$

Where:

**Equation 1**

$P_1$  = Pressure 1 (m)

$P_2$  = Pressure 2 (m)

$FlowP_1$  = Flow at pressure P1 (m<sup>3</sup>/h)

$FlowP_2$  = Flow at pressure P1 (m<sup>3</sup>/h)

$P_{CF}$  = Pressure correction factor =  $(P_1/P_2)^{pow}$

pow = Power exponent.

Part 4 of the model deals with the economic loss associated with water loss. The objectives of the integration of economic loss into the loss of water are ensured when water suppliers are aware of the importance of preventative measures. The cost will also include active leakage control measures. The process is streamlined by including; the marginal cost of water, the unit costs for leakage detection activities and costs associated with Active Leakage Control activities. The marginal cost of water is calculated from the purchase price from the water supplier. Johannesburg Water is the representative Water Board for the Halfway House region. In certain instances, water suppliers may store and treat raw water. The unit costs for leakage detection activities are flexible for the water supplier information. This is because several rows in the provided excel sheet are open/available for the user to include their own items and assign their own individual rates.

Individual rates include the supervision as a percentage of inspection costs which depends largely on the discretion of the water supplier (Lambert *et al.*, 2002).

Further objectives of part 4 include the usage of previously obtained information and calculates the cost of intervention for the three Active Leakage Control scenarios and includes; the calculation of unavoidable losses, determining base levels of annual real losses, calculations of the water losses that occur at each active leakage control level and to calculate the total intervention required for all three active leakage control scenarios (Marunga *et al.*, 2006). Background losses are separated into unavoidable losses and those that are avoidable. This helps the water supplier with planning the mitigation of avoidable losses. In instances where active leakage control influences only the burst leakages, the background leakage will remain unaffected. The background leakage must thus be calculated first. The calculated unavoidable background losses only provide a theoretical minimum level at which the background losses can be achieved. Lambert *et al.* (2002) derived a factor of 2 to be appropriate for significantly good conditioned infrastructure whereas areas with worse infrastructure conditions and lower payment levels will require a factor of 5 and greater, (Lambert *et al.*, 2002). The background losses are then measured at the estimated burst losses which will result in the base level of all real losses that are included in the study.

The last calculation in part 4 is the total intervention for active leakage control. Active leakage control is important to help water suppliers determine which is the most appropriate and cost-effective intervention to apply to a water leakage scenario. Part 5 and 6 of the model requires information for the generation of the final graph depicting the ECONOLEAK model output. The parameters already entered thus far will be used to generate the curve. Part 5 encompasses the calculations which led to the final output for the curve. Based on the information provided in the previous parts of the model, six items of interest are generated and will be depicted on the curve. These items are namely: the unavoidable background losses, the base level of real losses which include reported bursts, the actual cost of the loss of water, the active leakage control and the total costs of intervention.

The curve will depict the total cost for intervention and indicate the minimum cost between the 6 and 24-month intervention periods. The total costs generally level out between a 12 and 24-month period as observed from previous studies (Hoko *et al.*, 2017). The curve will also indicate whether the costs increase or decrease depending on the active leakage control periods. The graph can also become asymptotic to represent a certain level of real losses that is impossible to prevent. The economic level of leakage is represented by the point at which costs of water and active leakage control converge as seen in the figure below.

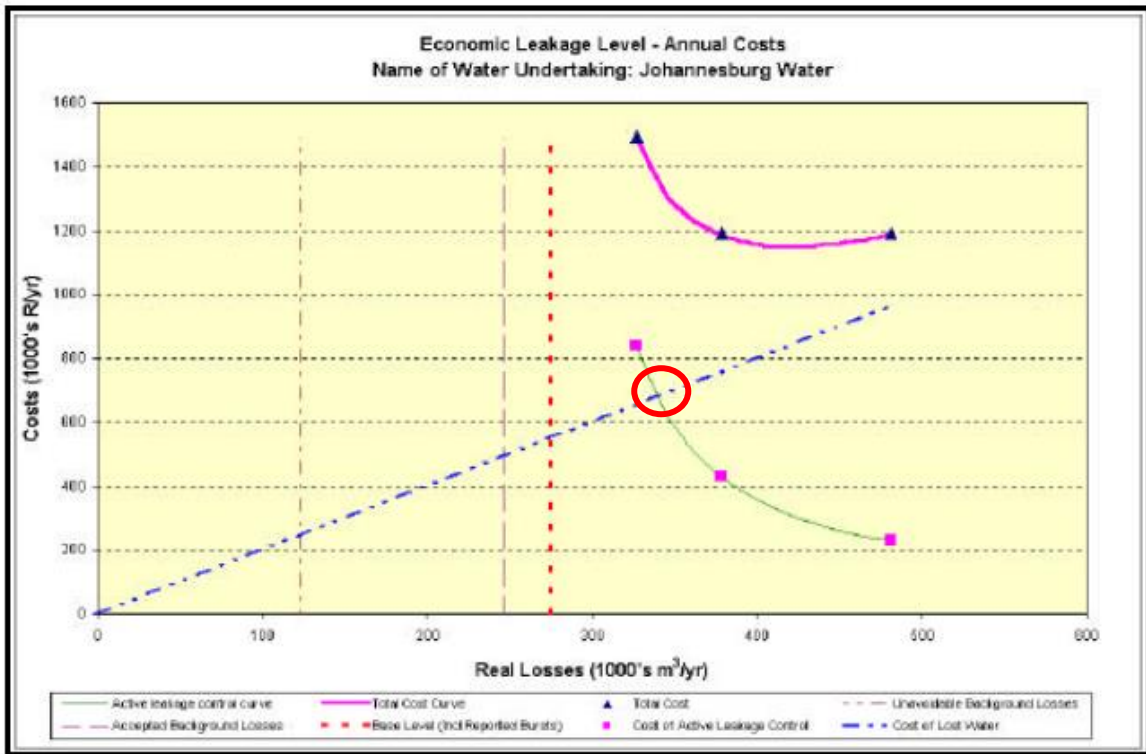


Figure 14. Example of the annual costs graph (Lambert *et al.*, 2002)

### 3.3 Calculations performed in the ECONOLEAK Model

#### 3.3.1 Part 1: General information and calculation of Unavoidable Annual Real Losses and Infrastructure Leakage Index

The calculations performed in each part of the model are provided in more detail in Addendum 1 and were derived from the ECONOLEAK Model created by Lambert *et al* (2002) , through the Water Research Commission (Lambert *et al.*, 2002)

##### System data

In part 1 of the model, the system data that is required is straight forward with most of the data provided directly by the water supplier as shown in Table 14 in Chapter 4.

##### Unavoidable Annual Real Losses (UARL): Basic Parameters

Data for this section about background, reported and unreported bursts is obtained from the water supplier for the transmission and distribution mains, connections and service pipes. The loses from the distribution components is summed to get real losses in litres/km/day/m pressure (see Addendum 6). To arrive at the UARL, equation (2) below (Lambert *et al.*, 2002) is applied

$$UARL = (18 \times Lm + 0.80 \times Nc + 25 \times Lp) \times P$$

**Equation 2**

Where:

$UARL$  = Unavoidable annual real losses (l/d)

$Lm$  = Length of mains (km)

$Nc$  = Number of service connections (main to the meter)

$Lp$  = Length of unmetered underground pipe from street edge to customer meters (km)

$P$  = Average operating pressure at average zone point (m)

These values are then converted from litres/ second to m<sup>3</sup>/hour, m<sup>3</sup>/day and m<sup>3</sup>/year (as seen in Addendum 1).

#### Infrastructure Leakage Index (ILI)

A theoretical minimum level of leakage of 2 is indicative of a well-managed system with low leakage incidents while a minimum level of 10 represents a system that is poorly managed and prone to leakage. The ILI is calculated as seen in equation 3 below (*Lambert et al., 2002*):

$$ILI \frac{CARL}{UARL}$$

**Equation 3**

Where:

$CARL$  = Current Annual Real Losses, the real losses for the period under consideration expressed in terms of l/conn/d or m<sup>3</sup>/year etc and later calculated using Equation 4 below.

*Current Annual Real Losses CARL = Water Losses – Current Annual Apparent Losses (CAAL)*

**Equation 4**

### **3.3.2 Part 2: Losses from reported and unreported bursts**

#### Duration for reported bursts at 50m standard pressure

The awareness and location as well as the repair time are recorded in days and must be entered into the model by the water supplier using their records. The model then calculates the total days that are used to find and repair the burst. The losses in m<sup>3</sup>/hour must be filled in by the water supplier.

Basic information on unreported bursts at 50m standard pressure

The unreported bursts are expressed as a percentage of the reported bursts, the N1 value for bursts as well as the losses are all required by the water supplier. Different types of leakage paths have different values of N1 (Pressure (P) to the power N1), which can range from 0.5 to 2.5 (Lambert et al., 2002). Values of N1 derived from tests on small sectors of distribution systems are usually in the range of 0.5 to 1.5. In this instance, the N1 values for the service reservoirs, transmission and distribution mains, connections and service pipes are calculated using equation (5) below derived by (Lambert *et al.*, 2002).

*L varies with  $P^{N1}$*

**Equation 5**

Number of bursts per year

The frequency of bursts per year is given by the water supplier. The number of bursts is then calculated for each distribution component (transmission mains, distribution mains, connections and service pipes) as per the equation below:

Transmission and distribution mains:

*Number of bursts = Length of mains × frequency of bursts*

**Equation 6**

Connections and service pipes

*Number of bursts = Number of service connections × frequency of bursts ÷ 100*

**Equation 7**

Losses from reported bursts (adjusted for local pressure)

The number of bursts per year, the duration days of the burst, as well as the rate of losses per hour of adjusted local pressure, are used to calculate the average losses in m<sup>3</sup>/day as seen below.

*Losses from reported bursts =*

*Number of bursts per year × duration days of the burst × 24 m × rate of loss  $\frac{m^3}{hour} P^{N1} / 365$*

**Equation 8**

Losses from unreported bursts at regular inspection intervals (adjusted for local pressure)

In this section, losses can be calculated for temporal scales of 24, 12, and 6 months.

Every 24 months:

$$\text{Losses from unreported bursts every 2 years} = \text{Average losses} \frac{m^3}{\text{day}} \times 365 + \text{repair time}$$

**Equation 9**

Every 12 months:

$$\text{Losses from unreported bursts every year} = \text{Average losses} \frac{m^3}{\text{day}} \times \frac{365}{2} + \text{repair time}$$

**Equation 10**

Every 6 months:

$$\text{Losses from unreported bursts every 6 months} = \text{Average losses} \frac{m^3}{\text{day}} \times \frac{365}{4} + \text{repair time}$$

**Equation 11**

### **3.3.3 Part 3: Costs of water and intervention costs**

The marginal cost of water

The marginal cost of water includes the amount of bulk supply of imported water or the amount from the water supplier's own sources. It also includes the amount used for power and chemicals in the water distribution system that is from either imported or own sources. These values must be sourced directly from the water supplier.

Costs for leak detection

These costs include; cost for regular sounding per km, percentage coverage required for correlation, the cost for correlation per km, supervision as a percentage of inspection costs, measuring minimum night flows, administrative set up costs, the cost to repair mains and the cost to repair the service/connection leak. These values must be sourced directly from the water supplier as seen in Addendum 6.

Costs of intervention at regular intervals

These costs are calculated for every 24 months, every 12 months and every 6 months. To get the amount of every 24 months, the value is divided by 2, the value is divided by 1 for every 12 months and divided by 0.5 for every 6 months.

Administrative set up costs= *Administrative cost* ÷ 2

**Equation 12**

Manpower inspection costs=

(*Cost for regular sounding per km*

+ (*% coverage required for correlation*) × *cost for correlation per km*)

× *Total length of mains/2*

**Equation 13**

Supervision costs= *Manpower inspection costs* × *supervision as % of inspection costs*

**Equation 14**

Mains repair costs=

*Number of unreported bursts per year (transmission and distribution mains)* ×  
*cost to repair mains leak*

**Equation 15**

Connection repair costs=

*Number of unreported bursts per year (connections and service pipes)* ×  
*cost to repair services or connection leakages*

**Equation 16**

The total costs are then calculated by the addition of all the answers to the calculations seen above.

### **3.3.4 Part 4: Financial analysis for active leakage control**

*Unavoidable background losses (adjusted for local pressure) in m<sup>3</sup>/day*

Transmission mains=-

*Unavoidable background leakage* × *length of transmission mains* × 24 (*P<sup>N1</sup>/1000*)

**Equation 17**

Distribution mains=

*Unavoidable background leakage* × *length of distribution mains* × 24 (*P<sup>N1</sup>/1000*)

**Equation 18**

Connections=

$$\text{Unavoidable background leakage} \times \text{number of service connections} \times 24(P^{N1}/1000)$$

**Equation 19**

Service pipes:

$$\text{Unavoidable background leakage} \times \text{number of service connections} \times 24 (P^{N1}/1000)$$

**Equation 20**

Service reservoirs:

$$\text{Unavoidable background leakage Total volume of Storage Reservoirs in the System} \times 10$$

**Equation 21**

Base level of annual real losses

A= Base level of background losses m<sup>3</sup>/day

B=-Total background losses for bursts m<sup>3</sup>/day

C= Losses for interventions m<sup>3</sup>/day

**Table 5.** Base level for annual real losses

Component	Equations (m <sup>3</sup> /day)
Storage Reservoirs	<b>Equation 22</b>
	(A + B) for storage reservoir
Transmission Mains	<b>Equation 23</b>
	(A + B) for transmission mains
Distribution Mains	<b>Equation 24</b>
	(A + B) for distribution mains
Connections	<b>Equation 25</b>
	(A + B) for connections
Service Connections	<b>Equation 26</b>
	(A + B) for service connections

Water losses for a number of interventions per year

The total calculated previously for the storage reservoirs remains the same.

**Table 6.** Water losses for number of interventions per year

Component	24 months	12 months	6 months
Services reservoirs	$B$	$B$	$B$
Transmission mains	<b>Equation 27</b>	<b>Equation 28</b>	<b>Equation 29</b>
	(A + C) (24 months)	(A + C) (12 months)	(A + C) (6 months)
Distribution Mains			
Connections			

The sum of all the data is calculated for every 24 months, every 12 months and every 6 months and is then converted to m<sup>3</sup>/year.

The total intervention cost is then calculated in Rands/year:

Total cost= *Highest marginal cost of water water losses for number of interventions per year*  
**Equation 30**

Total intervention costs

The total intervention costs for every 24 months, every 12 months and every 6 months are derived from part 3 and the cost of losses are calculated as seen above. The sum of the intervention cost and losses are calculated by the model.

**3.3.5 Part 5 and 6: Curve fitting information and a summary graph of intervention costs against savings**

Curve fitting for intervention costs and leakage costs compared

$L_{one}$ ,  $L_{two}$  and  $L_{three}$  are the total water losses for a number of interventions for every 6 months, every 12 months and every 24 months respectively and takes the total in m<sup>3</sup>/year.  $L_b$  is the base level of annual real losses and includes the total annual real losses in m<sup>3</sup>/year.

$C_1$ ,  $C_2$  and  $C_3$  are the total costs of intervention for every 6 months, every 12 months and every 24-month interval in Rands.

**Table 7.** Curve fitting for intervention costs and leakage costs compared

<b>Equation 31:</b> $L_1 - L_b = L_1$	<b>Equation 32:</b> $L_2 - L_b = L_2$
<b>Equation 33:</b> $L_3 - L_b = L_3$	<b>Equation 34:</b> $L_3 - L_2$
<b>Equation 35:</b> $L_2 - L_1$	<b>Equation 36:</b> $L_2^2 - L_1^2$
<b>Equation 37:</b> $L_3^2 - L_2^2$	<b>Equation 38:</b> $C_1 L_1$
<b>Equation 39:</b> $C_2 L_2$	<b>Equation 40:</b> $C_3 L_3$
<b>Equation 41:</b> $C_3 L_3 - C_2 L_2$	<b>Equation 42:</b> $C_2 L_2 - C_1 L_1 = 1.5305E^{10}$

#### Curve fitting for the leakage graph

Curve fitting is performed to ensure the graph represents data that is easily understandable and can be interpreted. Once curve fitting has taken place, the values calculated are used in a table which contains values used in the graph. All procedures in fitting the curve can be accessed in the ECONOLEAK Model (<http://www.wrc.org.za/knowledge-hub/e-tools/>).

### 3.4 Questionnaire design and distribution

The purpose of this section is to investigate the causes of water leakages and bursts in the study area with the intention of analysing data and proposing recommendations for better management of the water distribution network based on input from the residents who live in Region A.

Prior to the distribution of questionnaires, ethical clearance from the University of Pretoria, Department of Natural and Agricultural Sciences had to be obtained (Refer to Addendum 4 for proof of ethical clearance). In obtaining ethical clearance, various other permissions from the participants had to be obtained. Firstly, consent from the custodian of data and manager of the Johannesburg Water Midrand Depot offices had to be obtained. Mr Akani Shibambu is the custodian of the data and the manager of the Johannesburg Water Depot in Region A. He granted permission and signed a permission letter attached as Addendum 2A and Addendum 2B that allowed the distribution of questionnaires to the rest of the targeted employees. Secondly, permission from complex representatives was obtained after meetings with the various chairpersons were conducted. Once all permissions were obtained, the questionnaires were distributed in the sample area shown in Figure 3.

Furthermore, only the employees at the Johannesburg Water Depot that deal with water distribution and associated problems are participants in this study. Their insight and in-depth knowledge regarding the mitigation and management of water leakages is beneficial in addressing the objectives and the aim of this study. One complex per study area as seen in Figure 3 was chosen to ensure a good distribution of the data. The complexes chosen are; Pacific Gardens, Waterfall Estate, San Bernadino, Carlswald Manor, Erand Gardens, Kyalami Estate, Tallyns and Crescentwood Country Estate and are found within the areas listed above. The permission obtained from the complex representatives is attached as Addendum 3A to Addendum 3H.

### **3.4.1 Sample selection and distribution**

The definitive test of a sample design is how well it represents the features of the population that it purports to represent. In measurement terms, the sample must be valid. The validity of the sample depends on the accuracy of the sample which depends largely on the degree of bias present and the precision of the sample and the estimate (Semykina *et al.*, 2018). In non-probability sampling, the researcher does not have any way of guaranteeing or forecasting that each element of the population will be represented in entirety by the sample (Walliman, 2017).

This study has two groups of participants. The first group is known as the informants and are the employees at the Johannesburg Water Midrand Depot. The inclusion criteria are the employees working with water distribution, leakages, shortages and management of the impacts associated with water leakages. The exclusion criteria comprise of those employees that work at Johannesburg Water but are not involved with water leakages and distribution. The estimated literacy level of the informants is high, and some level of understanding of water leakages and management is expected of the informants. Participants who work with water leakages in the Johannesburg Water depot in Midrand will be recruited through non-probability sampling. The non-probability sampling technique that will be used is purposive-judgment sampling as employees dealing with water leakages are chosen. The employees will be chosen based on their association with water leakages in Johannesburg Water.

The second group of participants are the residents that are supplied by the water provided by the Johannesburg Water depot. These participants are also regarded as informants. The inclusion criteria for this group of informants requires them to be residents within the Midrand region and over 18. This ensures the accurate description of the impact experienced by the resident. Residents that are living outside of the sample area and, residents that are not over the age of 18 or do not live in the house in which the questionnaire was administered are excluded. Participants

who live in the study area are recruited through non-probability sampling. Regions, where the Johannesburg Water Midrand depot supplies water to, were identified as mentioned earlier and complexes in these regions were targeted for the administration of the questionnaires. The non-probability sampling technique that will be used is the convenience sampling method.

### **3.4.2 Sample size**

The respondents for this study included a sample size of 100 residents in the chosen study area. The other group of participants are the employees of Johannesburg Water who work primarily with the water distribution system and leakages in the network. The chosen sample size in this group was 10 as the Johannesburg Water Depot in Midrand is small in terms of size and employees.

### **3.4.3 Data Collection**

Initially, for the purpose of this study, a combination of face-to-face interviews discussing the questionnaire was to be conducted with the participants as listed in the sample frame. This data collection method did not deliver the required sample size as people had restricted time limits. An online questionnaire was therefore compiled because of the limited resources and time factor to complete the study. Due to the limited e-mail availability of participants, 100 of the questionnaires were administered in the form of hard copies while 30 of the questionnaires were accessed by participants in the form of an electronic link to the online version of the questionnaire. To ensure effective distribution of the online questionnaire, the links were added to WhatsApp groups to ensure that more than one person receives the link at a time. There were 10 hard copy questionnaires that were administered to the water suppliers.

### **3.4.4 Questionnaire design**

The collection of primary data relied totally on a standardised schedule or questionnaire. According to Cooper (2012), questionnaires have three categories of measurement namely: 1) target questionnaires (structured or unstructured), 2) classification questions and 3) administrative questions (Cooper, 2012). Administrative questions identify the interviewer, interview location, and conditions and are usually rarely asked of the participant. These questions become necessary when patterns within the data are required as well as any possible sources of error. Classification questions usually cover sociological demographic variables which allow the participant's answers to be grouped which further reveals patterns in the data. These questions can determine whether a participant has the necessary level of knowledge to participate. Target questions address the investigative questions of a specific study. These are grouped by topic in the survey. Target

questions may be structured (they present the participant with a fixed set of choices often called closed questions) or unstructured (do not limit responses but do provide a frame of reference for participants answers sometimes known as open- ended questions (Cooper, 2012).

Using a combination of the above-mentioned categories of measurement, the questionnaire was compiled in accordance with the aims and objectives of this study. The questionnaire consisted of open-ended questions, close- ended questions, forced choice questions and scaled or ranked questions. Open-ended questions offer the respondents an opportunity to provide their own evaluation or answers to the questions posed. This technique is used to maximise the respondent's perceptions and to minimise the influence of the researcher's perceptions on the respondents. Where close ended questions are posed, the study provides a list of possible responses that the respondent can select. Close-ended questions deal with specific issues and are used to simplify or evoke a response by giving the answer to the questions by a simple YES or NO. Forced choice questions involved the respondents selecting from given alternatives. In certain instances, respondents were permitted to choose more than one alternative. With regards to the scale or ranked questions, interviewers have to choose responses that resonate with their viewpoint. Scales or number systems can be used but it must be noted that not all scales capture the same intensity of measure. These techniques have been applied in Section 2.5 by Hoffman (2016) who identified water leakages and pipe bursts as one of the main contributors to water supply shortages by using data obtained from questionnaires (Hoffman DJ, 2016).

#### **3.4.5 Pilot Study**

A researcher may sometimes need to do a brief exploratory investigation or pilot study to investigate procedures, measurement instruments, or methods of analysis. A brief pilot study is an excellent way to determine the feasibility of the study (Arain *et al.*, 2010). The pilot study was conducted with ten respondents from the sample group. All the relevant changes and feedback were incorporated into the final development of the questionnaire.

#### **3.4.6 Final Questionnaire**

The final questionnaire was formulated from the study's literature review and research objectives. Refer to Addendum 5A for the questionnaire administered to the water suppliers and Addendum 5B for the questionnaire administered to residents.

Table 8 and 9 below illustrate the key sections and components of the final questionnaire and the types of questions are also included.

**Table 8.** Key components of the questionnaire for the water suppliers

Components of the questionnaire		Measurement questions
Section 1	Employment information	Administrative questions
Section 2	Socioeconomic data	
Section 3	Water leakages	Target questions
Section 4	Cost associated with water leakages	
Section 5	Water shortages	
Section 6	Impact of water leakages and shortages	
Section 7	Leak detection	

**Table 9.** Key components of the questionnaire for residents

Components of the questionnaire		Measurement questions
Section 1	Residential data	Administrative questions
Section 2	Socioeconomic data	
Section 3	Water leakage perceptual and attitudinal assessment	Target questions
Section 4	Cost implication and mitigation of water leakages and shortages	
Section 5	Notification of pipe bursts	
Section 6	Impact of water shortages	
Section 7	Billing systems	

### 3.4.7 Administration of questionnaires

The questionnaire was administered to 130 sample units in the residential sample population frame while 10 sample units were administered to the water supplier. The administration process is outlined in Table 10 below.

**Table 10.** Administration of questionnaires

<b>Step</b>	<b>Process</b>
1	Establish contact with key stakeholders from the sample frame in order to get the required permission to administer the questionnaire. Key stakeholders were the chairperson of each complex and the custodian of the Johannesburg Water data.
2	Emails were then sent out to the targeted population sample who agreed to participate in the research study.
3	Questionnaires and cover letters were sent out to explain in detail the purpose of the study and instructions on completing and returning the questionnaire. An electronic link containing the questionnaire was also provided to residents who were willing to provide their email address or cellphone number.
4	Follow-up communication was undertaken as reminders to complete the questionnaire.

### **3.4.8 Data analysis**

#### **3.4.8.1 Level of measurement**

The questionnaire administered to residents and water suppliers consisted of questions that encompass interval, ordinal and nominal scales. Descriptive statistics were used to analyse the data and was displayed in terms of frequencies, mean, median, mode, range, standard deviation and variance.

The nominal scale is the first level of measurement and is also used as a categorical scale to assign a value to an object for classification purposes. Calculations are not generally performed in the instance of nominal scales as no quantities are expressed in this category. The second level of measurement also known as the ordinal scale represents descriptive qualities and allows an order to be established. Once again, calculations cannot be performed on ordinal scales due to the lack of origin of scale. Ordinal scales are formed based on the intrinsic value of the concept put forward. The third level of measurement is the interval scale which has both ordinal and nominal characteristics. The interval scale is one of numerical value as the variables are often known and the differences between the variables can be calculated. Those variables with similar characteristics are classified in the interval level of measurement.

Statistical analysis can be performed on this type of scale to reveal data such as the mean, median and mode. The fourth level of measurement is known as the ratio scale which identifies the difference in variables. The ratio scale is calculated by offering the option of a zero value. The ratio scale can also identify the order of variables in the scenario (Zikmund *et al.*, 2013). Table 11 below depicts the levels of measurements that were used in the study and during the compilation of questions that were administered to the residents and water suppliers.

**Table 11.** Levels of measurement used in the study (Cooper *et al.*, 2011)

Measurement scale	Characteristics of data	Basic operation	empirical	Used in this study
Nominal	Classification (mutually exclusive and collectively exhaustive), but no order, no distance, or natural origin	Determination of equality	of	Yes
Ordinal	Classification and order	Determination of greater or lesser value	of	Yes
Interval	Classification, order and distance	Determination of equality of intervals or differences	of	Yes
Ratio	Classification, order, distance and natural origin	Determination of equality of ratios	of	No

#### 3.4.8.2 Data preparation

Data preparation is an important step in the analysis of data. It involves not only the entry of data but also the coding and editing of data. Data preparation ensures that the data is accurate and viable for analysis while the conversion from raw data to classified data is done correctly. The first step performed was the editing of data which involved the identification of omissions and errors. During this step in the process of data analysis, errors can be corrected if possible, which ensures that data quality standards remain high. The researcher coded the closed and open-ended responses by assigning numbers to the responses which grouped the answers into selected categories. Open-ended question responses were coded and recorded in electronic format for retrieval upon request.

#### 3.4.8.3 Data interpretation

The Statistical Package for the Social Sciences (SPSS) was used to perform data processing. Functions of the SPSS include information storage and retrieval, data modification and programming, report writing, statistical analysis and electronic storage. The statistical analysis

procedures in the SPSS system ranges from simple descriptive statistics to multivariate techniques. Data obtained in this section include frequencies, mean, standard deviation, range, maximum and minimum. Multiple response questions were also derived and were expressed in the highest percentages for each case.

Cross tabulation and Fisher's Exact Test were used to establish the classification of one variable of a nominal and ordinal scale and the relationship established in relation to another variable on the same nominal and ordinal scale. Cross tabulation allowed the comparison of data from two or more categories once the data was grouped. Fisher's Exact test of statistical significance was used for the categorical data and examined the association between the types of classification in the cross tabulations. The probability value (p-value) determined whether the null hypothesis can be accepted or rejected. The standard level of significance used for Fisher's Exact test of statistical significance is 0.05. If the p-value is greater than 0.05, the null hypothesis cannot be rejected and there is no association between the categorical data. If the p-value is less than 0.05 then the null hypothesis can be rejected, and an association is present.

This study relied on the SPSS programme for data processing and the application of statistical procedures. The results and analysis generated by the programme are presented in chapter 4. Refer to Addendum 7A for the results from frequency testing and addendum 7B for the results from the cross tabulation.

## Chapter 4- Results and discussion

### 4.1 Demographics of the study area

Descriptive statistical analysis techniques were used in this part of the study. During the analysis, the body of data is described using frequency graphs and tables illustrating key findings of the analysis. The demographics of the research questionnaire is presented in this section along with the data obtained regarding pipe bursts and leakages.

#### 4.1.1 Response rate

A high response rate is important in ensuring that the research is representative because it gives the reader an understanding of the scale, the scope and the validity of the research (Quinlan, 2011).

Table 12 below shows the response rate for this study.

**Table 12.** Response rate from residents and water suppliers

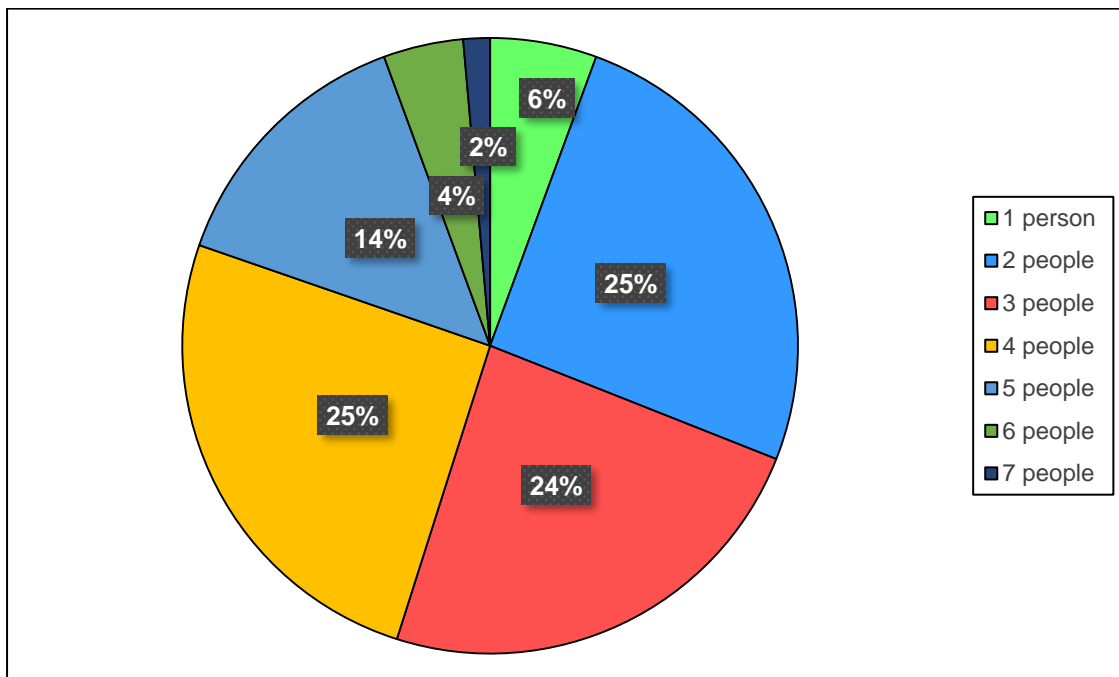
	Sample frame	Planned response (%)	Actual response (%)
<b>Response rate from residents</b>			
Number of respondents	130	65 (50%)	72 (55%)
<b>Response rate from water suppliers</b>			
Number of respondents	10	5 (50%)	2 (20%)

With regards to Table 12 above, no random sample error is observed for the residents. as the researcher managed to increase the sample size as opposed to the planned number of 65 respondents. However, a random sample error for water suppliers was realised as the researcher encountered a decrease in sample size.

Demographics of the study area included employment information, gender distribution and tenure of households. Information from the following residential complexes found in the study area namely; Pacific Gardens, Waterfall Estate, San Bernadino, Carlswald Manor, Erand Gardens, Kyalami Estate, Tallyns and Cresentwood Country Estate is also summarised in Figure 16-18 below. Many households (about 74 %) as seen in Figure 15 have 2 - 4 people and only 2% had 7 members in a household. The lowest number of females recorded for households was 0 and the

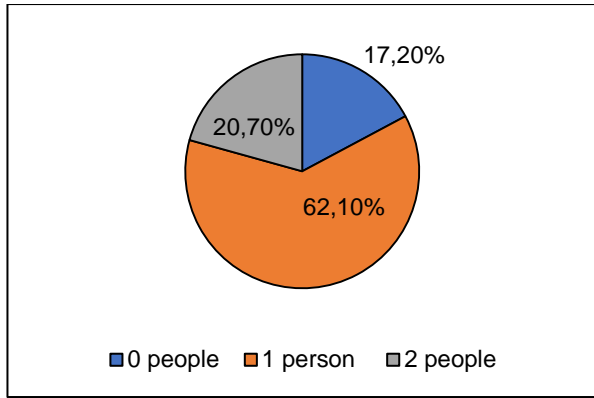
highest number of females recorded in households was 4. The lowest number of males in a household was recorded as 1 and the maximum number of males in a household was 4. Further analysis based on gender shows a mean of 1.7 for male and female and a standard deviation between 0.793 and 0.969 for male and female respectively.

In this case, data for male and female shows that the standard deviation was not spread out far from the mean and hence the level of range in gender was low as recommended by (Malec, 2018).

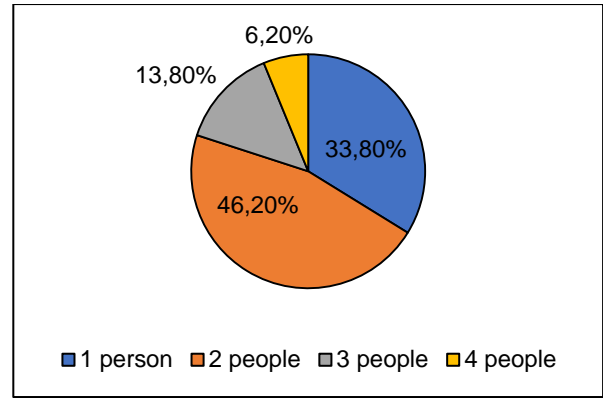


**Figure 15.** Showing the valid percentage of residents in households found in the study area.

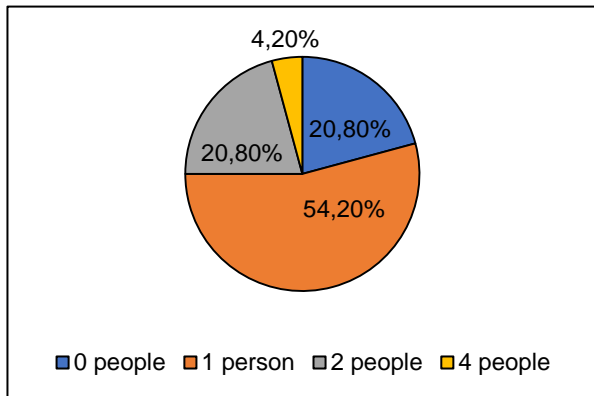
In order to run a household and its needs, the study investigated the employment status for the residents. Figure 16 to Figure 18 below shows a breakdown by percentage of those self-employed, employed and unemployed residents within households.



**Figure 16.** Percentage of residents that are self-employed.



**Figure 17.** Percentage of residents that are employed.



**Figure 18.** Percentage of residents that are unemployed.

**Table 13.** Tenure, type of dwelling and length of stay in the household

Tenure	Percentage (%)
Owner	66.2
Rental	26.8
Lease hold	5.6
Other	1.4
<b>Type of dwelling</b>	
Single storey	52.9
Double storey	42.9
Outbuilding (garage, etc)	1.4
Other (please specify)	2.9
<b>Length of stay in the household</b>	
Less than one year	12.7
1 - 5 years	52.1

6 - 10 years	15.5
11 - 15 years	7.0
16 - 20 years	5.6
More than 20 years	7.0

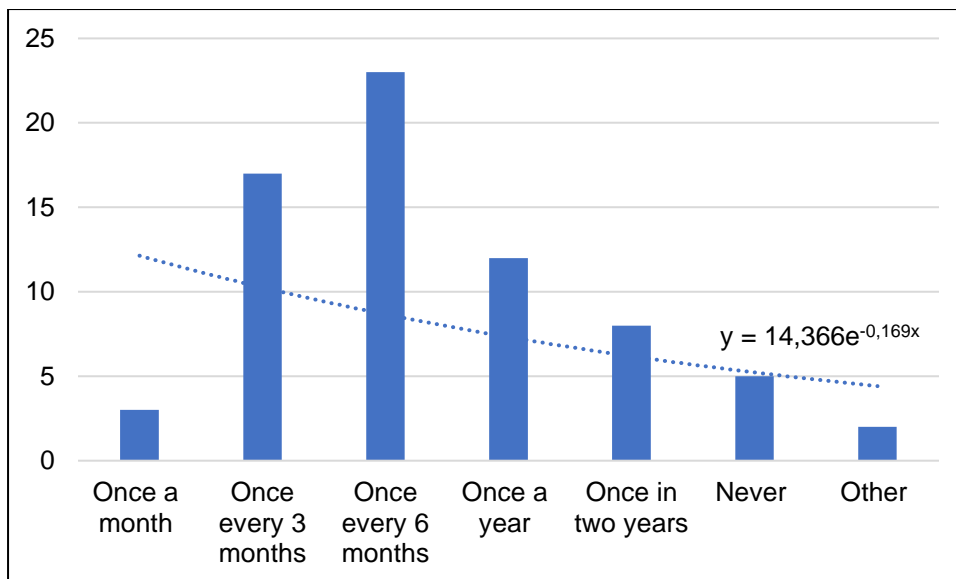
The following information was derived from Table 13 above.

Majority of residents are the owners of the household that they reside in while the minority fall within the lease hold category. Majority of residents live in s single storey houses while the minority of residents live in outbuildings. Most residents have lived for 1-5 years in their current household while a smaller group of residents have lived in their household for 16-20 years. This implies that residents in Region A do not live in their houses for long periods of time and move before 5 years have passed.

It must be noted that limited information was obtained from the water supplier due to the sample size and number of respondents being low. This resulted in insignificant demographic values obtained from frequency testing using the SPSS package.

#### **4.2 Water leakage assessment**

In Region A, 83.1% of residents have experienced water leakages or a burst pipe while living in the area, whereas 16.9 % of residents living in Region A did not experience water leakages. This means that a big percentage of the sample size experienced leakages implying that it is a significant issue in the region. Findings reveal that a percentage of annual real losses occur in distribution mains (24%) and connections (70,7%). This was established through monitoring programmes and site visits conducted by the water supplier along the distribution network.



**Figure 19.** Frequency of bursts experienced by residents.

Respondents were asked to select how often they personally experience pipe bursts. Results of their experience are shown in Figure 19 above. Residents indicate to have experienced at least a burst every 6 months. The trend shows a gradual decrease with time, with the lowest being once a month. According to the statistical evidence received from residents, the 6-month interval of leakage intervention supported by the ECONOLEAK Model is appropriate and cost effective. However, due to the number of leakages recorded directly by the water supplier, a 4-month leakage intervention interval is what they operate on because there are leakages that residents are not aware of due to unreported bursts. Cross tabulation was performed to establish whether there was a relationship between the lengths of stay of residents who reported bursts in the study area and the frequency of pipe bursts experienced.

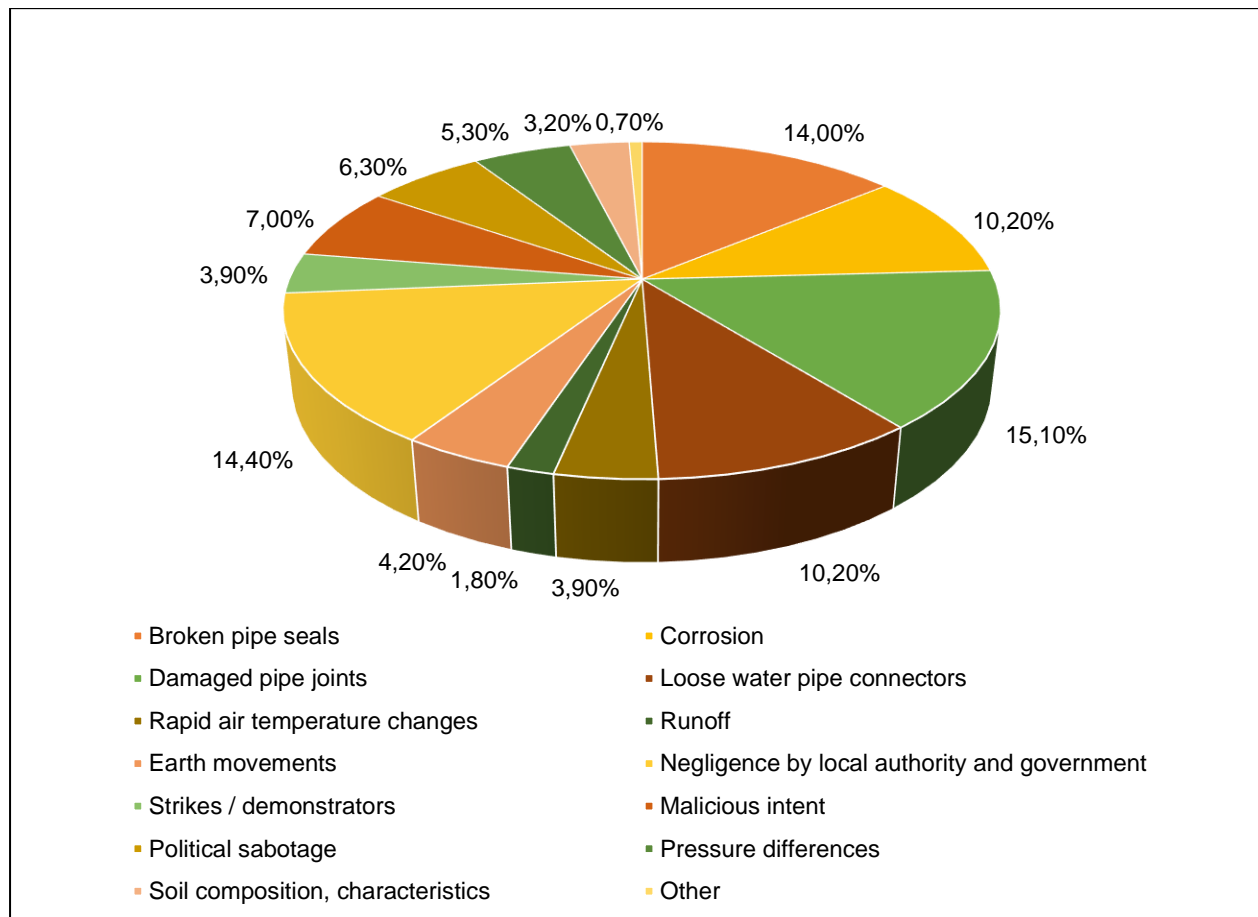
***Relationship between the lengths of stay of residents in the study area and the frequency of burst pipes experienced:***

H<sub>0</sub>: There is no association between the lengths of stay of residents in the study area and the frequency of burst pipes experienced

H<sub>1</sub>: There is an association between the lengths of stay of residents in the study area and the frequency of burst pipes experienced

The resultant p-value of 0.858 was more than the 0.05 level of significance. Therefore, the null hypothesis cannot be rejected while the alternative hypothesis can be rejected. There is no significant association between the length of stay of residents in the study region and the frequency

of burst pipes experienced. This relationship also tells us that it is not about how long you stayed that lessened the bursts, nor is it that bursts are reported by the same people given the fact that the majority of the respondents have stayed in the area for 1-5 years. Rather bursts occur due to other reasons especially along the connections which make up the biggest component in the distribution network.



**Figure 20.** Shows causes of water leakages in Region A as described by residents.

In Figure 20 above, damaged pipe joints were the most selected reason for water leakages amongst residents. They also identified negligence by local authorities and government as well as broken pipe seals as other main causes. Runoff was the least selected option for causes of water leakages along with soil composition and characteristics, rapid air temperature changes and strikes/demonstrators. This could be attributed to their level of technical understanding of distribution mechanisms. According to water suppliers, the reasons that pipe bursts occur most frequently in Region A is due to intruding tree roots, rapid temperature changes and pressure differences. The water supplier works with the system daily and conducts maintenance and monitoring which allows them to understand the cause of the leakage from more than a perceptual viewpoint but rather an overall technical viewpoint.

A major objective in water leakage management is to ensure the proper maintenance and operation of infrastructure to reduce the cost of mitigation and the impact on the surrounding environment (Aboelnga *et al.*, 2018). Within the context of urbanisation, problems of water supply and leakages are ever increasing as man's need for water and land is growing continuously. Therefore, the design and location of infrastructure such as pipelines, reservoirs and dams along with the planning of residential areas depend on the provision of water supply and the cost to supply water effectively. In this regard, the generation of cost due to water leakages can yield accurate information for water suppliers.

#### 4.3 Quantification of real and apparent losses in the network

It is envisaged that the ECONOLEAK Model would contribute towards proposing appropriate management strategies and techniques to minimise or at least reduce the cost associated with water leakages. This, however, requires an understanding of the distribution system in order to work out the apparent losses. System data includes the input description shown in the table and also described below.

**Table 14.** System data

Input Description	Variable	Field Data	Units
Length of Transmission Mains	Lm_t	56	km
Length of Distribution Mains	Lm_d	976	km
Total Length of Mains	Lm	1032	km
Number of Service Connections	Ns	52000	Number
Density of Service Connections (per km of mains)	Ns/Lm	50	Per km
Length of underground pipe per connection (if greater than 10m)	Ls	0	m
Total volume of Storage Reservoirs in the System	Vol	91,8	MI
Percentage of time system is pressurised during the year	T	100	%
Average Operating Pressure of Transmission Mains	P_t	50	metres
Average operating pressure of reticulation system when system pressurised	P	50	metres
Population served by the supply system	Pop	420000	Number

The transmission mains are used to move larger quantities of water throughout the Midrand area and are often larger, 16"-20" in diameter. Large quantities of water are moved from the source of supply such as the reservoir after treatment to the smaller distribution mains (Mergelas *et al.*, 2005). The transmission mains that supply water to the study region are 56 km in length.

The distribution mains are generally smaller in diameter (4"-12") and transport less water than the transmission mains at a time. The distribution mains are found along the city streets. The length of the distribution mains is 376 km. The total length of distribution and transmission mains are 1032 km throughout the study region.

There are 52 000 service connections with a density of 50 per km of mains. Service connections are classified as either non-standard or standard. Standard connections are simpler in terms of civil planning than the non-standard connections and are usually used for a single dwelling (Taswater, 2018). Standard connections are used for basic activities covered by customers on a regular basis such as connecting water meters, sewerage connections and relocation of water meters. Standard connections are usually smaller in diameter than the non-standard connections and include water meter relocations that are under a distance of 3 meters and connections of 20 mm or 25 mm.

The non-standard connections are larger than the standard connections and vary greatly in complexity with more requirements in terms of civil planning (Taswater, 2018). Due to the non-standard connections being larger in size, extensive excavation, road alterations, drilling and permits as well as approvals from various authorities are required. Standard connections are usually found in suburban areas whereas non-standard connections are found in the city or Central Business District (CBD). The length of underground service connections is not included in the ECONOLEAK model if it is less than 10 meters. Therefore, underground service connections exist but are not included in the model as they are below the limit required for the model.

Johannesburg Water has two storage reservoirs that can be seen in Figure 5 above. The total volume of storage reservoirs in the system is 31.8 Ml. The two storage reservoirs are used to supply water to Region A, to approximately 420 000 people. The percentage of time the system is pressurised within the year is 100%, meaning that the system is continuously being pressurised. When water leakages occur in pipes of larger diameters, pressure readings become significant, especially in areas with predominantly low-pressure systems. If pressure changes are not monitored, then leakages go unnoticed for years as they do not appear on the surface. The appropriate pressure is also essential in the functioning of the distribution system and keeping the consumer content. The average operating pressure of the transmission mains is 50 m standard pressure. The average operating pressure of the reticulation system is also 50 m standard pressure. Pressures in the system under normal operating conditions should range between 50 and 80 psi which is 70 m pressure and under.

The next part of the model deals with the basic parameters required for the Unavoidable Annual Real Losses such as background leakages which are leakages below the level of detection, reported bursts which are visible to people and unreported bursts that are not visible to people as well as the total burst pipes experienced.

The unavoidable background losses are adjusted for local pressures and require data for the service reservoirs, transmission mains, distribution mains, connections and services pipes. The field data required is the Unavoidable Background Leakage (UBL), the constant leakage exponent (N1) value and the UBL per day. The only part of this section in the model that needed to be filled in was the unavoidable background leakages and the N1 values, the model then calculated the loss per day on each component as seen in Table 15 below. The leakage exponent (N1) values for all the transmission and distribution mains, connections, service pipes and services reservoirs are a constant value of 1.5.

The service reservoir used to supply Region A with water has four primary functions; it is used to balance the demand of the distribution system as the demand fluctuates, it allows the source to give phased outputs that are steady or differ; it ensures that appropriate pressure levels are kept in the distribution system; it provides a supply of water during shut downs of water plants, pumps and main reservoirs and lastly the reservoir is a reserve of water that can be used in cases of emergency such as fires (Gray, 2010).

**Table 15.** Unavoidable Background Losses (Adjusted for Local Pressure)

<b>Details</b>	<b>Unavoidable Background Leakage at 50m standard pressure</b>	<b>N1 Value</b>	<b>Unavoidable Background Leakage (m<sup>3</sup>/day)</b>
1.Service Reservoirs	0.1 % of capacity/day	1.5	32
2.Transmission Mains	20 l/km/hr at 50m	1.5	27
3.Distribution Mains	20 l/km/hr at 50m	1.5	468
4.Connections	1.25 l/conn/hr at	1.5	1560
5.Service pipes	0.00 l/conn/hr at	1.5	0
<b>Total Unavoidable Background Leakage (m<sup>3</sup>/day)</b>			<b>2147</b>

### Transmission mains

Background leakages are those below the level of detection and were calculated by the model. Background leakages are as follows: the transmission mains were 9.60 litres/km/day per 50-meter standard pressure. For reported bursts, background leakages in the transmission mains were 5.80

litres/km/day 50-meter standard. Lastly, for the unreported bursts, the background leakage in the transmission was 2.60 litres/km/day 50-meter standard. The unavoidable background leakage for the transmission mains was 20 l/km/hr at 50m standard pressure resulting in 27 m<sup>3</sup>/day.

The study also established the time the maintenance team became aware of the burst and the time it took to locate it. This was considered as a loss in time; thus, the model works out the losses from reported and unreported bursts. Data for the transmission mains for the awareness and location, repair, total days used by the model and losses in m<sup>3</sup>/hour respectively was 0.50 days, 0.50 days, 1 day and 30 m<sup>3</sup>/hour.

The N1 value for bursts for all mains, connections and service pipes remained a constant 0.5 and the losses were 12.0 m<sup>3</sup>/hour. If the average N1 value is close to 1, a linear relationship can be assumed (Lambert, 2002). The N1 values for the study are in the range of 0.5 to 1.5, thus representing a smaller distribution system indicative of a smaller supply area. The frequency of reported bursts for the transmission mains was 0.030 per km/mains/year.

In order to establish the number of bursts per year, basic information on unreported bursts and the duration rates for reported bursts at 50m standard pressure is required. Using equation (6), the number of bursts per year for the transmission mains was calculated as 1.7 km mains/year. The duration of days taken to locate the burst was 1 day. Given the 50m standard pressure rate of 30.0 m<sup>3</sup>/hour, the average losses of water were calculated to be 3.3 m<sup>3</sup>/day. (Details are indicated in the output table in Addendum 6)

### Connections

The background leakages for connections were 0.60 litres/conn/day per 50-meter standard pressure. For reported bursts, the connections were 0.04 litres/conn/day per meter pressure. Unreported bursts for connections were 0.16 litres/conn/day per meter pressure. The unavoidable background leakage for the connections was 1.25 l/conn/hr at 50m standard pressure and the unavoidable background leakage per day was 1560 m<sup>3</sup>/day. It takes 5 days for service men to become aware and locate the leakage.

Findings reveal that it takes 6.00 days to repair bursts. This gives a total of 11.00 days and 1.6 m<sup>3</sup>/hour of losses through reported and unreported bursts. The losses via connections contribute 33% for the unreported bursts as a percentage of reported bursts. The frequency for reported bursts was 2500 per 1000 connection/year and the number of bursts was 130. The frequency for unreported bursts was 0.825 per 1000 connection/year and the number of bursts was 42.9. For the foregoing, it is evident that a significant number of bursts occurred along the

connections but got to be reported several times because the community could visibly detect them. On the other hand, unreported bursts were many but not frequently reported because they were not visible.

Where interventions are required, an indication of losses through unreported and reported bursts can be worked out. For example, at 50m standard pressure, the hourly loss for the unreported bursts was 1.6 m<sup>3</sup>/hour, resulting in average losses of 150.4 m<sup>3</sup>/day. At the same standard pressure of 50m, hourly loss along connections were 1.6 m<sup>3</sup>/hour leading to average losses of 4.51 m<sup>3</sup>/day. This thus indicates that where a routine check is carried out to detect unreported bursts, losses through connections would amount to 1674.4 m<sup>3</sup>/day every 24 months, 850.8 m<sup>3</sup>/day every 12 months and 438.9 m<sup>3</sup>/day every six months. The implication is that one incurs few losses along the connections if they are routinely checked every 6 months and interventions are applied.

#### Distribution mains

The total unavoidable annual real losses are 18 litres/km/day at 50-meter standard pressure and consists of background losses, reported and unreported bursts. This translates to 320 836 m<sup>3</sup>/year for the system. Basic information on unreported bursts indicates 5% of what was reported resulting in 6.0 m<sup>3</sup>/hour of losses. The number of bursts per year for the distribution mains was 146.4, the duration of days taken to locate the burst was 1.5 days, the rate of loss at 50m standard pressure was 12.0 m<sup>3</sup>/hour and the average losses of water was calculated to be 173.3 m<sup>3</sup>/day. The losses that would be incurred when an intervention is done in 24 months is 1055.5 m<sup>3</sup>/day, 528.5 m<sup>3</sup>/day in the case of 12 months and 265.0 m<sup>3</sup>/day every six months.

#### Service pipes

The density of service connections is 50km per kilometre of mains. The total unavoidable annual real losses are 25 litres/km/day at 50-meter standard pressure within the study area. This loss does not reflect in the overall system because it is a loss incurred by the users.

The service pipes in terms of reported and unreported bursts have a value of 5.00 days for awareness and location, 6.00 days for repair time of bursts, a total of 11.00 days and 1.6 m<sup>3</sup>/hour of losses through water leakages. It is easier to collect this data for reported bursts because they are easier to locate and repair once the water suppliers are alerted. The service pipes account for 33% of losses for the unreported bursts as a percentage of reported bursts.

In South Africa, the average duration for unreported bursts is based on an intensive leakage control programme which uses night-flow measurements once a month on water distribution

systems that vary. A linear relationship is assumed between pressure and leakage rate, which was supported by the methodology developed by Lambert and McKenzie (2002) that estimates the unavoidable losses for the overall infrastructure using pressure. They allocate a threshold value of 2% per annum that represents infrastructure that is in good condition and operation is in line with best practice guidelines from worldwide systems. Due to financial constraints experienced by the country's water supplier, the value of 2% is too high. A realistic value for RSA is a value between 0.25% and 0.5% (Chiipanthenga, 2008). UARL is thus presented in a segmental form for easy interpretation in equation (2) above. Results in Table 16 below show that differences in bursts between the different components mentioned above have a large influence on the total UARL. The UARL for the local system is good when compared to the international system.

**Table 16.** Unavoidable Annual Real Losses (UARL) for the system

<b>Field data</b>				
	<b>Litres/second</b>	<b>m<sup>3</sup>/hr</b>	<b>m<sup>3</sup>/day</b>	<b>m<sup>3</sup>/yr</b>
<b>Transmission Mains</b>	0,58	2,1	50	18409
<b>Distribution Mains</b>	10,17	36,6	878	320836
<b>Connections</b>	24,07	86,7	2080	759720
<b>Service Pipes</b>	0,00	0,0	0	0
<b>Total Losses</b>	<b>34,82</b>	<b>125,4</b>	<b>3009</b>	<b>1098964</b>

#### Infrastructure Leakage Index

The first parameter involved in calculating the ILI is the water supplied to the system. In Region A, the actual amount of water supplied to the system is 330 382 06 m<sup>3</sup>/year. Part of this supply is authorised consumption, while the other is unauthorised. Unauthorised consumption is a total of illegal water withdrawals and connections that bypass meters (unbilled water). Unauthorised consumption can further be classified as unbilled but authorised and does not generate any revenue. The unbilled metered consumption can include water supply to institutions at no charges which can be used for flushing mains and firefighting (WMI, 2018).

The authorised consumption of water for the study region is 248 777 69 m<sup>3</sup>/year, giving a current total annual water loss of 81 604 37 m<sup>3</sup>/year. Thus, the apparent losses as a percentage

of total losses are 24.7% which translates into 201 562 8 m<sup>3</sup>/year. Apparent losses are water that is assumed to be lost through physical leakages.

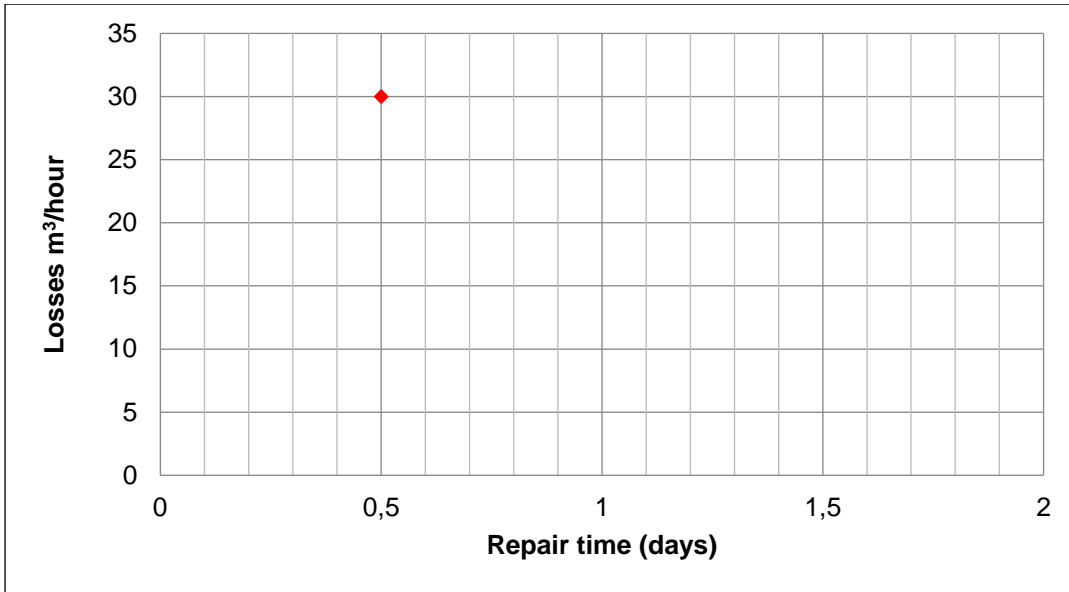
The Current Annual Real Losses (CARL) of the system was determined using equation (4) and yielded a loss of 614 480 9m<sup>3</sup>/year. To arrive at the overall Unavoidable Annual Real Losses, equation (2) is applied to reveal a loss of 10 989 64 m<sup>3</sup>/year. A good indicator of the state of infrastructure is reflected by the Infrastructure Leakage Index as emphasized by (Liemberger, 2003). Hence the ILI which is derived using equation (3) was 5.6. This was far less than what Chiipanthenga (2008) found out for the Blantyre Water Supply area (Chiipanthenga, 2008). It is recommended that in developing countries such as the Republic of South Africa, infrastructure should be upgraded if the ILI is more than 8 (Fantozzi *et al.*, 2006); (Lambert *et al.*, 2002). From this analysis, it is shown that the infrastructure used in Region A's water distribution network is in good condition as the ILI is below 8.

#### **4.4 ECONOLEAK Model analysis and implications**

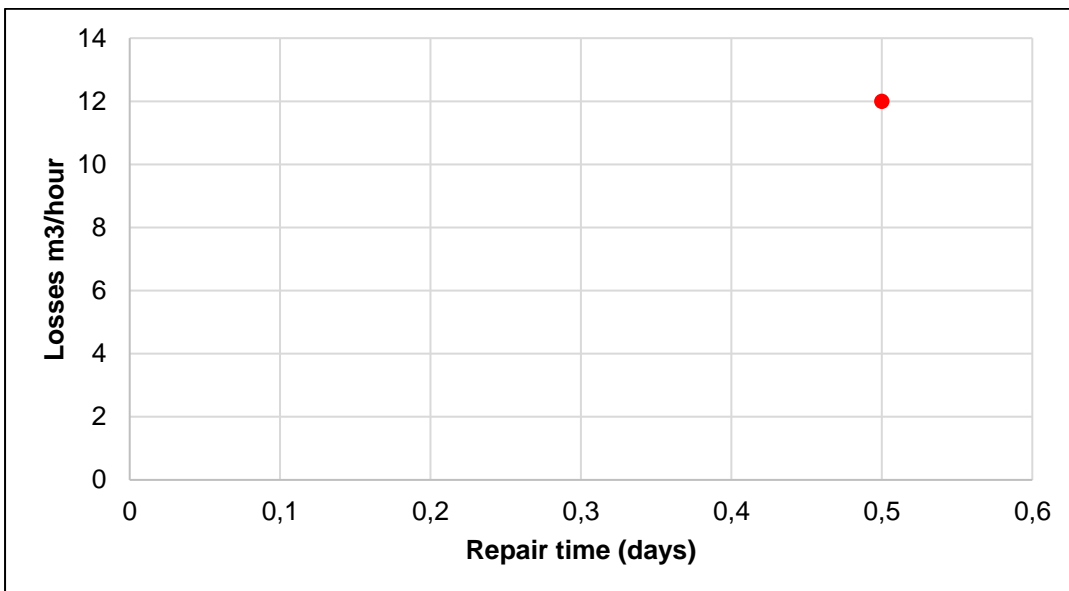
##### **4.4.1 Reported and unreported pipe bursts in the water distribution network**

The model uses base information to calculate losses from reported and unreported bursts. Losses from reported and unreported bursts can be difficult to estimate if the water supplier does not regularly update the system with current information. A proper record of reliable information regarding bursts needs to be maintained by the water supplier to ensure accurate information is used to calculate losses through bursts. Rates and duration of reported bursts at 50m standard pressure are included because they have financial implications. If the leaks are repaired at a faster rate, the volume of water lost with each leak will be less and the financial cost associated with the leakage will be reduced. The study area witnessed a number of bursts along the distribution system while bursts were more frequent on the connections. This could be explained by the many connections in the area resulting from the nature in housing arrangements.

Figure 21 below illustrates the resultant relationship between the time it takes to repair a burst pipe and the amount of water lost. In the instance of the transmission mains, the repair time was 0.5 days and the associated loss of water was higher (30 m<sup>3</sup>/hour). According to Johannesburg Water, the transmission mains are much shorter than the service connections, therefore, even 0.5 days repair time is still too long and results in excessive leakage as seen in Figure 22 and 23 below.



**Figure 21.** Relationship between repair time in days vs losses in m<sup>3</sup>/hour for transmission mains.



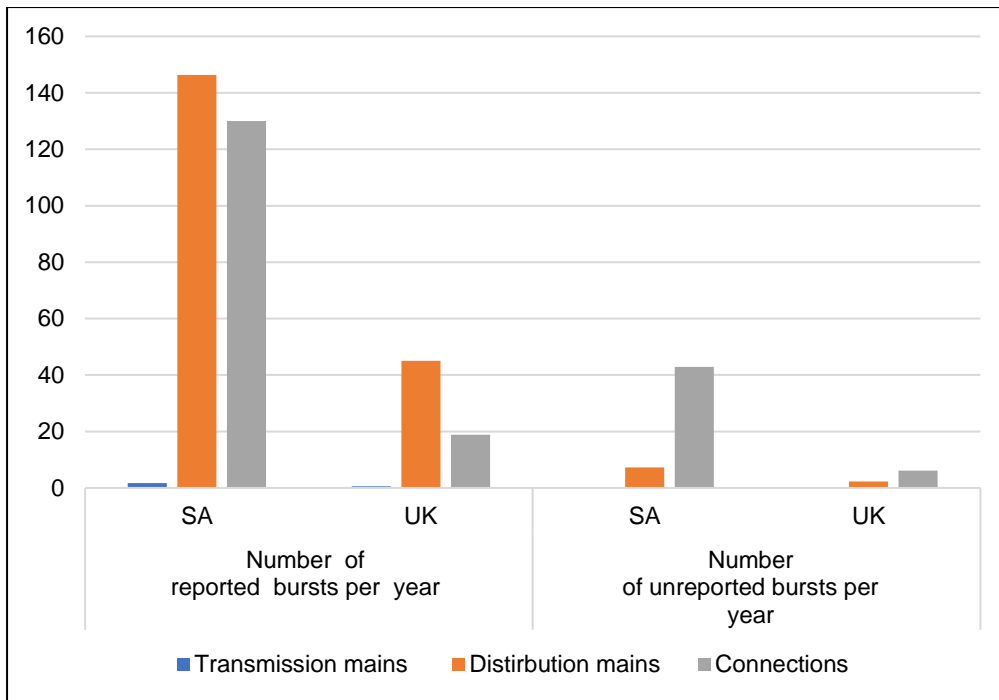
**Figure 22.** Relationship between repair time in days vs losses in m<sup>3</sup>/hour for distribution mains.

In the instance of service connections, the repair time was longer, but the losses were much less. Johannesburg Water stated that there are a number of service connections and it usually takes more than 6 days to locate and repair the leakage. In 2018, Johannesburg Water was able to optimally locate a leakage and repair it hence less water was lost from service connections as seen in Figure 23 below. Further, it must be noted that the service connections in Region A are in good condition, therefore minimal losses through leakage are seen in Figure 23 below.



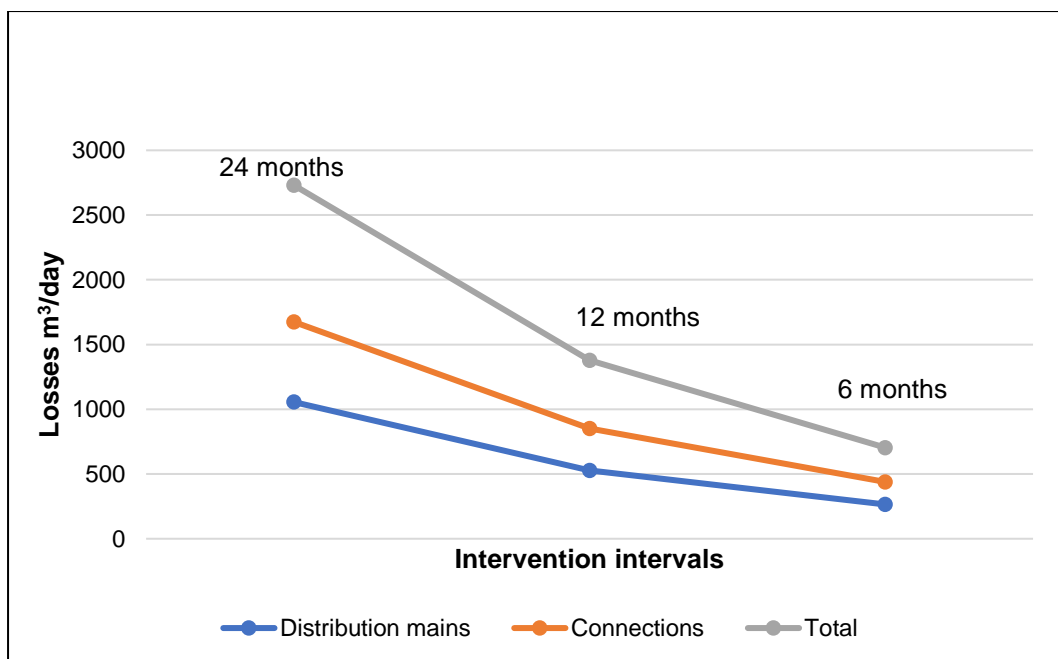
**Figure 23.** Relationship between repair time in days vs losses in m<sup>3</sup>/hour for service connections.

A similar study was conducted in the United Kingdom and RSA to investigate the number of reported and unreported bursts (Lambert, 2002). In Figure 24 below, RSA has a higher number of reported bursts per year in the distribution and transmission mains as well as their connections in comparison to the UK. RSA also has a higher number of unreported bursts in the distribution and transmission mains. Bursts in RSA are also prominent in connections as compared to the UK. The possible reasons for this may include a loss in physical and hydraulic integrity as described in Section 2.1 above.



**Figure 24.** Graph depicting differences in recorded bursts from the Republic of South Africa (2014) versus the United Kingdom (2002).

Figure 25 below depicts the data derived from unreported bursts that were detected through regular inspections. The graph shows that the longer the period between inspections, the higher the losses associated with bursts. For the intervention period of 24 months, the highest losses were observed as 2730 m<sup>3</sup>/day, whereas during the 6-month intervention period the lowest losses can be observed at 704 m<sup>3</sup>/day. Therefore, from the results obtained in the model, it can be deduced that it is best to check the water distribution system regularly and apply active leakage control on a 6-month basis. The quicker bursts are detected, and active leakage control is applied, the less water will be lost from the system. However, the cost of paying for interventions on a 6-monthly basis may be higher and was determined in Section 4.4



**Figure 25.** Losses from unreported burst at regular inspection intervals adjusted for local pressure.

This project learns from a study conducted in Liantang, China, where Active Leakage Control was undertaken (Yuchen Lu, 2014 ). The 161 km distribution network in Liantang served a population of 300 000. There were approximately 18 588 water meters, with Non-Revenue Water accounting for 160,000 m<sup>3</sup>/ month, equivalent to 16.9% in 2014. The physical leakage per year was 1 514 380 m<sup>3</sup> and 173 m<sup>3</sup>/h while the rate was 13.9%. The apparent leakage was 84.481 m<sup>3</sup>/ year and the apparent leakage rate was 0.8%. The city undertook Active Leakage Control measures which included the management of the water balance, management of the inlet water meter calibration and water meter measurement efficiency assessment. These values are impressive for Liantang City compared to Johannesburg where the study area is located. For example, the total NRW for Johannesburg had decreased from 38.2% in June 2010 to 37.8% in December 2012 (McKenzie *et al.*, 2012). This exceeds the target level of 20% for South African cities and the target of 25% for Johannesburg.

The study was interested in establishing the impact burst pipes had on residents in Region A. Options were listed as seen below and the percentage selection is given in Table 17 below. From these results, it is deduced that the largest problem that residents experienced with burst pipes is the resultant impact of water shortages. This was followed by the weakening of road surfaces causing potholes, the cost implication of pipe bursts and the time wasted. The impact of mould, fungi and algal bloom came at the bottom of the choices. Cross tabulations were performed to establish the association between the type of dwelling and the impact of bursts on residents. Below are the significant associations discovered and can be seen in Addendum 7B.

**Relationship between type of dwelling and the cost implications:**

H<sub>0</sub>: There is no association between the type of dwelling and burst pipe cost implications

H<sub>1</sub>: There is an association between the type of dwelling and burst pipe cost implications

The resultant p-value of 0.05, had a 5% level of significance. Therefore, the null hypothesis can be rejected. Thus, there is an association between the between the type of dwelling and cost implications incurred during burst pipes. The larger households may have a higher cost associated with running the household as compared to smaller households whenever a burst occurred.

**Table 17.** Impact of burst pipes

<b>Impact</b>	<b>Percentage</b>
The weakening of road surfaces leading to potholes	14.6%
Damage to underground piping	4.9%
Damage to foundations of buildings	8.0%
Cost implications (buying water, paying for no water, not going to work)	14.6%
Time wastage	14.6%
Health impacts (resulting from dirty water)	11.1%
Mould, fungi and algae bloom growth	3.5%
Water shortages and loss of water	18.1%
Paying for lost water	10.2%
Other	0.4%

The other interesting result is related to the physical changes in water supplied to residents during a water leakage or water shortage. Respondents observed a change in the colour followed by a change in the taste of water. The change in the odour of water or sediments found in the water was least selected by residents. During a water shortage, chlorine builds up in the water distribution system. Chlorine has a bleaching effect which may be the reason that a change in the colour of water occurs during and after water leakages (Heibati *et al.*, 2017).

The project sought to understand whether leakages and bursts may cause residents to relocate in future. Results reveal that 95.8% of residents perceive that water leakages in Region A will increase over time while 2.8% thought that water leakages will not increase over time. However,

81.7% of residents stated that the pipe burst problem is not serious enough to warrant them to move from their locality to another area. There were 15.5% of residents that would move to another area. Reasons for remaining in the region include safety, the speed with which water leakages and potholes are fixed, proximity to school and work, viable cost of living and cost of moving being too high, people just bought a house in the region, it is centrally located, water leakages do not occur often in the household, hope that conditions will improve, comfort of the house, good community environment, adequate water supply, acceptance of water leakages and lethargic to move. Water suppliers were asked if they thought the problem of water shortages were serious enough to warrant relocation of residents to which “yes” was the common answer.

**Table 18.** The cost incurred to residents due to pipe bursts

Expense	Cost		
	Low	Medium	High
a. Cost of water	12.7%	32.4%	46.5%
b. Cost of driving to the source of water	33.8%	28.2%	22.5%
c. Time implications incurred during shortage	9.9%	31.0%	47.9%
d. Paying a contractor to fix the problem	18.3%	16.9%	50.7%
e. Cost of calling a service provider	31.0%	23.9%	31.0%
f. Cost of not working/ reporting for work	15.5%	23.9%	43.7%
g. Cost of not having water at my business premises	21.1%	19.7%	38.0%
h. Cost of cleaning up	25.4%	32.4%	26.8%
i. Cost of paying for lost water	15.5%	16.9%	54.9%

In Table 18 above, the cost incurred to residents was categorised into various options. The first being the cost of water, where most residents selected the option of high. The cost of driving to get water was considered low by residents. This can be attributed to the fact that; they collect few litres to get them by as they wait for the pipe burst and water shortage to be fixed. Some residents have rain harvest tanks which they use and share with others. The time implication aspect during pipe bursts was translated into the cost in which most of the residents selected as high. Paying a contractor to fix the problem was considered a high cost by residents, simply because it is money that has to be spent urgently and was not budgeted for. The cost of calling a service provider was tied between high and low. The cost of not working or reporting for work and the cost

of not having water at business premises were considered high by residents. This is true for businesses that have to rely on water such as; car washing bays, hair salons among others. The cost of cleaning up after a pipe burst was selected as medium by a majority of residents. This can be a serious issue if the burst happened inside the house, otherwise, it was considered medium because most residents' experience has been around bursts and leakages outside their yard. The cost of paying for lost water was high for residents, especially where leakages go undetected along connections.

Notifying residents of pipe bursts and potential water leakages in their region is important as it helps them to plan their day around the water shortage and to budget for water shortages (Shibambu, 2019 ). The study sought to find out if residents receive burst pipe alerts in their community to which 67.6% answered “yes” and 22.5% answered “no” while 9.9% selected “uncertain.” Majority of residents within the study area were notified of pipe bursts through friends or relatives (37.3%) while the rest were notified by the water supplier (19.4%), town/board council (16.4%) and media (13.4%). The message of the pipe burst to residents was investigated and found to be predominantly communicated through WhatsApp Groups and SMS notifications. The residents do not receive notifications from the water supplier who mainly uses Twitter for communication. Therefore, the method of alerting the public of the pipe burst used by the water supplier is insufficient and needs to be improved by using communication methods that resonate with residents.

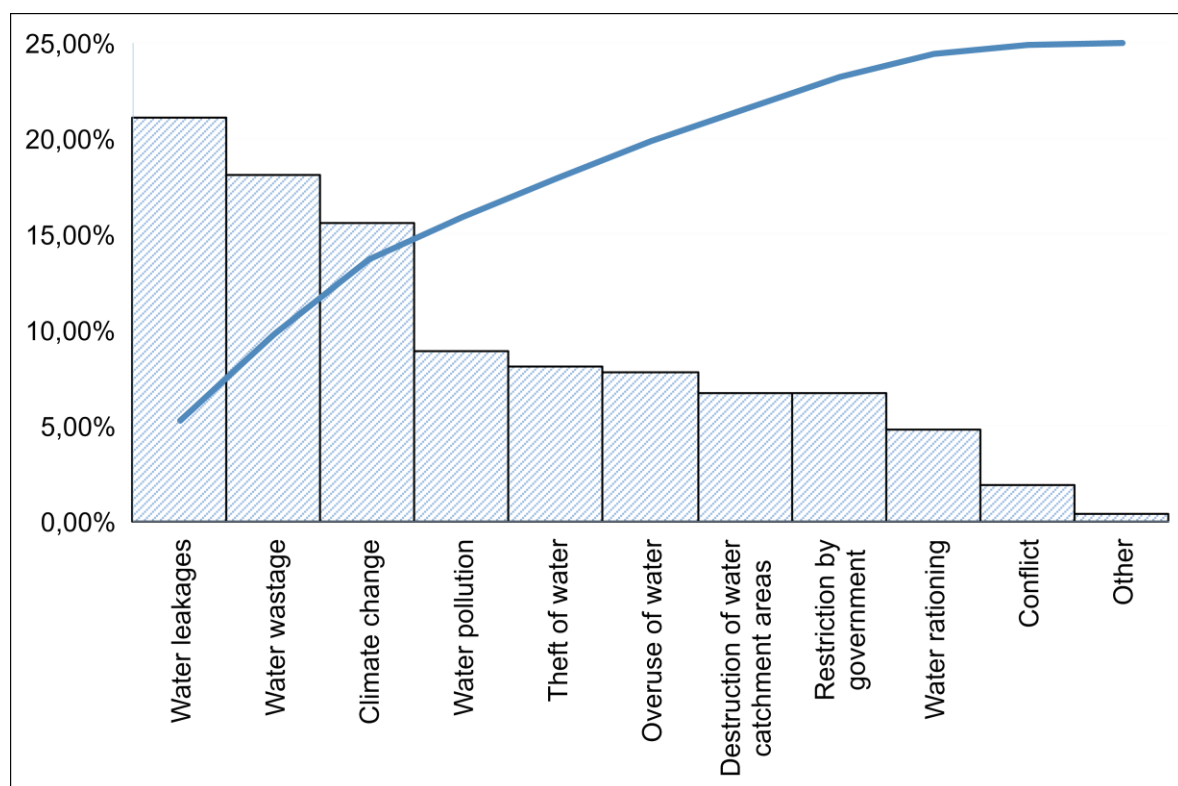
During the water leakage and water shortage, residents did either one of the following:

**Table 19.** Actions that were taken by residents during water shortages

Action	Frequency	Valid percentage
Waited for the pipe to be fixed and water to be restored	32	47.8%
Contacted the water supplier to report the problem	8	11.9%
Changed working hours around the water leakage and shortage	3	4.5%
Left the house for the duration of the leakage and shortage	5	7.5%
Communicated to household members to conserve water	9	13.4%
Stored the little water from taps that are left prior to complete closure	10	14.9%

From Table 19 above, it was observed that most of the residents in Region A waited for the pipe to be fixed and water to be restored instead of acting further. Residents also store the little water that is left in taps when their water is cut to be used during the water shortage. This saves on the extra cost of purchasing water from shops during water leakages. The message of water conservation during the time of the leakage is also conveyed to members of the household. It was found that a small percentage of residents leave their house during the water leakage. Leaving the house to buy water during water shortages may be inconvenient to the residents as it could disrupt their routine. A minority of residents change their hours during a water leakage as most companies do have a reserve of water enabling employees to continue working.

Water shortages are not always caused by pipe bursts, there are other factors that may play a role in the cause of a water shortage. Residents were given further options as to what they thought caused water shortages in Region A as shown in Figure 26 below. The main cause of water shortages as perceived by residents is water leakages meaning that water leakages are a serious problem in the region. It was also found that climate change, water pollution and theft of water contribute to water shortages as selected by residents.

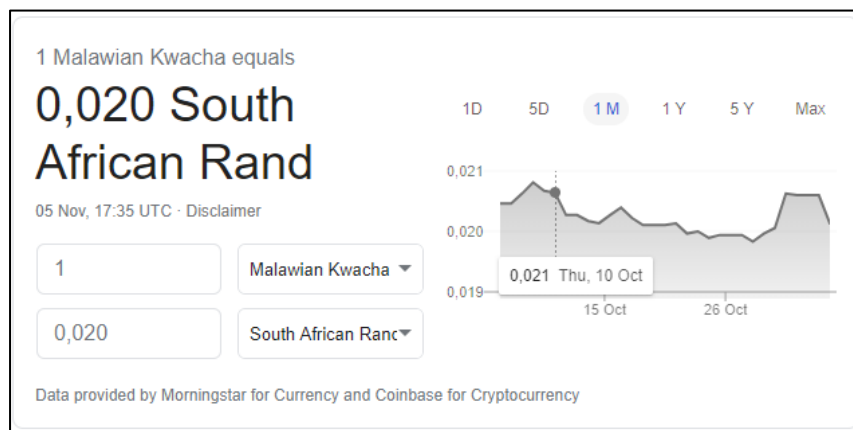
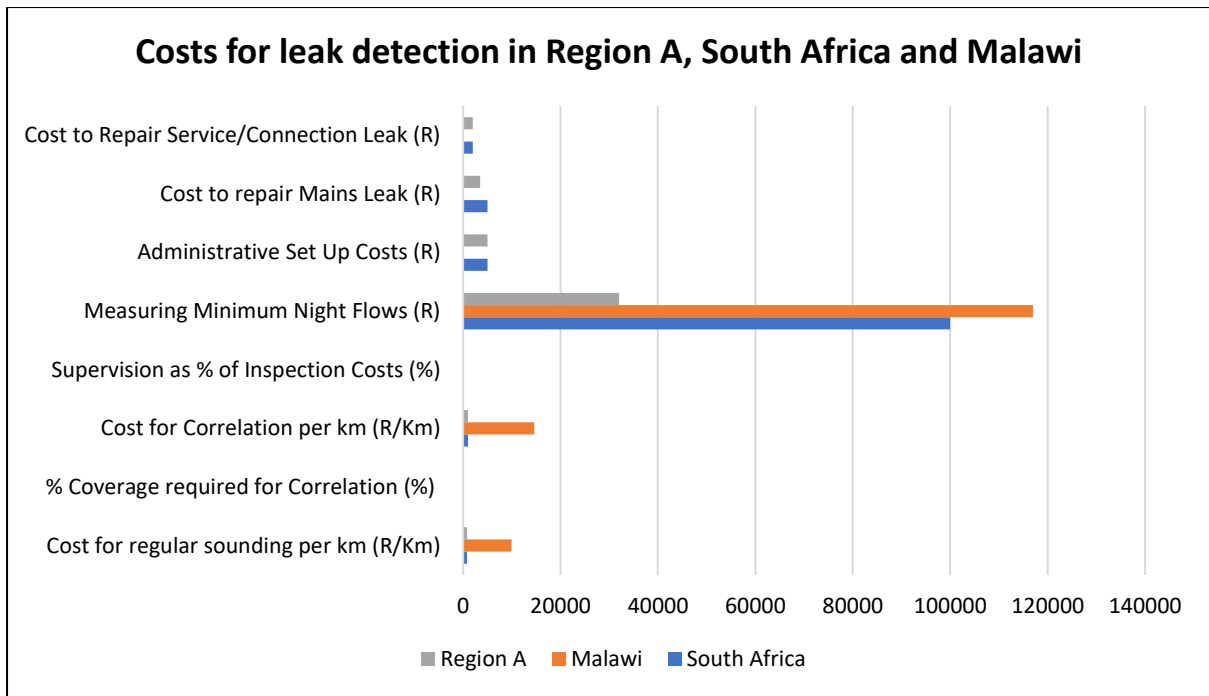


**Figure 26.** Causes of water shortages chosen by residents.

#### 4.4.2 Costs associated with leakage detection and intervention

Leakage detection is an essential part of the costs in the water supply system. If the water supplier takes longer to detect the point of leakage, water will be wasted and hence the associated cost of the leakage will be higher. The model uses the various components in a typical Active Leakage Control initiative. Active Leakage Control is an approach taken to actively send teams to areas of concern that specialise in leakage detection and repair. Once the team arrives on site they search for the unreported or reported bursts and repair it as explained in (Xu *et al.*, 2014). The team from Johannesburg Water ensures that the burst is recorded as well as the location of the burst. The ECONOLEAK model requires information from the water supplier to define any extra items and assign standard rates to the costs.

The first step is to detect leakage through basic sounding techniques in the network. This sounding technique is then followed by an acoustic process including a detailed leak location with leak noise correlators to identify the point of physical leakage. For Johannesburg Water, the cost for regular sounding in Rands per kilometre is R780. The percentage of coverage required for correlation between each point of sounding is 20% of a kilometre. The cost of correlation in Rands per kilometre is R1000, notwithstanding the supervision costs. These costs include the repair of the leakage and detection of the leakage including the supervision of a team to ensure leakage detection and repair. The supervision costs as a percentage of the inspection costs are 15%. The measurement of Minimum Night Flows cost R32 000. The Minimum Night Flows uses average pressures and inflow data in the chosen District Metered Area (Farah *et al.*, 2017). Leak detection and administrative inaccuracies that are associated with the leakage and customer metering make up the administrative set-up costs. The administrative set-up costs for Region A was R5000. Once the leakage is identified, the cost of repair along the mains is R3500. The cost to repair the connection leakage or to repair the service pipes is R2000. When comparing the results of this study to a similar study undertaken in Malawi(Hoko *et al.*, 2017), a scenario shown in Figure 27 is encountered.



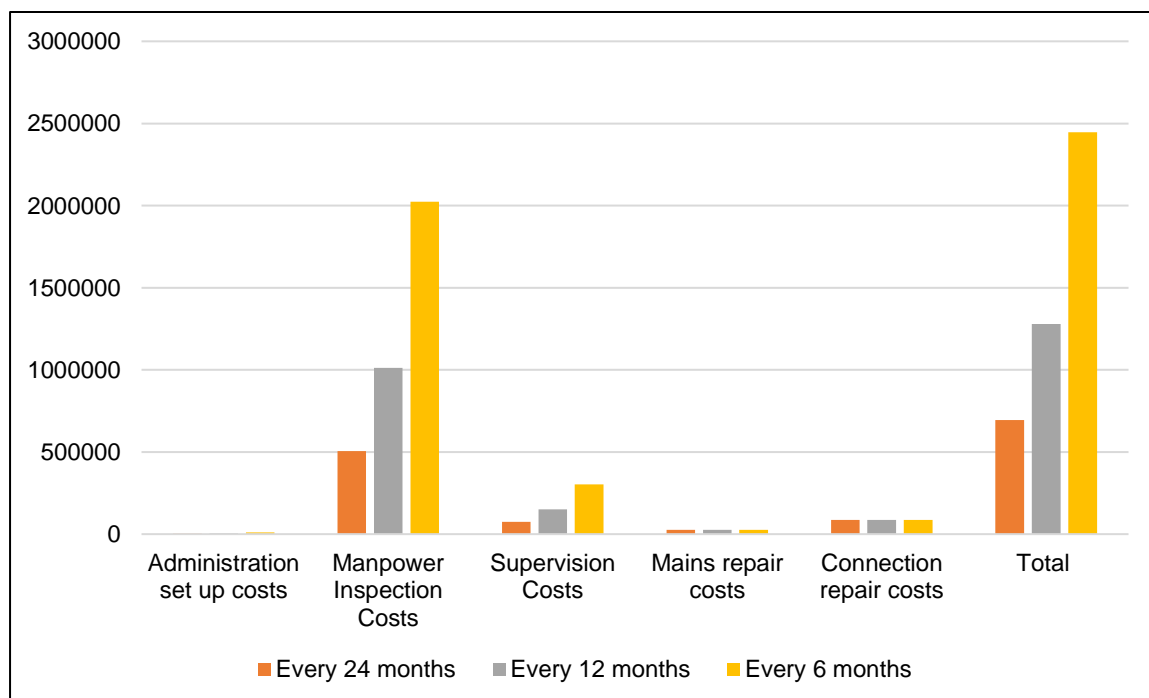
**Figure 27.** Costs for leakage detection in different areas of Sub-Saharan Africa and the Malawian Kwacha.

Although Region A is significantly smaller in population size when compared to Malawi, the aim is to make a comparison in the cost of leakage detection only. The Malawian Kwacha was converted to Rands. Using the 5<sup>th</sup> of November 2019 as a base day; the Kwacha to Rand was 1:0.02. Results shown in Figure 27 above reveals that Malawi incurs the highest cost of leakage detection when compared to RSA and more specifically Midrand. In the United States of America (USA), there are devices that aim to bring the acoustic sensor close to the source of sound and point of leakage. This is done through the running of a free-swimming acoustic sensor in the pipeline to increase sensitivity to small bursts. This method costs, on average, \$25 000 per kilometre along transmission mains. Another method used is to develop algorithms that allow sounds to be detected over longer distances. These algorithms can isolate the sound accurately

and are a less expensive approach. This method is implemented by the USA for transmission main leakage detection at \$10 000 per kilometre at limited sensitivity (Laven *et al.*, 2012). This is higher than the costs of leakage detection in the Johannesburg Water distribution network. For example, the cost to detect leakages in the entire Johannesburg network in 2018 came to R505 680.

Costs in relation to leakage detection are however a function of the time it takes to intervene. Intervention is worked out at regular intervals (24, 12 and 6 months) to ensure that the system is continuously assessed for leakages in order to minimise the associated costs. Once the costs for leak detection is entered in the model, the next step is to calculate the costs for intervention at regular intervals.

In Figure 28 below, it is observed that the costs of intervention on a 6-monthly basis is the highest compared to intervention every 12 months and every 24 months. Costs of intervention for every 24 months is the lowest as the period between the money being spent on intervention costs is longer. However, this contradicts the finding in relation to the 6-month active leakage control period above which concluded that water losses are higher when mitigated after a longer period such as that of a 24-month interval. Therefore, the water supplier must decide on whether to save on intervention costs by not checking the system regularly, and risk water losses occurring more frequently and bearing the inevitable cost of money being spent to fix the burst or to maintain the system frequently and reduce the chances of water being lost through bursts.



**Figure 28.** A graphic presentation of costs for intervention at temporal scales 24, 12 and 6 months.

The losses that have been calculated in part 1 and 2 of the model are associated with unreported and reported bursts. The next step deals with the calculation of the value of water that is lost through the reported and unreported bursts. The bulk supply of water for Region A was purchased at R10 per m<sup>3</sup>. The water is transported from the Vaal Dam as described in Section 1.4 and then stored in the Erand reservoirs and water tower. The power used to run the operation from Johannesburg Water supply sources was R0.75 per m<sup>3</sup>, the rest is sourced from Eskom. The chemicals used were from the water supplier's own sources, therefore, costing R0.05 per m<sup>3</sup>.

In comparison with the Blantyre Water System in Malawi, bulk supply of water incorporates the power used in distribution, storage and chemicals to treat water. The bulk supply of imported water for Blantyre is R27.39 per m<sup>3</sup>, power supply from own sources costs R17.82 per m<sup>3</sup>, and the chemicals are derived from other sources at R1.54 per m<sup>3</sup>, (Kalulu *et al.*, 2010). The marginal cost of water for the Blantyre Water System in Malawi is significantly higher than that of the Region A's water distribution network in Midrand, South Africa. The Blantyre Water Board serves a larger population as compared to Region A which results in the significant difference between the marginal costs of each system.

The study sought to understand the personal costs incurred by the respondents in Region A. The assumption was that residents experienced cost implication during mitigation of water leakages, pipe bursts and the subsequent water shortages. For instance, residents perceived the cost of fixing a leakage by the water supplier to be in the range of R20 001 - R40 000, but there were residents who estimated it to cost more than R100 000. Table 20 below illustrates the approximate expenditure that occurs during a pipe burst callout. However, it was difficult for the water supplier to quantify as it is situation dependent. Pipe bursts are different and require different solutions which is why the water supplier gave the rate in certain instances. Residents and water suppliers selected the same category for the approximate cost of fixing a leakage.

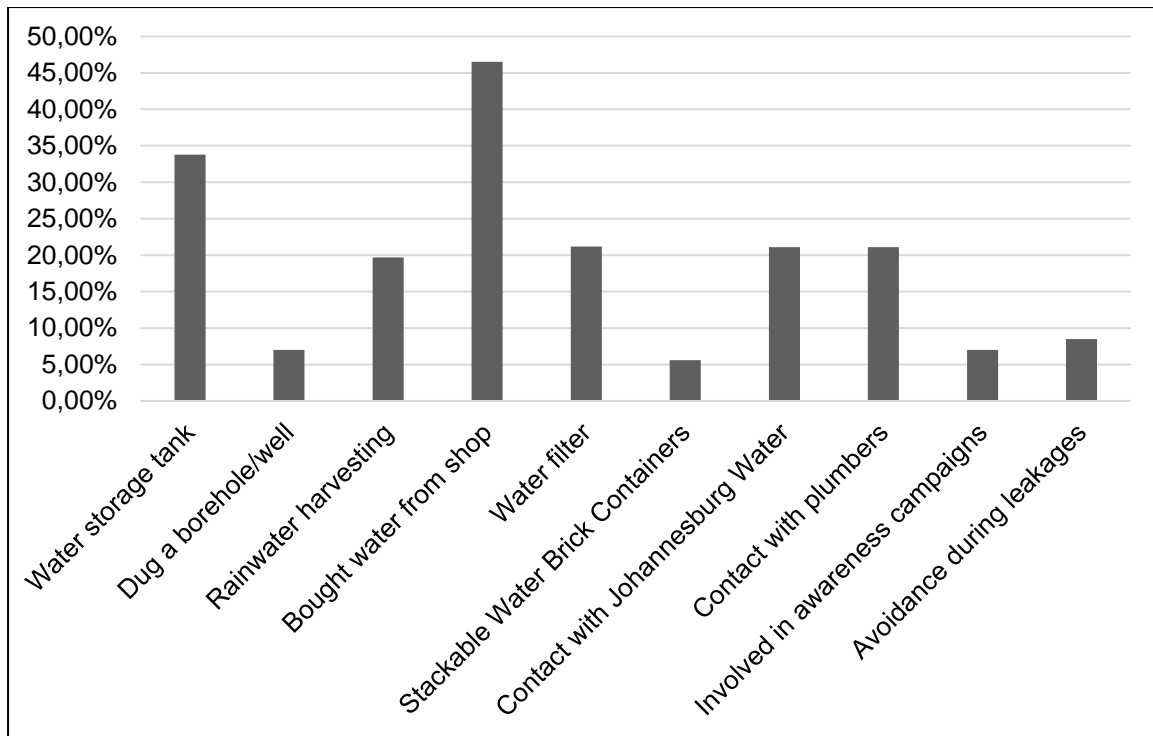
**Table 20.** Approximate expenditure during pipe burst callout (from water Johannesburg Water for Region A)

<b>Expense</b>	<b>Cost (respondent 1)</b>	<b>Cost (respondent 2)</b>
a. Equipment costs (in Rands)	R250/hour	R3000
b. Distance to burst pipe in (Rand/km)	Situation dependent	10km
c. Time spent (in hours or part of an hour)	3 hours	Situation dependent
d. Labour costs (in Rands/hour)	R120/hour/per person	R1000
e. Personal Protective Equipment (in Rands)	R8/hour	R1000

Seeing that residents were conscious about the costs of attending to water leakages or pipe bursts, the study was compelled to find out how residents acted in any of the events. It was revealed that 67.6% of residents acted while 29.6% of residents waited for the water to be restored. The mitigation method adopted by most of the residents was to buy water from the shop. Water is essential for the daily activities of residents, therefore, buying water from the shop is the most used method by residents in Region A. The method employed least by residents was using stackable water brick containers. See other responses in Figure 29 below.

Respondents made suggestions and recommendations on how to minimise water leakages and bursts in the study area like maintenance and upgrading of water infrastructure, monitoring and planning by local authorities, awareness regarding water conservation, repairs being done properly and promptly by efficient staff, transplanting trees and maintaining them, installation of meters, insulation of water pipes, maintaining sufficient budget for maintenance, due diligence by contractors to ensure that location of pipes is known to minimize damage, accountability of local authorities, regular checks of water bills, water conservation and better management of water resources, fix and maintain pipelines especially asbestos ones, replace joints that are broken quickly and send out staff that are specialised, alternative water purification systems, and stop new developments that will impact the water distribution network.

The results are shown below. According to the water supplier, maintenance of existing infrastructure is the most suitable option in mitigating pipe bursts and reducing the severity of leakages as it is cost effective. It was further concluded that using models may not be effective for them as it would require training employees.



**Figure 29.** Steps that were taken by residents to mitigate water leakages.

Once the base losses are established, the total water losses for a number of interventions can be analysed for three Active Leakage Control scenarios, namely; every 24 months, every 12 months and every 6 months. The losses from the unreported bursts are then calculated based on the number of bursts as estimated previously and can be seen in Table 21 below which shows that the highest water losses occur during 24-month intervention intervals which result in the highest cost associated with active leakage control.

**Table 21.** Water losses for a number of interventions per year

Details	Every 24 months	Every 12 months	Every 6 months
<b>Storage Reservoirs</b>	183,6	183,6	183,6
<b>Transmission Mains</b>	57,1	57,1	57,1
<b>Distribution Mains</b>	2165,8	1638,7	1375,2
<b>Connections</b>	4944,9	4121,2	3709,4
<b>Service Connections</b>	0,0	0,0	0,0
<b>Total (m<sup>3</sup>/day)</b>	<b>7351,3</b>	<b>6000,6</b>	<b>5325,2</b>

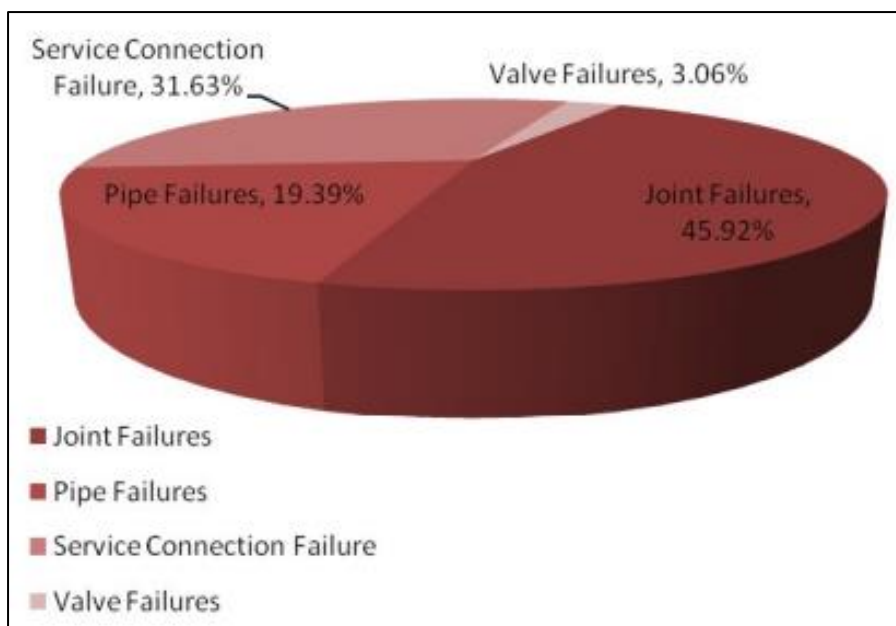
Details	Every 24 months	Every 12 months	Every 6 months
Total (m <sup>3</sup> /year)	2683230	2190217	1943711
Cost (Rand/yr)	26832300	21902172	19437108

The final calculation in part 4 of the model is the annual intervention costs for active leakage control for every 6, 12 and 24 months as seen in Table 22 below. The calculation uses the unit rates and the cost of water losses previously calculated. The total intervention costs are the final leakage calculation undertaken in the ECONOLEAK model. Part 4, in concurrence to the results from part 3, shows that the costs of the intervention of water losses at an interval of 6 months are higher than the cost of intervention every 12 months and every 24 months. This cost was broken down in part 3 and shows that the more frequently leakages are attended to the higher the collective cost of mitigation. This, in turn, lowers the losses present in the system.

**Table 22.** Total intervention costs

Details	Field Data		
	Intervention Cost	Cost of Losses	Total
Every 24 months	695452	26832300	27527752
Every 12 months	1279484	21902172	23181656
Every 6 months	2447548	19437108	21884656

A similar project that has experiences to share was done in the UK and India. The UK case study revealed that the cost of the 6-month active leakage control interval is the highest, while the 12-month interval of active leakage control was the lowest (Bhagwan *et al.*, 2014). A water audit analysis tool that can analyse and determine the components of the water balance for the Jaipur water utility in India was developed (Sharma *et al.*, 2018). Findings of the study have shown that real losses in the water utility constitute 37% of the total water that is supplied to the region while apparent losses constitute 8% of the system. The highest failures reported are those in the joints as seen in Figure 30 below. In Region A, the highest amount of failures and subsequent losses were seen in connection failures. Further results in the study reveal that water losses are subsequently reduced with frequent active leakage control as a form of mitigation. These methods include regular inspections, pipeline management and water loss implementation plans (Sharma *et al.*, 2018).



**Figure 30.** Types of system failures causing subsequent water losses in Jaipur, India (*Sharma, 2018*)

#### 4.4.3 Curve fitting information for the final graph

The last part of the model uses the information derived in parts 1 to 4 and presents it in the graph that is shown in Figure 31 below. Part 5 of the model contains all the information that is used to create a graph that is shown in part 6 of the model.

**Table 23.** Curve intervention costs versus leakage costs

Details	Field Data
$L_{one}$ (Total for every 6 months in $m^3/day$ )	1943711
$L_{two}$ (Total for every 12 months in $m^3/day$ )	2190217
$L_{three}$ (Total for every 24 months in $m^3/day$ )	2683230
$L_b$ (Total for bursts in $m^3/year$ )	1686793
$L_1 - L_b = L_1$	256918
$L_2 - L_b = L_2$	503424
$L_3 - L_b = L_3$	996437
$L_3 - L_2$	493013
$L_2 - L_1$	246506
$L_2^2 - L_1^2$	1,8743E+11
$L_3^2 - L_2^2$	7,3945E+11
$C_1$ (Intervention costs every 6 months)	2447548
$C_2$ (Intervention costs for every 12 months)	1279484

Details	Field Data
C <sub>3</sub> (Intervention costs for every 24 months)	695452
C <sub>1</sub> L <sub>1</sub>	6,2882E+11
C <sub>2</sub> L <sub>2</sub>	6,4412E+11
C <sub>3</sub> L <sub>3</sub>	6,9297E+11
C <sub>3</sub> L <sub>3</sub> - C <sub>2</sub> L <sub>2</sub>	4,8851E+10
C <sub>2</sub> L <sub>2</sub> - C <sub>1</sub> L <sub>1</sub>	1,5305E+10
A	24045,1
B	0,0500
C	6,1934E+11
D (Marginal cost of water)	10,00

The information seen in Table 23 above involved various calculations that can be found in Addendum 1.

Refer to Section 3.3.5 above for the calculations (Equation 31-42) used in part 5 to produce the final graph.

The next part of the model performs curve fitting for the leakage graph as per Table 24 below.

**Table 24.** Curve fitting for Leakage Graph

<b>Leakage</b>	1943	2017	2091	2165	2239	2313	2387	2461	2535	2609	2683
	711	663	615	567	518	470	422	374	326	278	230
<b>Interventi on Costs</b>	2447	1912	1574	1341	1172	1043	9430	8623	7963	7415	6954
	548	449	204	593	216	688	73	77	92	79	52
<b>Total Costs</b>	2188	2208	2249	2299	2356	2417	2481	2547	2614	2683	2752
	4656	9076	0350	7258	7401	8392	7297	6120	9654	4360	7752

The input parameters used are those that are calculated in Table 24 above. Curve fitting is performed to construct the curve with a line of best fit and apply it to the series of data points generated from the different parts of the model (Chatterjee *et al.*, 2015). In order to ensure the curve is correct and can be easily interpreted, the model performs curve fitting for the graph using existing data points. Additional points are used for the graph as seen in Table 25 below.

**Table 25.** Additional points for the graph

Details	Field Data		
	Ymax	Ymin	X Value
Minimum Level of Leakage	21884656	0	784250
Target Level of Leakage	21884656	0	1568500
Total Leakage	21884656	0	1687949

The minimum level of leakage for a system is also known as the Unavoidable Annual Real Losses. The target level of leakage is derived by simply scaling up the UARL by a factor. In this scenario, the factor used was 1 to ensure that a logical target level of leakage is reached. The result shows a leakage level that is known to be the Target Minimum Real Losses (TMRL).

#### 4.4.4 Annual costs graph

The model provides information on the cost of active leakage control, the unavoidable background losses, the base level of background losses, the base level of real losses including reported bursts, the cost of lost water and the total intervention costs. These costs are grouped here as the annual costs incurred when a burst or leakage happens in the study area. Figure 31 below, indicates that the cost of lost water in R1000's per year increases as the amount of real losses increases in 1000's m<sup>3</sup>/year. The gradient is steep; therefore, the gradient is larger.

$$\text{Gradient } (m) = \frac{\Delta y}{\Delta x}$$

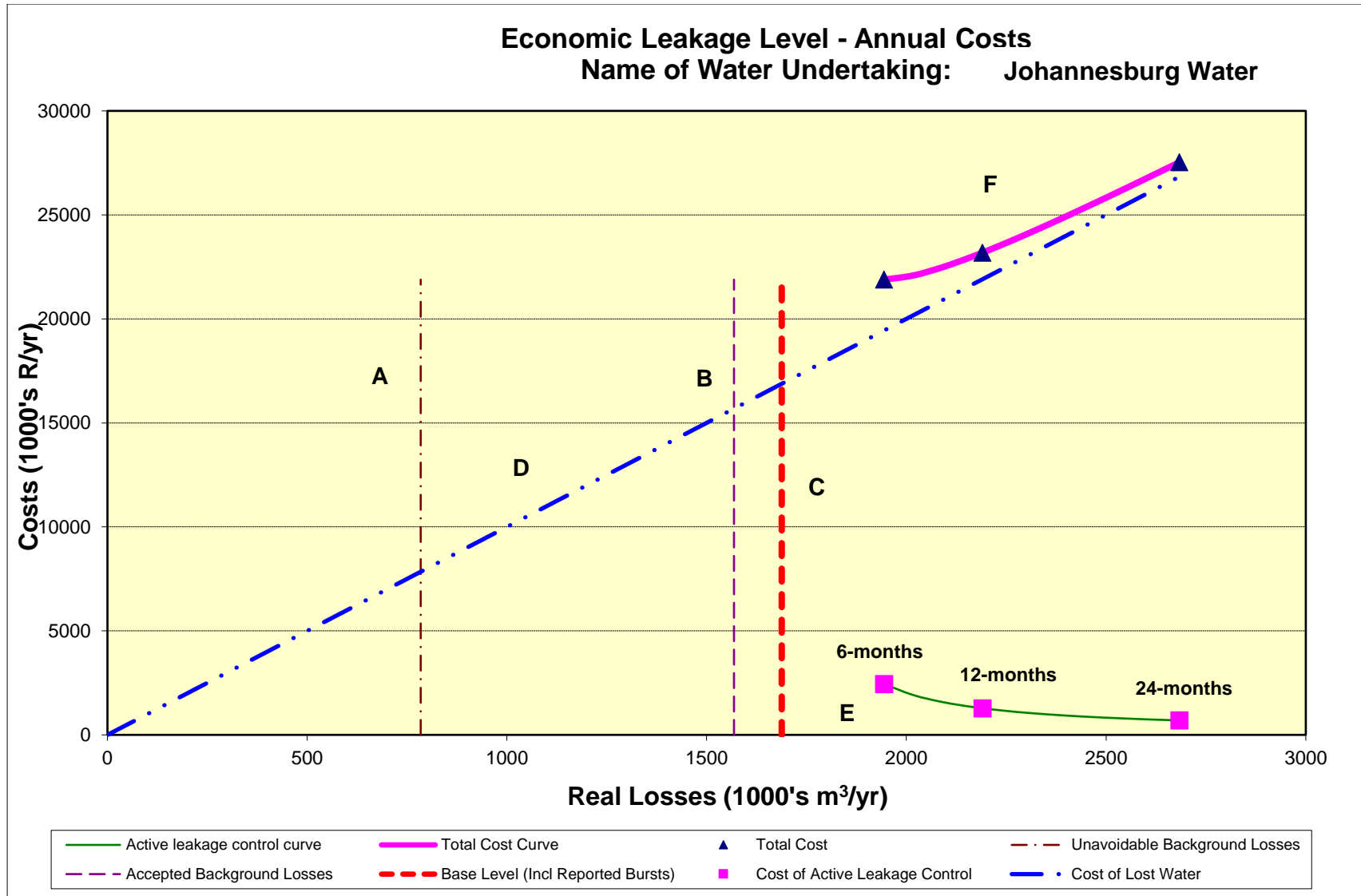
$$m = \frac{150\,000 - 100\,000}{2000 - 1500}$$

$$m = 100$$

#### Equation 43

The unavoidable background losses are depicted on the graph in Figure 31 below as **(A)**. Unavoidable background losses occur due to the small changes in the system that are undetected and have low flow rates. These losses are difficult to avoid from a technical view point but are usually considered manageable from an economic perspective (Sharma, 2008). The unavoidable background losses for Region A is 784 (1000's m<sup>3</sup>/year). The unavoidable background losses intersect the cost of lost water at 7800 (1000's R/year). The accepted background losses are represented by curve **(B)** on the graph below.

The accepted background losses include the cost of reducing the background losses along with the maintenance of the water distribution system and is measured against the cost of water saved as seen in the graph below. These losses are accepted as the cost of fixing the leakage outweighs the amount of water saved. The value of the accepted background losses for Region A is 1550 (1000's m<sup>3</sup>/year). The accepted background losses intersect the cost of lost water at 15 500 (1000's R/year). The unavoidable background losses and the accepted background losses are both included as real losses in the model as they can be accounted for by the water supplier. Real losses are leakages that occur on a very small scale in pipe joints and fittings as well as tanks used to store water.



**Figure 31.** Graph of results from the ECONOLEAK Model

The last type of water loss that is included as a real loss is the base level of losses which includes reported bursts. The base level of Annual Real Losses (ARL) is used as a prediction tool for the water distribution system in the case of real losses if all existing infrastructure is maintained. This also includes the detection and repair of leakages (Sharma, 2008). The base level of losses is indicated on the graph in Figure 31 and is represented as vertical line **(C)**. The base level of losses for Region A is 1650 (1000's m<sup>3</sup>/year). The base level of losses intersects the cost of lost water at 15 650 (1000's R/year). The cost of lost water through leakages is represented by curve **(D)** in Figure 31. The unavoidable background losses **(A)** and the accepted background losses **(B)** are both less than the total base level of annual real losses. The active leakage control curve is depicted in Figure 31 as curve **(E)**.

Active leakage control is the hands-on method of sending out teams that perform leakage detection and repair in zones of unreported burst pipes (Xu *et al.*, 2014). There are three points chosen for the cost of active leakage control that is joined to form the active leakage control curve. The x-values are those calculated for water losses for a number of interventions per year as seen in part 4. The y-values are the total costs of intervention at regular intervals as calculated in part 3 of the ECONOLEAK Model.

The first point on the active leakage control curve is for the 6-month intervention, the second point on the curve is the 12-month intervention and the last point is the 24-month intervention. The implication is that the total cost increases rapidly as the period of active leakage control is increased above the 6-month intervention interval and becomes asymptotic to the level of real losses. This highlights the fact that no matter the amount of money spent there will always be some level of real losses in the system. If the frequency of active leakage control is increased so too will the associated cost.

The total cost of intervention is represented by curve **(F)** above and illustrates the total cost for water losses for a number of interventions as seen in part 4 for x-values. The y-values are the total intervention costs found in part 4. The cost of active leakage control increases from the 6-month intervention to the 12-month intervention as the cost of lost water increases, therefore suggesting that the lowest cost is associated with the 6-month intervention. The cost of lost water **(D)** increases as the intervention period decreases **(E)**. The cost of intervention **(F)** thus increases as the intervention period decreases **(E)**. The study thus suggests that the implementation of active leakage control every 6 months will be appropriate for the Johannesburg Water system. Fantozzi (2006) indicated that the short run economic level of leakage (SRELL) is attained when the lost water curve is equal to the Active Leakage Control curve (Fantozzi *et al.*, 2006). However, In Region A, the curve for lost water is above that of

the Active Leakage Control curve due to the economic level of leakage being exceeded, active leakage control is therefore necessary.

During an interview with the Johannesburg Water Depot Manager for Region A, on the 1<sup>st</sup> of July 2019, it was established that the cost of bulk supply of water is currently R10 per cubic meter. Upon further discussions, it was noted that Johannesburg Water uses a System Applications Products which generates a date once every 4 months for a team to go out and undertake Active Leakage Control as part of demand management. The ECONOLEAK Model has suggested a 6-month intervention period as it is more cost effective, whereas the SAP System (Shibambu, 2019 ). It will cost Johannesburg Water more money to fix burst pipes that are left for longer than 4-months; therefore, routine maintenance is performed during shorter intervention periods.

#### **4.5 Suggestions to minimise water loss and strategies for effective water supply management**

The following suggestions were made by residents of region A on how to minimise water shortages; reduce the washing of cars and excessive garden watering, improve alerting methods of water shortages, better reaction and maintenance by local authorities and competent staff, improved infrastructure and awareness programmes, mitigation measures and monitoring, building more reservoirs and water towers to increase storage, maintain water pressure, use grey water for toilets, irrigation, etc, practice water harvesting, increase water supply, use leakage detection devices, ensure contingent plans are in place, improve management, partake in local government initiatives, fix all existing leakages and bursts and impose water restrictions to ensure no further wastage of water occurs.

During the study, residents were asked to give their opinion on how local authorities can contribute and assist in the reduction of water shortages. Their suggestions included among the others; repair damaged infrastructure, attend to water leakages in time, better management of funds and resources, improve town planning & infrastructure including storm water, water conservation initiatives, consistent monitoring, improved awareness and communication, address pollution directly, conduct research on alternative sources of water, stop malicious intent, provide water tanks to residents, increase water supply, educate and train staff, keep reliable records, promote transparency with residents, impose fines for water wastage, take initiative and conduct surveys for the need of upgrading infrastructure.

The study was interested in establishing the extent of Region A's resident's involvement in issues concerned with the management of water shortages. Top on the list of how respondents reacted especially when there was a water leakage was to report the problem to Johannesburg Water. A considerable percentage (38.0%) of residents were keen to report about water leakage. Other actions taken included attending community meetings (14.1%) and attending local authority meetings (13.0%). Among the residents, 9.8% had signed a petition regarding the water shortage while 8.7% of residents reported the water shortage to a member of a committee concerned with service delivery. Interestingly, 2.2% created a street group to pressurise service delivery and 1.1% joined a protest group on the streets.

The success of action by water consumers can only be achieved through any local initiatives or community awareness campaigns. Johannesburg Water has performed the following initiatives in Region A; local authority meetings, community meetings, water conservation information distribution, television advertisements, government campaigns, notices, incentives or rewards, penalties or fines.

Cross tabulation was performed to establish the association between the response given by residents once alerted of water shortages and the ways in which the residents involved themselves with the management of water shortages. There was only one significant association between the categories and is seen below.

***Relationship between residents waiting for the pipe to be fixed and water to be restored and attending community meetings.***

H<sub>0</sub>: There is no association between residents waiting for the pipe to be fixed and water to be restored and attending community meetings.

H<sub>1</sub>: There is an association between residents waiting for the pipe to be fixed and water to be restored and attending community meetings.

The resultant p-value of 0.029 was lower than the 0.05 level of significance. Therefore, the null hypothesis can be rejected, and the alternative hypothesis can be accepted. There is an association between residents waiting for the pipe to be fixed and water to be restored and attending community meetings. Implying that a certain percentage of people (not significant) got involved in community meetings, because of the impact of the water shortage and are more likely to participate in water leakage management.

The next important step after leakage detection and reducing the cost associated with leakages is to ensure the appropriate maintenance of operating systems. Maintenance functions include the quantities of network components being held in supply stores found in municipal areas for the rapid replacement and repair of pipes (Karbhari, 2015).

Water meters are useful for monitoring water usage. However, due to the aging of water meters, maintenance and replacement of old water meters must take place. If the water meter is maintained and functions optimally it can help reduce unnecessary water usage and loss (Koech *et al.*, 2015). Pipes should be maintained prior to the ending of their economic service lives to ensure leakages are prevented and to save the cost of repairing burst pipes. District meters are isolated from the rest of the distribution system and are installed at specific supply points. These areas are installed with Pressure Reducing Valves which ensures the management of pressure within the system and can be implemented into District Metered Areas (Giugni *et al.*, 2013). The PRV can limit the pressure within the outlet to attain a certain maximum value, that it will not surpass which reduces costs. Pressure controls using time-modulations can also be implemented into the PRV but will vary on a 24-hour period which leads to higher pressures during the night when the demand is low.

It has become evident that access to clean water is jeopardized by water leakages and traditional approaches to solving modern day problems are no longer compatible. In a study conducted by Marunga *et al.* (2006), Water Demand Management (WDM) is used in Mutare, Zimbabwe (Marunga *et al.*, 2006). This is a new approach that is aimed at addressing the demand for water and the need to improve the efficiency of distribution systems. The two WDM strategies that are implemented in this study are pressure management and leakage control.

Mutare, much like the study area of Midrand, also experiences many water leakages. These water leakages are also due to aging infrastructure and metering that was only functioning at 25% at high system pressures. Another problem identified was a loss of 57% of the water due to Unaccounted for Water. The aim of the study was to implement pressure management in the system where normal operating pressure varied around 75-85 m. The programme used to model pressure management was called Epanet (Marunga *et al.*, 2006). Epanet modelled the pressure distribution where results were derived by using the Minimum Night Flows and showed that at 77 m, Unaccounted for Water due to leakage was only at 25%. Epanet used nodal elevations based on a consumption value of 1m<sup>3</sup> per property per

day to determine the pressure at peak hourly flows. The Hazen- Williams formula was used for the model to simulate pressure (Marunga *et al.*, 2006).

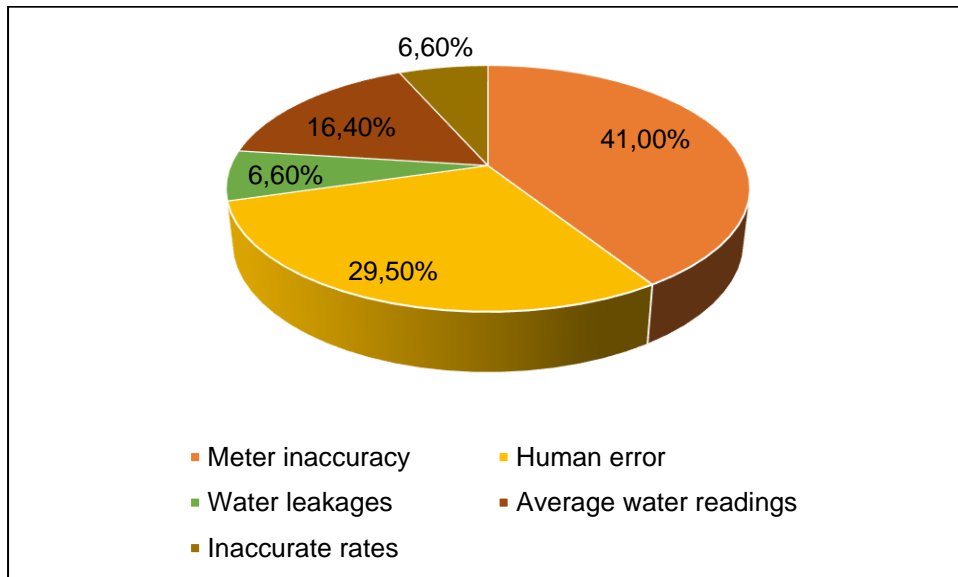
In a study conducted by Puust *et al* (2010), various methods for leakage management in pipe networks were assessed (Puust *et al.*, 2010). The aim of the study was to assess various methods of leakage management and their optimal functioning. In order to achieve the aim of the study, different management methods were classified into areas which focus on the quantification of the amount of water lost. Leakage detection methods were concerned primarily with hotspots and lastly, leakage mitigation and control models were used to help prevent future leakages.

The two approaches taken were the top-down approach and the bottom up approach. The top down approach uses leakage assessment practices to assess the overall water balance and the water that is consumed in the system. A leakage estimate was derived during this methodology and can be referred to as the crude estimate. This will help in the decision making process of pipe leakages but cannot identify potential areas of leakage (Puust *et al.*, 2010). The second approach is the bottom up approach and requires more information such as the systems accounting principles and billing records to ascertain the competence of the water distribution system. Two procedures can be used, either the 24-Hour Zone Measurement (HZM) or the Minimum Night Flow. The HZM uses temporary areas of isolation within the distribution network and uses the inflow from one or two points and was found to be most beneficial (Candelieri *et al.*, 2013).

Residents who live in Region A have also taken an interest in the billing system that is used in their residential area. Through the analysis of billing systems, discrepancies in the costing of water and volumes of water used or supplied can be identified (Reddick, 2018). Amongst the residents living in Region A, 85.7% of 72 residents have received an inaccurate bill while 14.3% have never received an inaccurate bill. The causes of the inaccurate billing, according to residents, can be seen in Figure 32 below. The main cause of inaccurate billing was due to meter inaccuracy followed by human error. The lowest selected cause of inaccurate billing was due to water leakages. This could be an indication of the extent to which the residents are unaware of the leakage problem, or the leakage problem is not that serious

However, 94.4% of residents stated that smart meters are a good option for billing accuracy while 5.6% of residents do not encourage smart meters They propose that other methods of improving billing include monthly and consistent actual meter readings, pre-paid meters and only paying for water that comes into the household. They further stated that their

current meters do work, and the installation of smart meters may be inconvenient. It also may be cheaper to fix existing meters. Water suppliers do not encourage smart meters as the installation is expensive and the existing meters can be upgraded at a lower cost.



**Figure 32.** Reasons that residents experienced inaccurate billing

## **Chapter 5- Conclusion and recommendations**

The objectives of this study were to investigate the causes of water leakages and bursts in the study area within the Midrand region, investigate the costs associated with leakage detection and intervention, quantify real and apparent losses in the network and make suggestions and recommendations to minimise water loss and propose strategies for effective water supply management through the use of the ECONOLEAK Model and the distribution of questionnaires.

The results obtained showed that a pragmatic approach is possible towards mitigating water leakages in a cost effective and time efficient manner. The ECONOLEAK Model can thus be used as a tool to assess the optimal active leakage control period, the accepted background losses, the total cost incurred due to water leakages, the base level of reported bursts and the unavoidable background losses. Based on the results of the study, the following conclusions and recommendations can be made:

### **5.1 Conclusions and recommendations derived from the ECONOLEAK Model**

#### **Conclusions**

- i. It was found that in Region A of the Johannesburg Water supply area, reported bursts accounted for 84.71% of the total bursts for the year of 2018. While the remaining unaccounted-for bursts leading to water leakages was 15.29% of the total bursts. The total Unavoidable Annual Real Losses for the system was 1.098964 m<sup>3</sup>/year. This reflects well for the Johannesburg Water suppliers as they know where most of their bursts have taken place. This can aid in the mitigation of bursts and reduce the amount of time and money spent locating the bursts as compared to those bursts that are unaccounted for.
- ii. The ECONOLEAK model was found to be a suitable prediction tool for pipeline replacement. The Infrastructure Leakage Index for Region A was calculated by the model to be 5.6. In developing countries such as South Africa, an Infrastructure Leakage Index above 8 would ideally require pipeline replacement (Yuchen Lu, 2014 ). Therefore, according to the ECONOLEAK Model, Region A does not need to replace pipelines currently.
- iii. The ECONOLEAK Model analysed the costs associated with leak detection and intervention and all real and apparent losses were quantified in Section 3.3. The graph in Section 4.4.4 shows that active leakage control is required for Region A's water distribution system. The ECONOLEAK Model suggested a 6-month intervention period for Active Leakage Control as a more cost-effective interval, whereas the SAP System used by

Johannesburg Water suggests a 4-month intervention period due to the number of leakages.

## **Recommendations**

Based on the analysis, findings and conclusions derived above, the following recommendations can be made.

### ***Institutional***

- The utility in the Johannesburg Water supply area must start active leakage control immediately as this will aid in the effective management of real and apparent losses.
- Johannesburg water currently uses Pressure Reducing Valves and have a system of routine maintenance and monitoring. However, due to the influx of people into the water utility region, the appropriate urban water demand management options must be put in place which could include the following (Task *et al.*);
  - the setting of appropriate tariffs which consider the needs and willingness to pay of the poor;
  - improved revenue collection;
  - the formation of water user associations to represent and reflect the demands of local people;
- Bulk meters can be used to monitor water usage to target and reduce higher consumption.
- The water supplier should assume the role of the facilitator in organising and coordinating emergency and conservation actions required of residents and private based institutions.
- The roles and functions of various formal and informal institutions within the study area need to be rationalised in terms of the possible functional support they can provide during periods of crises.
- Organisations that send out pipe burst, and water shortage alerts should state what type of measures can be taken. Assistance can be provided to residents in times of shortages such as the provision of water tanks.
- Organisational support in terms of monitoring infrastructure needs to be established to inform the relevant authorities of possible large water leakages and shortages.

### ***Technical***

- Smart meters are relatively expensive. Due to the large number of houses found in Region A, prepaid meters are a better option as compared to the conventional meters that are

used and the option of smart meters. Prepaid meters can be installed in regions with a higher Minimum Night Flow.

- Pressure reduction should be implemented in areas where high pressures can be reduced significantly irrespective of payback periods based on leakage/pressure and pressure/burst frequency relationships. This can be done by using Pressure Reducing Valves, reticulation valves, fire hydrants and pipe components at intervals. The fire hydrant can be positioned so that it can be used as a scour valve (scour valves are located at low points or between valve sections of the pipeline to allow periodic flushing of the lines to remove sediment and reduce system pressures) (Van Niekerk *et al.*, 2015).
- Water suppliers can install a pump station that assists the operation of all pumps and equipment.
- Water level indicators can be checked on a regular basis and discrepancies or variations can be assessed.
- A maintenance register can be kept for reservoirs and pipes. Reservoirs can be checked for overflow and signs of leakage.
- Data loggers and programmes such as Zednet can be used to track Minimum Night Flows and hence identify leakages and provide the optimal solution in the instance of a leakage. It shortens the process of identifying leakages and therefore reduces the cost associated with lost water.
- The ECONOLEAK Model has 3 leakage intervention intervals only. To make the model more accurate and precise, more leakage intervention intervals can be added to reflect the periodic accuracy with which interventions should take place.

### ***Financial***

- The condition of existing services should be evaluated, and only then should decisions be made on the appropriateness of new versus upgraded infrastructure as well as the level of services instituted. This issue will have cost implications for the implementing organisation as well as the community involved.
- It is also recommended that the local authority budget for maintenance of the systems, programmes and assets to be procured which might have recurrent cost implications.
- The community should be adequately consulted with regards to tariff structures that might be changed or increased to accommodate the various planning and construction exercises to prevent future leakages and shortages.
- In the instance of illegal connections and those who cannot afford to pay for water, social packages can be distributed. There are child headed households that may require such packages.

## ***Education***

- Insuring homes against damage during pipe bursts is an important decision that all homeowners should consider. The full range of costs and benefits, including social dislocation to individuals, should be fully compensated by adequately insuring property and life.
- There is also a need for educational authorities and voluntary conservation organisations to conduct environmental education programmes as part of an awareness programme informing the community on how the environment can be managed and what benefits can be accrued.
- It is proposed that a forum be established to give the community an opportunity to express their opinions, expectations and perceptions surrounding environmental problems and issues such as water leakages and shortages. Propagation of community involvement in urban decision-making should also be encouraged.

## ***Legal***

South Africa's institutional structure for delivering water is well developed and involves the national and provincial government, municipalities, water services providers, water service intermediaries, water services committees and water boards (Toxopeüs, 2019). There are various legislative and regulatory frameworks that assist the institutional structure in the management of water supply. In addition to this, Best Practice Guidelines were compiled by the Department of Water and Sanitation that should be implemented by mines, municipalities and irrigation schemes, industries and other water users. Below are some examples of the documents available to regulate water supply and demand;

- National Water Conservation and Demand Management Strategy
- National Water Resource Strategy
- The National Water and Sanitation Plan
- Integrated Water Quality Management Policy and Strategy
- Reconciliation strategy for water
- The Water Services Act 108 of 1997
- The National Water Act 36 of 1998 and regulations (example- GN 982 of 2017-National Norms and Standards for Domestic Water and Sanitation Services)
- National Environmental Management Act 107 of 1998 which includes the management of water resources
- South African Water Quality Guidelines. 2<sup>nd</sup> Edition. Volume 1: Domestic use.

- Bests Practice Guideline - G3: Water Monitoring Systems.

All the examples above deal with aspects of water resource protection, management, access, conservation and monitoring. The problem faced is a lack of communication and synergy between the different institutions in the management of water resources and supply thereof. The implementation of the documents and political will to do so is also lacking. The absence of responsibility, and enforcement of legislation makes it more difficult to implement the strategies, policies and Best Practice Guidelines and that have been developed.

Social upliftment and education and the most difficult of all, changing perceptions and social and personal attitudes are some of the most important aspects in our failure to conserve and protect our water. Bad governance in combination with non-payments challenges the financial management of water resources.

## **5.2 Conclusions and recommendations derived from the questionnaire survey**

### **Conclusions**

- i. It was found that 83.1% of residents in the study area have experienced a burst pipe or water leakage while living in the area. The water supplier, Johannesburg Water, stated that they are informed of water leakages at least once a month or more frequently. Therefore, water leakages are a significant problem in Region A.
- ii. Residents selected damaged pipe joints and negligence by local authorities as to the main cause of water leakages while water suppliers stated that intruding tree roots, rapid temperature changes and pressure differences cause pipe bursts in Region A.
- iii. Residents felt that the worst impact experienced during water leakages is water shortages and loss of water accompanied by a change in the colour of water once it is restored after a water shortage.
- iv. The largest cost incurred by residents during times of water leakages and shortages is the cost of buying water and driving to sources of water.
- v. Water suppliers stated that pressure management, meters to monitor water usage, upgrading old infrastructure and increasing the frequency of maintenance of infrastructure will mitigate pipe bursts and subsequent water leakages.
- vi. Residents are informed about pipe bursts and water leakages by friends and relatives while Johannesburg Water sends out the notices, radio alerts and newspapers. There is, therefore, a communication gap between residents and the water supplier.

- vii. In terms of activities during water leakages and shortages, 47.8% of residents wait for the burst pipe to be fixed and water to be restored instead of acting while 11.9% of residents report the burst to the water supplier.
- viii. In terms of meter inaccuracies and water leakages, 85.7% of residents have received an inaccurate bill due to human error and 94.4% of residents would suggest smart meters to detect leakages. Water suppliers stated that they would not use smart meters to detect water leakages as the installation is expensive.

### **Recommendations**

The following recommendations were given by residents in Region A and Johannesburg Water employees dealing with the water distribution network.

#### ***Minimising water leakages and bursts***

The following suggestions and recommendations made by residents to minimise water leakages and bursts in the study area;

- Maintaining and upgrading water infrastructure in the study region.
- Ensure monitoring and planning is conducted by local authorities.
- Increased awareness regarding water conservation.
- Repairs should be done correctly and promptly by efficient staff.
- Trees must be maintained and relocated away from pipelines that they have the potential to intrude.
- Water meters can be used to detect water leakages and bursts.
- Proper budgeting should be undertaken regarding the maintenance of the water distribution network.
- Due diligence must be done by contractors to ensure that the location of pipes is known.
- Local authorities must take accountability in mitigating the problem of water leakages and shortages.
- Water bills should be checked on a regular basis.
- Water conservation must be practiced in conjunction with the improved management of water resources.
- Pipe joints that are broken must be fixed quickly and competent staff must be employed.
- Investigation of alternative water purification systems.
- The approval of new developments that have an extensive impact on water distribution infrastructure must be duly considered.

### ***Minimising water shortages***

The following suggestions were made by residents to assist in the reduction of water shortages;

- Reduce the frequency with which cars are washed along with excessive watering of gardens.
- Water shortage alert methods must be improved as residents are informed by friends and relatives of the water shortage and not by the water supplier.
- Improved reaction and maintenance by local authorities and competent staff is necessary.
- Infrastructure management must be improved while awareness programmes are implemented.
- More reservoirs and water towers must be built to increase the storage of water.
- Grey water can be used for toilets and irrigation along with other water use activities.
- Water harvesting can be practiced by residents.
- Leakages detection devices should be used to identify water shortages promptly.
- Residents and water suppliers should partake in local government initiatives.
- Water suppliers should focus on fixing all existing leakages and bursts to maximise resource use efficiency.
- Impose water restrictions when necessary to ensure no further wastage of water occurs.

### ***The role of local authorities in preventing water shortages***

The following suggestions were given by residents regarding the role that local authorities can play in preventing water shortages;

- Ensure that damaged infrastructure is repaired while attending to water leakages promptly.
- Maintain the water distribution network and focus on improving the management of funds and resources.
- Improve town planning and infrastructure along with storm water management.
- Promote water conservation initiatives while improving awareness and communication within the community.
- Carry out research initiatives on alternative sources of water.
- Reduce the occurrence of malicious intent.
- Provide water tanks to residents and assist in increasing water supply.
- Educate and train staff to assist with mitigating water shortages.

- Keep reliable records pertaining to water leakages and shortages or ensure that the water supplier has these records.

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## ADDENDUM 1: CALCULATIONS PERFORMED IN THE ECONOLEAK MODEL

### Part 1: General information and calculation of Unavoidable Annual Real Losses and Infrastructure Leakage Index

#### **Unavoidable Annual Real Losses (UARL)**

Equation 2:

$$UARL = (18 \times Lm + 0.80 \times Nc + 25 \times Lp) \times P$$

$$UARL = (18 \times 1032km + 0.80 \times 52\,000\text{ connections} + 25 \times 0\text{ connections}) \times 50m$$

$$UARL = 3008800 \frac{l}{d} \div 1000$$

$$UARL = 3008,8 \text{ m}^3/d \times 365,25$$

$$UARL = 3008,8 \text{ m}^3/\text{year} \times 365,25$$

$$UARL = 1098964,2 \text{ m}^3/\text{year}$$

UARL is measured in  $\text{m}^3/\text{year}$

#### **Infrastructure Leakage Index (ILI):**

Equation 3:

$$ILI = \frac{CARL}{UARL}$$

$$ILI = 6144809,061 \text{ m}^3/\text{year} \div 1098964 \text{ m}^3/\text{year}$$

$$ILI = 5,6$$

ILI is an index and does not have a unit

Equation 4:

Current Annual Real Losses CARL = Water Losses – Current Annual Apparent Losses (CAAL)

$$CARL = 8160437 \frac{\text{m}^3}{\text{year}} - 2015627,939 \frac{\text{m}^3}{\text{year}}$$

$$CARL = 6144809,061 \frac{\text{m}^3}{\text{year}}$$

## Part 2: Losses from reported and unreported bursts

### Number of bursts per year

Equation 6:

Number of bursts = Length of mains and number of service connections  $\times$  frequency of bursts

Transmission mains:  $0.030 \text{ per km} \frac{\text{mains}}{\text{yr}} \times 56\text{m} = 1.7 \text{ number of bursts}$

Distribution mains:  $0.150 \text{ per km} \frac{\text{mains}}{\text{yr}} \times 976\text{m} = 1.7 \text{ number of bursts}$

Equation 7:

Number of bursts = Number of service connections  $\times$  frequency of bursts  $\div$  100

Connections:  $2.5 \text{ per } 1000 \frac{\text{conn}}{\text{yr}} \times 52\,000 \div 1000 = 130 \text{ number of bursts}$

### Losses from reported burst (adjusted for local pressure)

Equation 8:

Losses from reported bursts =

Number of bursts per year  $\times$  duration days of the burst  $\times$  24 h  $\times$  rate of loss  $\frac{\text{m}^3}{\text{hour}} P^{N1} / 365$

Transmission mains:  $1.7 \text{ bursts per year} \times 1 \text{ duration days} \times 24 \times 30 \frac{\text{m}^3}{\text{hour}} = \text{ANS}_{365}^{0.5} = 3,3$

Distribution mains:  $146.4 \text{ bursts per year} \times 1.5 \text{ duration days} \times 24 \times 12 \frac{\text{m}^3}{\text{hour}} = \text{ANS}_{365}^{0.5} = 117,3$

Connections:  $130 \text{ bursts per year} \times 11 \text{ duration days} \times 24 \times 1.6 \frac{\text{m}^3}{\text{hour}} = \text{ANS}_{365}^{0.5} = 150.4$

### Losses from unreported bursts at regular inspection intervals (adjusted for local pressure)

Equation 9:

Every 24 months:

Losses from unreported bursts every 2 years = Average losses  $\frac{\text{m}^3}{\text{day}} \times 365 + \text{repair time}$

Transmission mains:  $0 \frac{\text{m}^3}{\text{day}} \times (365 \text{ days} + 0.5 \text{ days}) = 0,0 \text{ m}^3/\text{day}$

Distribution mains:  $2.89 \frac{\text{m}^3}{\text{day}} \times (365 \text{ days} + 0.5 \text{ days}) = 1055,5 \text{ m}^3/\text{day}$

Connections:  $4.51 \frac{m^3}{day} \times (365 \text{ days} + 6 \text{ days}) = 1674,4 \text{ m}^3/day$

Service pipes:  $0 \frac{m^3}{day} \times (365 \text{ days} + 6 \text{ days}) = 0,0 \text{ m}^3/day$

*Equation 10:*

Every 12 months:

*Losses from unreported bursts every year = Average losses  $\frac{m^3}{day} \times \frac{365}{2} + \text{repair time}$*

Transmission mains:  $0 \frac{m^3}{day} \times (365 \text{ days}/2 + 0.5 \text{ days}) = 0,0 \text{ m}^3/day$

Distribution mains:  $2.89 \frac{m^3}{day} \times (365 \text{ days}/2 + 0.5 \text{ days}) = 528,5 \text{ m}^3/day$

Connections:  $4.51 \frac{m^3}{day} \times (365 \text{ days}/2 + 6 \text{ days}) = 850,8 \text{ m}^3/day$

Service pipes:  $0 \frac{m^3}{day} \times (365 \text{ days}/2 + 6 \text{ days}) = 0,0 \text{ m}^3/day$

*Equation 11:*

Every 6 months:

*Losses from unreported bursts every 6 months = Average losses  $\frac{m^3}{day} \times \frac{365}{4} + \text{repair time}$*

Transmission mains:  $0 \frac{m^3}{day} \times (365 \text{ days}/4 + 0.5 \text{ days}) = 0,0 \text{ m}^3/day$

Distribution mains:  $2.89 \frac{m^3}{day} \times (365 \text{ days}/4 + 0.5 \text{ days}) = 265,0 \text{ m}^3/day$

Connections:  $4.51 \frac{m^3}{day} \times (365 \text{ days}/4 + 6 \text{ days}) = 438,9 \text{ m}^3/day$

Service pipes:  $0 \frac{m^3}{day} \times (365 \text{ days}/4 + 6 \text{ days}) = 0,0 \text{ m}^3/day$

### **Part 3: Costs of water and intervention costs**

*Costs for an intervention at regular intervals*

*Equation 12:*

Every 24 months:

Administrative set up costs= *Administrative cost* ÷ 2

Administrative set up costs:  $R5000 \div 2 = R2500$

Every 12 months

Administrative set up costs: R5000

Every 6 months

Administrative set up costs:  $R5000 \div 0,5 = R10\ 000$

*Equation 13:*

Manpower inspection costs=

$$\begin{aligned} & (\text{Cost for regular sounding per km} \\ & \quad + (\% \text{ coverage required for correlation}) \times \text{cost for correlation per km}) \\ & \quad \times \text{Total length of mains}/2 \end{aligned}$$

Every 24 months:

Manpower inspection costs:  $+(R780\text{km} + (20\% \div 100) \times R1000\text{km}) \times 1032\text{km} \div 2 = R505680$

Every 12 months:

Manpower inspection costs:  $+(R780\text{km} + (20\% \div 100) \times R1000\text{km}) \times 1032\text{km} \div 1 = R1011360$

Every 6 months:

Manpower inspection costs:  $+(R780\text{km} + (20\% \div 100) \times R1000\text{km}) \times 1032\text{km} \div 0,5 = R2022720$

*Equation 14:*

Supervision costs= *Manpower inspection costs*  $\times$  *supervision as % of inspection costs*

Every 24 months:

Supervision costs:  $R505680 \times 15\% = R75852$

Every 12 months:

Supervision costs:  $R1011360 \times 15\% = R151704$

Every 6 months:

Supervision costs:  $R2022720 \times 15\% = R303408$

*Equation 15:*

Mains repair costs=

*Number of unreported bursts per year (transmission and distribution mains) ×  
cost to repair mains leak*

Every 24 months

Mains repair costs: *(0 number of bursts per year + 7.3 number of bursts per year) ×  
R3500 = R25620*

Every 12 months

Mains repair costs: *(0 number of bursts per year + 7.3 number of bursts per year) ×  
R3500 = R25620*

Every 6 months

Mains repair costs: *(0 number of bursts per year + 7.3 number of bursts per year) ×  
R3500 = R25620*

*Equation 16:*

Connection repair costs=

*Number of unreported bursts per year (connections and service pipes) ×  
cost to repair services or connection leakages*

Every 24 months

Connection repair costs: *(42.9 number of bursts per year + 0 number of bursts per year) ×  
R2000 = R 85800*

Every 12 months

Connection repair costs: *(42.9 number of bursts per year + 0 number of bursts per year) ×  
R2000 = R 85800*

Every 6 months

Connection repair costs: *(42.9 number of bursts per year + 0 number of bursts per year) ×  
R2000 = R 85800*

#### **Part 4: Financial analysis for active leakage control**

##### ***Unavoidable background losses (adjusted for local pressure) in m<sup>3</sup>/day***

All calculations take place at 50 m pressure

*Equation 17:*

Transmission mains=

*Unavoidable background leakage × length of transmission mains × 24 (P<sup>N1</sup>/1000)*

$$= 20 \frac{l}{km \cdot hr} \times 56 km \times 24 (50^{1,5}/1000)$$

$$= 27 m^3/day$$

*Equation 18:*

Distribution mains=

*Unavoidable background leakage × length of distribution mains × 24 (P<sup>N1</sup>/1000)*

$$= 20 \frac{l}{km \cdot hr} \times 976 km \times 24 (50^{1,5}/1000)$$

$$= 468 m^3/day$$

*Equation 19:*

Connections=

*Unavoidable background leakage × number of service connections × 24(P<sup>N1</sup>/1000)*

$$= 1,25 l/conn/hr \times 52000 \times 24 (50^{1,5}/1000)$$

$$= 1560 m^3/day$$

*Equation 20"*

Service pipes=

*Unavoidable background leakage × number of service connections × 24 (P<sup>N1</sup>/1000)*

$$= 0 l/conn/hr \times 52000 \times 24 (50^{1,5}/1000)$$

$$= 0 m^3/day$$

*Equation 21:*

Service reservoirs:

*Unavoidable background leakage Total volume of Storage Reservoirs in the System × 10*

$$= 0,1 \% \text{ of capacity/day} \times 91,8 \text{ Ml} \times 10 (50^{1,5}/1000)$$

$$= 92 m^3/day$$

##### **Base level for annual real losses**

A= Base level of background losses m<sup>3</sup>/day

B=-Total background losses for bursts m<sup>3</sup>/day

C= Losses for interventions m<sup>3</sup>/day

Base level for annual real losses

Details	Equations (m <sup>3</sup> /day)
<b>Storage Reservoirs</b>	<b>Equation 22</b>
	(A + B) for storage reservoir
	=183,6 m <sup>3</sup> /day + 0 m <sup>3</sup> /day= 183,6 m <sup>3</sup> /day
<b>Transmission Mains</b>	<b>Equation 23</b>
	(A + B) for transmission mains
	53,8 m <sup>3</sup> /day + 3,3 m <sup>3</sup> /day = 57,1 m <sup>3</sup> /day
<b>Distribution Mains</b>	<b>Equation 24</b>
	(A + B) for distribution mains
	937,0 m <sup>3</sup> /day + 173,3 m <sup>3</sup> /day= 1110,2 m <sup>3</sup> /day
<b>Connections</b>	<b>Equation 25</b>
	(A + B) for connections
	3120,0 m <sup>3</sup> /day + 150,4 m <sup>3</sup> /day =3270,4 m <sup>3</sup> /day
<b>Service Connections</b>	<b>Equation 26</b>
	(A + B) for service connections
	0,0 m <sup>3</sup> /day + 0,0 m <sup>3</sup> /day =0,0 m <sup>3</sup> /day

Water losses for number of interventions per year

Component	24 months	12 months	6 months
<b>Services reservoirs</b>	B	B	B
	= 183,6 m <sup>3</sup> /day	= 183,6 m <sup>3</sup> /day	= 183,6 m <sup>3</sup> /day
	<b>Equation 27</b>	<b>Equation 28</b>	<b>Equation 29</b>
	(A + C) (24 months)	(A + C) (12 months)	(A + C) (6 months)
<b>Transmission mains</b>	57,1 m <sup>3</sup> /day +0,0 m <sup>3</sup> /day	57,1 m <sup>3</sup> /day +0,0 m <sup>3</sup> /day	57,1 m <sup>3</sup> /day +0,0 m <sup>3</sup> /day
	= 57,1 m <sup>3</sup> /day	= 57,1 m <sup>3</sup> /day	= 57,1 m <sup>3</sup> /day
<b>Distribution Mains</b>	1110,2 m <sup>3</sup> /day +1055,5 m <sup>3</sup> /day	1110,2 m <sup>3</sup> /day + 528,5m <sup>3</sup> /day	1110,2 m <sup>3</sup> /day +265,0 m <sup>3</sup> /day

	= 2165,8 m <sup>3</sup> /day	= 1638,7m <sup>3</sup> /day	= 1375,2 m <sup>3</sup> /day
<b>Connections</b>	3270,4 m <sup>3</sup> /day +1674,4 m <sup>3</sup> /day	3270,4 m <sup>3</sup> /day +850,8 m <sup>3</sup> /day	3270,4 m <sup>3</sup> /day +438,9 m <sup>3</sup> /day

**Total intervention costs**

Equation 30

Total cost=

Highest marginal cost of water water losses for number of interventions per year

Every 24 months: R2683230 × 2

Every 12 months: R2190217 × 2

Every 6 months: R1943711 × 2

**Part 5 and 6: Curve fitting information and summary graph of intervention costs against savings**

Curve fitting for intervention costs and leakage costs compared

<b>Equation 31:</b> $L_1 - L_b = L_1$	<b>Equation 32:</b> $L_2 - L_b = L_2$
$1943711m^3/year - 1686793m^3/year = 256918 m^3/year$	$2190217m^3/year - 1686793m^3/year = 503424 m^3/year$
<b>Equation 33:</b> $L_3 - L_b = L_3$	<b>Equation 34:</b> $L_3 - L_2$
$2683230m^3/year - 1686793m^3/year = 996437 m^3/year$	$996437m^3/year - 503424m^3/year = 493013m^3/year$
<b>Equation 35:</b> $L_2 - L_1$	<b>Equation 36:</b> $L_2^2 - L_1^2$
$503424m^3/year - 256918m^3/year = 246506m^3/year$	$503424^2 m^3/year - 256918^2 m^3/year = 1.8743E^{11} m^3/year$
<b>Equation 37:</b> $L_3^2 - L_2^2$	<b>Equation 38:</b> $C_1 L_1$
$996437^2 m^3/year - 503424^2 m^3/year = 7.3945E^{11} m^3/year$	$R2447548 \times R256918 = R6.2883E^{11}$
<b>Equation 39:</b> $C_2 L_2$	<b>Equation 40:</b> $C_3 L_3$

$R1279484 \times R503424 = R6.4412E^{11}$	$R695452 \times 996437m^3/year = R6.9297E^{11}m^3/year$
<b>Equation 41:</b> $C_3L_3 - C_2L_2$	<b>Equation 42:</b> $C_2L_2 - C_1L_1$
$R6.9297E^{11} - 6.4412E^{11} m^3/year = R4.8851E^{10}m^3/year$	$R2.802E^{12} - 4.76E^{12} m^3/year = 1.5305E^{10} m^3/year$

## ADDENDUM 2: PERMISSIONS FROM WATER SUPPLIER

### Addendum 2A: Signed permission letter from the custodian of data



UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA

Dear Sir

**RE: REQUEST FOR PERMISSION TO DO RESEARCH USING JOHANNESBURG WATER COLLECTED DATA**

I hereby wish to apply for permission to gain access to existing data at the Johannesburg Water Depot in Midrand.

My research project will involve collecting information from the Johannesburg Water supplier. My research topic is "Investigating Water Leakages in the Midrand Region and the Associated Cost Through Implementation of the Econoleak Model."

This study will involve the assessment of various causes of bursts in the network, water leakages and subsequent water loss in selected wards of the Midrand region. In order to achieve the overall aim of this study, further objectives have been devised and are as follows; to investigate the causes of water leakages and bursts in the study area of the Midrand region, to investigate the costs associated with leak detection and intervention, to quantify real and apparent losses in the network, and to make suggestions and recommendations to minimise water loss and propose strategies for effective water supply management.

I would like to gain access to the data Johannesburg Water has collected regarding my project to complete my objectives using the Econoleak Model. It is my presumption that the research findings will make a creditable contribution towards identifying leakages in the network in a time efficient and cost-effective manner.

Yours sincerely,

Deshree Pillay

Handwritten signature of Deshree Pillay on a dashed line.

Permission Granted

Akani Shivambu

Handwritten signature of Akani Shivambu on a dashed line.

**Addendum 2B: Signed permission letter from the manager of Region A's depot**



UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA

Dear Sir

**RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH IN THE JOHANNESBURG WATER DEPOT**

I hereby wish to apply for permission to gain access to conduct research at the Johannesburg Water Depot in Midrand.

My research project will involve collecting information from the Johannesburg Water supplier. My research topic is "Investigating Water Leakages in the Midrand Region and the Associated Cost Through Implementation of the Econoleak Model."

This study will involve the assessment of various causes of bursts in the network, water leakages and subsequent water loss in selected wards of the Midrand region. In order to achieve the overall aim of this study, further objectives have been devised and are as follows; to investigate the causes of water leakages and bursts in the study area of the Midrand region, to investigate the costs associated with leak detection and intervention, to quantify real and apparent losses in the network, and to make suggestions and recommendations to minimise water loss and propose strategies for effective water supply management.

I would like to hand out questionnaires to Johannesburg Water employees that are working at the Midrand depot who will be able answer questions regarding my research. It is my presumption that the research findings will make a creditable contribution towards identifying leakages in the network in a time efficient and cost-effective manner.

Yours sincerely,

Deshree Pillay

Handwritten signature of Deshree Pillay on a dashed line.

Permission Granted

Akani Shivambu

Handwritten signature of Akani Shivambu on a dashed line.

### ADDENDUM 3: PERMISSIONS FROM RESIDENTS

#### Addendum 3A: Permission from the representative in Pacific Gardens

#### PARTICIPANT'S INFORMATION & INFORMED CONSENT DOCUMENT

**STUDY TITLE:** Investigating water leakages in the Midrand region and the associated cost through implementation of the Econoleak Model.

**Supervisor:** Dr FWN Nsubuga

**Principal Investigator/s:** Deshree Pillay

**Institution:** University of Pretoria

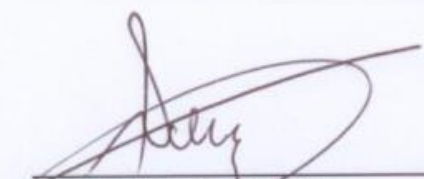
**Dear Prospective Participant**

Dear Mr / Ms / Mrs Dan Pillay representing the Pacific Gardens (complex/ estate name).

- I confirm that the person requesting my consent to take part in this study has told me about the nature and process, any risks or discomforts, and the benefits of the study.
- I have also received, read and understood the above written information about the study.
- I have had adequate time to ask questions and I have no objections to participate in this study.
- I am aware that the information obtained in the study, including personal details, will be anonymously processed and presented in the reporting of results.
- I understand that I will not be penalised in any way should I wish to discontinue with the study and my withdrawal will not affect my employment or student status.
- I am participating willingly.
- I have received a signed copy of this informed consent agreement.

PACIFIC GARDENS  
Complex name (Please print)

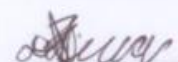
20/01/2019  
Date

  
Representative's signature

20/01/2019  
Date

DESHREE PILLAY  
Researcher's name (Please print)

20/01/2019  
Date

  
Researcher's signature

20/01/2019  
Date

**Addendum 3B: Permission from the representative in Waterfall Estate**

**PARTICIPANT'S INFORMATION & INFORMED CONSENT DOCUMENT**

**STUDY TITLE:** Investigating water leakages in the Midrand region and the associated cost through implementation of the Econoleak Model.

**Supervisor:** Dr FWN Nsubuga

**Principal Investigator/s:** Deshree Pillay

**Institution:** University of Pretoria

**Dear Prospective Participant**

Dear Mr / Ms / Mrs Ravi Naidoo representing the Waterfall Estate (complex/ estate name).

- I confirm that the person requesting my consent to take part in this study has told me about the nature and process, any risks or discomforts, and the benefits of the study.
- I have also received, read and understood the above written information about the study.
- I have had adequate time to ask questions and I have no objections to participate in this study.
- I am aware that the information obtained in the study, including personal details, will be anonymously processed and presented in the reporting of results.
- I understand that I will not be penalised in any way should I wish to discontinue with the study and my withdrawal will not affect my employment or student status.
- I am participating willingly.
- I have received a signed copy of this informed consent agreement.

WATERFALL ESTATE  
Complex name (Please print)

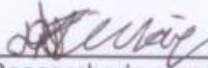
20/01/2019  
Date

  
Representative's signature

20/01/2019  
Date

DESHREE PILLAY  
Researcher's name (Please print)

20/01/2019  
Date

  
Researcher's signature

20/01/2019  
Date

**Addendum 3C: Permission from the representative in San Bernadino**

**PARTICIPANT'S INFORMATION & INFORMED CONSENT DOCUMENT**

**STUDY TITLE:** Investigating water leakages in the Midrand region and the associated cost through implementation of the Econoleak Model.

**Supervisor:** Dr FWN Nsubuga

**Principal Investigator/s:** Deshree Pillay

**Institution:** University of Pretoria


**Dear Prospective Participant**

Dear Mr / Ms / Mrs Kimberley Moody representing the San Bernadino (complex/ estate name).

- I confirm that the person requesting my consent to take part in this study has told me about the nature and process, any risks or discomforts, and the benefits of the study.
- I have also received, read and understood the above written information about the study.
- I have had adequate time to ask questions and I have no objections to participate in this study.
- I am aware that the information obtained in the study, including personal details, will be anonymously processed and presented in the reporting of results.
- I understand that I will not be penalised in any way should I wish to discontinue with the study and my withdrawal will not affect my employment or student status.
- I am participating willingly.
- I have received a signed copy of this informed consent agreement.

SAN BERNADINO  
Complex name (Please print)


20/01/2019  
Date

  
Representative's signature

20/01/2019  
Date

DESHREE PILLAY  
Researcher's name (Please print)

20/01/2019  
Date

  
Researcher's signature

20/01/2019  
Date

**Addendum 3D: Permission from the representative in Carlswald Manor**

**PARTICIPANT'S INFORMATION & INFORMED CONSENT DOCUMENT**

**STUDY TITLE:** Investigating water leakages in the Midrand region and the associated cost through implementation of the Econoleak Model.

**Supervisor:** Dr FWN Nsubuga

**Principal Investigator/s:** Deshree Pillay

**Institution:** University of Pretoria

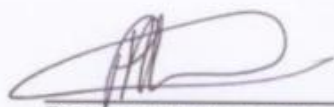
**Dear Prospective Participant**

Dear Mr / Ms / Mrs Prithvi Moodley representing the Carlswald Manor (complex/estate name)

- I confirm that the person requesting my consent to take part in this study has told me about the nature and process, any risks or discomforts, and the benefits of the study.
- I have also received, read and understood the above written information about the study.
- I have had adequate time to ask questions and I have no objections to participate in this study.
- I am aware that the information obtained in the study, including personal details, will be anonymously processed and presented in the reporting of results.
- I understand that I will not be penalised in any way should I wish to discontinue with the study and my withdrawal will not affect my employment or student status.
- I am participating willingly.
- I have received a signed copy of this informed consent agreement.

CARLSWALD MANOR  
Complex name (Please print)

20/01/2019  
Date

  
Representative's signature

20/01/2019  
Date

DESHREE PILLAY  
Researcher's name (Please print)

20/01/2019  
Date

  
Researcher's signature

20/01/2019  
Date

**Addendum 3E: Permission from the representative in Erand Gardens**

**PARTICIPANT'S INFORMATION & INFORMED CONSENT DOCUMENT**

**STUDY TITLE:** Investigating water leakages in the Midrand region and the associated cost through implementation of the Econoleak Model.

**Supervisor:** Dr FWN Nsubuga

**Principal Investigator/s:** Deshree Pillay

**Institution:** University of Pretoria

**Dear Prospective Participant**

Dear Mr / Ms / Mrs Brandon Sing representing the Erand Gardens (complex/ estate name).

- I confirm that the person requesting my consent to take part in this study has told me about the nature and process, any risks or discomforts, and the benefits of the study.
- I have also received, read and understood the above written information about the study.
- I have had adequate time to ask questions and I have no objections to participate in this study.
- I am aware that the information obtained in the study, including personal details, will be anonymously processed and presented in the reporting of results.
- I understand that I will not be penalised in any way should I wish to discontinue with the study and my withdrawal will not affect my employment or student status.
- I am participating willingly.
- I have received a signed copy of this informed consent agreement.

ERAND GARDENS  
Complex name (Please print)

20/01/2019  
Date

[Signature]  
Representative's signature

20/01/2019  
Date

DESHREE PILLAY  
Researcher's name (Please print)

20/01/2019  
Date

[Signature]  
Researcher's signature

20/01/2019  
Date

**Addendum 3F: Permission from the representative in Kyalami Estate**

**PARTICIPANT'S INFORMATION & INFORMED CONSENT DOCUMENT**

**STUDY TITLE:** Investigating water leakages in the Midrand region and the associated cost through implementation of the Econoleak Model.

**Supervisor:** Dr FWN Nsubuga

**Principal Investigator/s:** Deshree Pillay

**Institution:** University of Pretoria

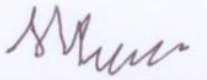
**Dear Prospective Participant**

Dear Mr / Ms / Mrs Morgan Pillay representing the Kyalami Estate (complex/ estate name).

- I confirm that the person requesting my consent to take part in this study has told me about the nature and process, any risks or discomforts, and the benefits of the study.
- I have also received, read and understood the above written information about the study.
- I have had adequate time to ask questions and I have no objections to participate in this study.
- I am aware that the information obtained in the study, including personal details, will be anonymously processed and presented in the reporting of results.
- I understand that I will not be penalised in any way should I wish to discontinue with the study and my withdrawal will not affect my employment or student status.
- I am participating willingly.
- I have received a signed copy of this informed consent agreement.

KYALAMI ESTATE  
Complex name (Please print)


20/01/2019  
Date

  
Representative's signature

20/01/2019  
Date

DESHREE PILLAY  
Researcher's name (Please print)

20/01/2019  
Date

  
Researcher's signature

20/01/2019  
Date

### Addendum 3G: Permission from the representative in Tallyns

#### PARTICIPANT'S INFORMATION & INFORMED CONSENT DOCUMENT

**STUDY TITLE:** Investigating water leakages in the Midrand region and the associated cost through implementation of the Econoleak Model.

**Supervisor:** Dr FWN Nsubuga

**Principal Investigator/s:** Deshree Pillay

**Institution:** University of Pretoria

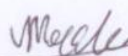
**Dear Prospective Participant**

Dear Mr / Ms / Mrs Vis Moodley representing the Tallyns (complex/ estate name).

- I confirm that the person requesting my consent to take part in this study has told me about the nature and process, any risks or discomforts, and the benefits of the study.
- I have also received, read and understood the above written information about the study.
- I have had adequate time to ask questions and I have no objections to participate in this study.
- I am aware that the information obtained in the study, including personal details, will be anonymously processed and presented in the reporting of results.
- I understand that I will not be penalised in any way should I wish to discontinue with the study and my withdrawal will not affect my employment or student status.
- I am participating willingly.
- I have received a signed copy of this informed consent agreement.

TALLYNS  
Complex name (Please print)

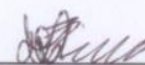
20/01/2019  
Date

  
Representative's signature

20/01/2019  
Date

DESHREE PILLAY  
Researcher's name (Please print)

20/01/2019  
Date

  
Researcher's signature

20/01/2019  
Date

### Addendum 3H: Permission from the representative in Cresentwood Country Estate

#### PARTICIPANT'S INFORMATION & INFORMED CONSENT DOCUMENT

**STUDY TITLE:** Investigating water leakages in the Midrand region and the associated cost through implementation of the Econoleak Model.

**Supervisor:** Dr FWN Nsubuga

**Principal Investigator/s:** Deshree Pillay

**Institution:** University of Pretoria

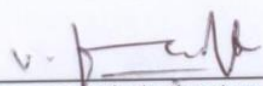
**Dear Prospective Participant**

Dear Mr / Ms / Mrs Strini Vadlamuri representing the Cresentwood (complex/  
estate name). Country Estate

- I confirm that the person requesting my consent to take part in this study has told me about the nature and process, any risks or discomforts, and the benefits of the study.
- I have also received, read and understood the above written information about the study.
- I have had adequate time to ask questions and I have no objections to participate in this study.
- I am aware that the information obtained in the study, including personal details, will be anonymously processed and presented in the reporting of results.
- I understand that I will not be penalised in any way should I wish to discontinue with the study and my withdrawal will not affect my employment or student status.
- I am participating willingly.
- I have received a signed copy of this informed consent agreement.

CRESSENTWOOD COUNTRY ESTATE  
Complex name (Please print)


20/01/2019  
Date

  
Representative's signature

20/01/2019  
Date

DESHREE PILLAY  
Researcher's name (Please print)

20/01/2019  
Date

  
Researcher's signature

20/01/2019  
Date

## ADDENDUM 4: ETHICAL CLEARANCE



UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA

Faculty of Natural and Agricultural Sciences  
Ethics Committee

E-mail: [ethics.nas@up.ac.za](mailto:ethics.nas@up.ac.za)

ETHICS SUBMISSION: LETTER OF APPROVAL

Miss D Pillay  
Department of Geography Geoinformatics and Meteorology  
Faculty of Natural and Agricultural Science  
University of Pretoria

**Reference number: 180000122**

**Project title: Investigating Water Leakages in the Midrand Region and the Associated Cost Through Implementation of the Econoleak Model**

Dear Miss D Pillay,

We are pleased to inform you that your submission conforms to the requirements of the Faculty of Natural and Agricultural Sciences Ethics committee.

Note that you are required to submit annual progress reports (no later than two months after the anniversary of this approval) until the project is completed. Completion will be when the data has been analysed and documented in a postgraduate student's thesis or dissertation, or in a paper or a report for publication. The progress report document is accessible on the NAS faculty's website: Research/Ethics Committee.

If you wish to submit an amendment to the application, you can also obtain the amendment form on the NAS faculty's website: Research/Ethics Committee.

The digital archiving of data is a requirement of the University of Pretoria. The data should be accessible in the event of an enquiry or further analysis of the data.

Yours sincerely,

A handwritten signature in black ink, appearing to read 'Z. de Vries'.

**Chairperson: NAS Ethics Committee**

## ADDENDUM 5: QUESTIONNAIRES

### Addendum 5A: Questionnaire administered to water suppliers

#### Questionnaire for water supplier

Please answer the following questions by crossing an (X) on the relevant block or writing down your answer in the space provided

**Please note: Water leakages does not include sewerage overflows**

Respondent number

#### 1. Employment information

- 1.1 Occupation: \_\_\_\_\_
- 1.2 Job title: \_\_\_\_\_
- 1.3 Summary of work responsibilities: \_\_\_\_\_

#### 2. Socioeconomic data

- 2.1 What is your highest completed level of education?
- 2.2 How long have you been working in this sector (in Years/Months)?  
 \_\_\_\_\_ years \_\_\_\_\_ months

#### 3. Water leakages

- 3.1 How often do you get alerted of burst pipes/leakages?
- 3.2 To your knowledge, in which part of Midrand do water leakages occur most frequently? Please select your answer below. Cross one.

a. Carlswald	1
b. Kyalami	2
c. Vorna Valley	3
d. Waterfall	4
e. Noordwyk	5
f. Sagewood	6
g. Erand	7
h. Halfway Gardens	8
i. Other (please specify)	9

- 3.3 Which of the following components has the highest water losses? Choose one.

a. Service reservoirs	
-----------------------	--

b. Transmission mains	
c. Distribution mains	
d. Connections	
e. Service pipes	

3.4 What are the main causes of water leakages?

3.5 Do you expect that more water leakages will occur in Midrand within the next few months?

Yes	1	No	2
-----	---	----	---

3.6 Please state the reason/s for your answer to 3.5

**4. Cost associated with water leakages**

4.1 How do you identify apparent and real losses in the water distribution network?

**Apparent losses:** the non-physical losses that occur in utility operations due to customer inaccuracies, systematic data handling errors in customer billing systems and unauthorized consumption.

**Real losses:** the physical losses of water from the distribution system, including leakage and storage overflows.

4.2 What is the approximate cost of fixing a water leakage? (This includes all equipment and travel)

4.3 Please state the approximate expenditure during a burst pipe call out.

Expense	Cost
a. Equipment costs (in Rands)	
b. Distance to burst pipe in (Rand/km)	
c. Time spent (in hours or part of an hour)	
d. Labour costs (in Rands/hour)	
e. Personal Protective Equipment (in Rands)	

4.4 Which leakage intervention interval would have the highest cost? Choose one.

a. Every 0.5 years (6 months)	1
b. Every 1 year (12 months)	2
c. Every 2 years (24 months)	3

4.5 How do you track water supply?

**5. Water shortages**

5.1 Do you think water shortages cause people to move?

Yes	1	No	2
-----	---	----	---

5.2 Do you send out water shortage alerts to residents?

Yes	1	No	2
-----	---	----	---

How do you send out water shortage alerts? Cross all that are applicable.

a. SMS	1
b. WhatsApp group	2
c. Radio advert	3
d. Newspapers	4
e. Television	5
f. Notices	6
g. Other (please specify)	7

5.3

5.4 How effective do you consider the alerts to be?

5.5 Suggest ways to improve the water shortage alert system.

## 6. Impact of water leakages and shortages

6.1 What are the consequences faced when a water leakage/ shortage is not attended to? Cross all that are applicable.

a. Cost implications	1
b. Water wastage	2
c. Consumer complaints/ strikes	3
d. Health impacts	4
e. Sedimentation at point of leakage	5
f. Quality reduction of water supply	6
g. Sanitation issues	7
h. Reduction in system capacity	8
i. Negative pressures	9
j. Pumping directly from the network	10
k. Excessive pressures	11
l. Low velocities	12
m. Wrong operational settings	13
n. Air in the system	14
o. Corrosion	15
p. Permeation	16
q. Dirty water with grit	17

6.2 What are the three most important strategies used by you to minimise water leakages? Please list them below.

6.3 With specific reference to water shortages, how would you rate/respond to the following factors in attempting to reduce severity of water leakage impacts (A score of 1 indicates that you are undecided and a score of 5 indicates that you strongly agree)

<b>Rating</b>	<b>Undecided</b>	<b>Strongly Agree</b>	<b>Disagree</b>	<b>Agree</b>	<b>Strongly agree</b>
---------------	------------------	-----------------------	-----------------	--------------	-----------------------

Pressure management to reduce leakages	1	2	3	4	5
Using meters to monitor water usage	1	2	3	4	5
Using meters to monitor water demand	1	2	3	4	5
Upgrading old infrastructure to reduce water leakages	1	2	3	4	5
Implementing models to help identify and mitigate costs of water leakages	1	2	3	4	5
Increase the frequency of maintenance of infrastructure	1	2	3	4	5
Construct more water towers and reservoirs	1	2	3	4	5
Dig boreholes on sites	1	2	3	4	5
Other (please specify)	1	2	3	4	5

6.4 Is there any form of community awareness/ mobilisation to improve the water supply management? Cross all that are applicable.

a. Local authority meetings	1
b. Community meetings	2
c. Water conservation information distributed	3
d. Television advertisements	4
e. Government campaigns	5
f. Notices	6
g. Incentives/rewards	7
h. Penalties/fines	8
i. Other (please specify)	9

6.5 Where else besides Midrand does this problem occur?

6.6 What are the three most adopted strategies to overcome this problem in the other regions?

6.7 How effective have these strategies been?

**7. Leakage detection**

7.1 Do you use smart meters for identifying leakages?

Yes	1	No	2
-----	---	----	---

7.2 If smart meters are not used, how do you identify leakages? List the methods below if applicable.

7.3 On average how long does it take to repair a burst pipe?

7.4 How are unreported bursts detected? Choose one.

a. Alerted by someone	1
b. Change in system pressures	2
c. Use of meters	3
d. Acoustic methods	4
e. Continuous system monitoring	5

7.5 How are unaccounted for water losses detected? Cross all that are applicable.

a. Reviewing registers	1
b. Updating registers	2
c. Field work	3
d. Water consumption patterns	4
e. Invoiced bills	5
f. Meter readings	6
g. Other (please specify)	7

7.6 How are water loss interventions and checks undertaken?

7.7 How effective is your leakage detection method?

7.8 If your leakage detection method is not very effective, suggest better methods below.

7.9 Would you consider implementing a model that determines the Economic loss of water leakages and suggests an active leakage control frequency which is at a suitable cost?

Yes	1	No	2
-----	---	----	---

**Thank you for taking time to participate in this study**

## Addendum 5B: Questionnaire administered to residents

### Questionnaire for adult household members

Please answer the following questions by crossing an (X) on the relevant block or writing down your answer in the space provided

**Please note: Water leakages does not include sewerage overflows**

Respondent number

#### 1. Residential data

- 1 Street name: \_\_\_\_\_
- 2 Complex name: \_\_\_\_\_

#### 2. Socioeconomic data

2. Number of persons in household: \_\_\_\_\_
  
- 2 How many adults in the household are:
  - a. Self-employed: \_\_\_\_\_
  - b. Employed: \_\_\_\_\_
  - c. Unemployed: \_\_\_\_\_
  
- 3 Number of males and females in the household
  - a. Males: \_\_\_\_\_
  - b. Females: \_\_\_\_\_

4 Tenure

5 Type of dwelling

6 Length of stay

#### 3. Water leakage perceptual and attitudinal assessment

- 1 Have you experienced a water leakage / burst water pipe while living in this complex?

If no, please skip this section and go to question 4.2

- 2 How often do you experience burst pipes?
  
- 3 Which of these do you think causes water leakages?  
Cross all that are applicable.

a. Intruding tree roots	1
b. Broken seals	2
c. Corrosion	3
d. Damaged pipe joints	4
e. Loose water connectors	5
f. Rapid temperature changes	6
g. Runoff	7
h. Earth movements	8
i. Negligence by local authority and government	9
j. Strikes / demonstrators	10
k. Malicious intent	11
l. Political sabotage	12
m. Pressure differences	13
n. Soil composition, characteristics (specifically acidity and physical properties)	14
o. Other(please specify)	15

4 How do burst pipes affect you?

5 Which of the following have you experienced during a water leakage in terms of drinking water? Cross all that apply.

a. Change in the colour of water	1
b. Change in the odour of the water	2
c. Change in the taste of the water	3
d. Sediments found in the water	4

6 Do you think the number of water leakages will increase over time?

7 Are your water burst problems serious enough to warrant you to move from this locality?

8 If your answer to 3.7 is "yes" then where would you move to?

9 Please give reasons for your answer in 3.8

1

0 If your answer to 3.7 is "no" please state the reason/s for remaining in this locality

1 Estimate the cost incurred to you by burst water pipes by crossing low, medium or high

4. **Cost implication and mitigation of water leakages and shortages**

4. What do you think is the approximate cost of fixing a water leakage for the water supplier? (This includes all equipment and travel)

2 Who should take responsibility for burst water pipes? Cross one that applies.

a. Residents have a responsibility to reduce the impact of burst water pipes in homes	1
b. It is the responsibility of the local authority to mitigate the impact of burst water pipes	2
c. It is the responsibility of central government to mitigate the impact of burst water pipes	3
d. Other (please specify)	4

3 Have you taken any steps to mitigate the impact of water leakages?

4 If “yes”, what steps did you adopt and indicate the total cost thereof.

Expenses	Yes (tick)	Cost in (Rands)
a. Water storage tank		
b. Dug a borehole/well		
c. Rainwater harvesting		
d. Bought water from shop		
e. Water filter		
f. Stackable Water Brick Containers		
g. Contact with Johannesburg Water		
h. Contact with plumbers		
i. Involved in awareness campaigns		
j. Avoidance during leakages		
k. Other (Please specify)		

5 Suggest how the present water leakages and bursts in your area could be minimised?

**5. Notification of pipe bursts**

1 Are you aware of any burst water pipe alerts within your community?

2 Who conveyed the alert of the burst pipe? Cross one that applies.

a. Town/board council	1
b. Water supplier	2
c. Media	3
d. Friends/ relatives	4
e. Other (please specify)	5

3 How was the alert conveyed? Cross one that applies.

a. SMS	1
b. WhatsApp group	2
c. Radio advert	3
d. Newspapers	4
e. Television	5
f. Notices	6
g. Other (please specify)	7

4 What was your response when the alert was conveyed? Cross one that applies.

a. Waited for the pipe to be fixed and water to be restored	1
b. Contacted my water supplier to report the problem	2
c. Changed my working hours around the water leakage and shortage	3
d. Left my house for the duration of the leakage and shortage	4
e. Communicated to household members to conserve water	5
f. Stored the little water from taps that are left prior to complete closure	6

5 Do you consider the burst pipe alert to be efficient?

#### 6. Impact of water shortages

Often, burst pipes and damaged water distribution infrastructure result in water shortages. The water resource is thus wasted and there will be a lack of water supplied to the region. Please respond to the questions below that follow in this regard.

1 Suggest how the present water shortages in your area could be minimised?

2 How frequently is your property affected by water shortages?

3 What do you think causes water shortages?

Cross all that are applicable.

a. Climate change (droughts)	1
b. Water leakages	2
c. Theft of water	3
d. Overuse of water	4
e. Water pollution	5
f. Water wastage	6
g. Conflict	7
h. Destruction of water catchment areas	8
i. Restriction by government	9
	1
j. Other(please specify)	0

4 How can local authorities assist and contribute towards preventing water shortages?

- 5 In which ways have you involved yourself in issues concerned with the management of water shortages? Cross all that are applicable.

a. Signed petition	1
b. Attended local authority meetings	2
c. Attended community meetings	3
d. Member of committee involved with water conservation	4
e. Reported to Johannesburg Water	5
f. Created a street group to pressurise service delivery	6
g. Reported malicious individuals	7
h. Joined a protest group on the streets	8
i. Formed a union	9
j. Other(please specify)	10

## 7. Billing systems

**Apparent losses:** the non-physical losses that occur in utility operations due to customer inaccuracies, systematic data handling errors in customer billing systems and unauthorized consumption.

**Real losses:** the physical losses of water from the distribution system, including leakage and storage overflows.

- 1 Have you ever received an inaccurate bill?

Yes	1	No	2
-----	---	----	---

- 2 What was the cause of the inaccurate bill? Cross one that applies.

a. Meter inaccuracy	1
b. Human error	2
c. Water leakages	3
d. Illegal water connections	4
e. Average water readings	5
f. Inaccurate rates	6

- 3 Do you think using smart meters is good for billing accuracy (including water leakages)?

- 4 If not then suggest alternative billing methods which includes water loss through leakages?

- 5 Do you think unauthorised consumption of water occurs (illegal water connections) in your complex?

Yes	1	No	2
-----	---	----	---

**Thank you for taking time to participate in this study**

## ADDENDUM 6: RESULTS FROM THE ECONOLEAK MODEL

### Excel sheet containing information pertaining to the ECONOLEAK Model

<b>ECONOLEAK : Leakage Economic Model for Active Leakage Control Evaluation</b> <b>Version 1a : 7 December 2001</b> <b>Copyright and All Rights Reserved.</b>	
<i>Copyright in the whole and every part of this program is the property of the South African Water Research Commission in association with Global Water Resources Ltd. and may not be used, sold, transferred, copied or reproduced in whole or in part or in any manner or form or on any media or to any other person without prior written consent of the Owner.</i>	
<b>This copy licensed to:</b>	<b>Johannesburg Water</b>
<b>Ref.</b>	
<b>Conditions of Use:</b>	
<ol style="list-style-type: none"><li>1. The program is protected with passwords which will not be revealed.</li><li>2. No liability will be accepted by the WRC in respect of any viruses transferred or claimed to have been transferred through use of the program. Copies of the disks have been virus checked before dispatch, but the purchaser should also check the disks for viruses.</li><li>3. No liability will be accepted by the WRC in respect of the use or misuse of this program by the purchasers or for the interpretation of any data or results arising from the use of the program. The program is customised for the specific situation of South Africa and should not be used for analysis of data from other locations where the assumptions might be inappropriate.</li><li>4. By opening the software and proceeding from this Licence Worksheet to the other Worksheets, the User accepts these Conditions of Use</li><li>5. This program is designed to operate using Microsoft Excel. If any difficulties are experienced with the installation or operation of this program, please contact the WRC or the developers (e-mail <a href="mailto:mckenzie@global.co.za">mckenzie@global.co.za</a>) quoting the name, version and issue date of the program.</li></ol>	

## 1. General

<b>Name of Water Undertaking:</b>		
<b>Name of Water Supply System:</b>	Johannesburg Water	
<b>Contact Details:</b>	<b>Name:</b>	
	<b>Address:</b>	
	<b>Tel:</b>	
	<b>Fax:</b>	
	<b>email:</b>	
	<b>Date:</b>	

## 2. System Data

Input Description	Variable	Field Data	Units	
Length of Transmission Mains	Lm_t	56	km	
Length of Distribution Mains	Lm_d	976	km	
Total Length of Mains	Lm	1032	km	
Number of Service Connections	Ns	5200 0	Number	See Notes 1 & 2
Density of Service Connections (per km of mains)	Ns/Lm	50	Per km	
Length of underground pipe per connection (if greater than 10m)	Ls	0	m	
Total volume of Storage Reservoirs in the System	Vol	91,8	MI	
Percentage of time system is pressurised during year	T	100	%	See Note 3
Average Operating Pressure of Transmission Mains	P_t	50	metres	
Average operating pressure of reticulation system when system pressurised	P	50	metres	See Note 4
Population served by the supply system	Pop	4200 00	Number	

1. The number of service connections is not always the same as the number of meters or billed accounts. For South African conditions, however, you can use the total of the number of metered accounts plus the estimated number of unmetered connections

2. In South Africa customer meters are usually located close to the street/stand boundary. If this is not the case for your system, then add a note here.

Insert your comments in this space.

3. Use T in % eg. If T = 80%, use 80 and not 0.8

4. If you do not have an accurate figure, please make a best estimate and provide brief details of how you derived it.

Insert your comments in this space.

### 3a. Unavoidable Annual Real Losses (UARL) : Basic Parameters

Details	Field Data				Units
	Background	Reported Bursts	Unreported Bursts	Total	
<b>Transmission Mains</b>	9,60	5,80	2,60	18,00	Litres/km / day per m pressure
<b>Distribution mains</b>	9,60	5,80	2,60	18,00	Litres/km / day per m pressure
<b>Connections</b>	0,60	0,04	0,16	0,80	Litres/conn/day per m pressure
<b>Service Pipes</b>	16,00	1,90	7,10	25,00	Litres/km/day per m pressure

### 3b. Unavoidable Annual Real Losses (UARL) for System

Details	Litres/second	m <sup>3</sup> /hr	m <sup>3</sup> /day	m <sup>3</sup> /yr
<b>Transmission Mains</b>	0,58	2,1	50	18409
<b>Distribution Mains</b>	10,17	36,6	878	320836
<b>Connections</b>	24,07	86,7	2080	759720
<b>Service Pipes</b>	0,00	0,0	0	0
<b>Total Losses</b>	34,82	125,4	3009	1098964

### 3c. Infrastructure Leakage Index (ILI)

Details	Field Data	Units
<b>1. Water Supplied to the System</b>	33038206	m <sup>3</sup> /yr
<b>2. Authorised Consumption</b>	24877769	m <sup>3</sup> /yr
<b>3. Current Total Annual Water Losses : 1 - 2</b>	8160437	m <sup>3</sup> /yr

Details	Field Data	Units
4. Apparent Losses as % of Total Losses	24,7	%
5. Apparent Losses	2015627,939	m <sup>3</sup> /yr
6. Current Annual Real Losses (CARL)	6144809,061	m <sup>3</sup> /yr
7. Unavoidable Annual Real Losses (UARL)	1098964	m <sup>3</sup> /yr
8. Infrastructure Leakage Index (ILI) : 6 / 7	5,6	

#### 4a. Duration and Rates for Reported Bursts @ 50m pressure

Details	Awareness and Location	Repair	Total Days	Losses m <sup>3</sup> /hr
Transmission Mains	0,50	0,50	1,00	30
Distribution Mains	1,00	0,50	1,50	12
Connections	5,00	6,00	11,00	1,6
Service Pipes	5,00	6,00	11,00	1,6

#### 4b. Basic Information on Unreported Bursts @ 50m pressure

Details	Field Data		
	Unreported as % of Reported	N1 Value for Bursts	Losses m <sup>3</sup> /hr
Transmission Mains	0	0,5	12,0
Distribution Mains	5	0,5	6,0
Connections	33	0,5	1,6
Service Pipes	33	0,5	1,6

#### 4c. Number of Bursts per year

Details	Field Data			
	Reported Bursts per Year		Unreported Bursts per Year	
	Frequency	Number of Bursts	Frequency	Number of Bursts
Transmission	0,030	1,7	0,000	0,0
Mains	(per km mains/yr)		(per km mains/yr)	
Distribution	0,150	146,4	0,008	7,3
Mains	(per km mains/yr)		(per km mains/yr)	
Connections	2,500	130,0	0,825	42,9
	(per 1000 conn/yr)		(per 1000 conn/yr)	
Service Pipes	0,000	0,0	0,000	0,0
	(per 1000 conn/yr)		(per 1000 conn/yr)	

#### 4d. Losses from Reported Bursts (adjusted for local pressure)

Details	Field Data			
	Number of Bursts per yr	Duration Days	Rate(@50m) m <sup>3</sup> /hr	Ave. Losses m <sup>3</sup> /day
	Transmission	1,7	1,0	30,0
Mains				
Distribution	146,4	1,5	12,0	173,3
Mains				
Connections	130,0	11,0	1,6	150,4
Service Pipes	0,0	11,0	1,6	0,0
Totals	278			327,0

#### 4e. Losses from Unreported Bursts at Regular Inspection Intervals (adjusted for local pressure)

Details	Rate(@50m) m <sup>3</sup> /hr	Ave Losses m <sup>3</sup> /day	Losses (m <sup>3</sup> /day) for interventions		
			Every 2 yrs	Every year	Every 6 months
Transmission Mains	12,0	0,00	0,0	0,0	0,0
Distribution Mains	6,0	2,89	1055,5	528,5	265,0
Connections	1,6	4,51	1674,4	850,8	438,9
Service Pipes	1,6	0,00	0,0	0,0	0,0
Totals		7,40	2730	1379	704

### 5a. Marginal Cost of Water

Details	Field Data		
	Imported	Own	Highest
	Water	Sources	
Bulk Supply	10,00		
Power		0,75	
Chemicals		0,05	
<b>Total</b>	10,00	0,80	10,00

### 5b. Costs for Leak Detection

Details	Field Data	Units
Cost for regular sounding per km	780	R / km
% Coverage required for Correlation	20	%
Cost for Correlation per km	1000	R / km
Supervision as % of Inspection Costs	15	%
Measuring Minimum Night Flows	32000	Rand
Administrative Set Up Costs	5000	Rand
Cost to repair Mains Leak	3500	Rand
Cost to Repair Service/Connection Leak	2000	Rand
10. Other 3		

### 5c. Costs for an Intervention at Regular Intervals

Details	Field Data		
	Every 2 years	Every 1 year	Every 6 months
Administration set up costs	2500	5000	10000
Manpower Inspection Costs	505680	1011360	2022720

Details	Field Data		
	Every 2 years	Every 1 year	Every 6 months
Supervision Costs	75852	151704	303408
Mains repair costs	25620	25620	25620
Connection repair costs	85800	85800	85800
<b>Total Costs</b>	<b>695452</b>	<b>1279484</b>	<b>2447548</b>

#### 6a. Unavoidable Background Losses (Adjusted for Local Pressure)

Details		Unavoidable Background Leakage	N1 Value	Unavoidable Background Leakage (m <sup>3</sup> /day)
1. Service Reservoirs		0,1		92
	% of capacity/day			
2. Transmission Mains		20	1,5	27
	l/km/hr @ 50m			
3. Distribution Mains		20	1,5	468
	l/km/hr @ 50m			
4. Connections		1,25	1,5	1560
	l/conn/hr @ 50m			
5. Service pipes		0,00	1,5	0
	l/conn/hr @ 50m			
<b>Totals</b>				<b>2147</b>

#### 6b. Base Level for Annual Real Losses

Details	Field Data
Unavoidable Background Losses	2147
Factor for Base Level losses	2,0
Total Base Background Losses	4294
Losses From Reported Bursts	327
<b>Base Level of Real Losses</b>	<b>4621</b>

#### 6c. Base Level of Annual Real Losses

	Field Data (m <sup>3</sup> /day)			
	Background Losses		Bursts	Total
Details	Basic	Base Level		
Storage Reservoirs	91,8	183,6		183,6
Transmission Mains	26,9	53,8	3,3	57,1
Distribution Mains	468,5	937,0	173,3	1110,2
Connections	1560,0	3120,0	150,4	3270,4
Service Connections	0,0	0,0	0,0	0,0
<b>Total (m<sup>3</sup>/day)</b>	<b>2147,2</b>	<b>4294,3</b>	<b>327,0</b>	<b>4621,4</b>
<b>Total (m<sup>3</sup>/year)</b>	<b>783713</b>	<b>1567427</b>	<b>119366</b>	<b>1686793</b>
<b>Cost (Rand/yr)</b>	<b>7837134</b>	<b>15674268</b>	<b>1193664</b>	<b>16867932</b>

#### 7. Water Losses for number of Interventions per year

	Field Data		
Details	Every 2 years	Every year	every 0.5 years
Storage Reservoirs	183,6	183,6	183,6
Transmission Mains	57,1	57,1	57,1
Distribution Mains	2165,8	1638,7	1375,2
Connections	4944,9	4121,2	3709,4
Service Connections	0,0	0,0	0,0
<b>Total (m<sup>3</sup>/day)</b>	<b>7351,3</b>	<b>6000,6</b>	<b>5325,2</b>
<b>Total (m<sup>3</sup>/year)</b>	<b>2683230</b>	<b>2190217</b>	<b>1943711</b>
<b>Cost (Rand/yr)</b>	<b>26832300</b>	<b>21902172</b>	<b>19437108</b>

#### 8. Total Intervention costs

Details	Field Data		
	Intervention Cost	Cost of Losses	Total
Every 2 years	695452	26832300	27527752
Every year	1279484	21902172	23181656
Every 0.5 Years	2447548	19437108	21884656

### 9a. Curve for Intervention Costs v Leakage costs

Details	Field Data
$L_{one}$	1943711
$L_{two}$	2190217
$L_{three}$	2683230
$L_b$	1686793
$L_1 - L_b = L_1$	256918
$L_2 - L_b = L_2$	503424
$L_3 - L_b = L_3$	996437
$L_3 - L_2$	493013
$L_2 - L_1$	246506
$L_2^2 - L_1^2$	1,8743E+11
$L_3^2 - L_2^2$	7,3945E+11
$C_1$	2447548
$C_2$	1279484
$C_3$	695452
$C_1L_1$	6,2882E+11
$C_2L_2$	6,4412E+11
$C_3L_3$	6,9297E+11
$C_3L_3 - C_2L_2$	4,8851E+10
$C_2L_2 - C_1L_1$	1,5305E+10
A	24045,1
B	0,0500
C	6,1934E+11
D	10,00

**9b. Curve Fitting For Leakage Graph**

<b>Field Data</b>	Leakage	1943 711	2017 663	2091 615	2165 567	2239 518	2313 470	2387 422	2461 374	2535 326	2609 278	2683 230
	Intervention Costs	2447 548	1912 449	1574 204	1341 593	1172 216	1043 688	9430 73	8623 77	7963 92	7415 79	6954 52
	Total Costs	2188 4656	2208 9076	2249 0350	2299 7258	2356 7401	2417 8392	2481 7297	2547 6120	2614 9654	2683 4360	2752 7752

**9c. Additional Points for Graph**

<b>Details</b>	<b>Field Data</b>		
	<b>Ymax</b>	<b>Ymin</b>	<b>X Value</b>
<b>Minimum Level of Leakage</b>	21884656	0	784250
<b>Target Level of Leakage</b>	21884656	0	1568500
<b>Total Leakage</b>	21884656	0	1687949

## ADDENDUM 7: RESULTS FROM STATISTICAL ANALYSIS

### Addendum 7A: Results from frequencies

#### Households: Initial frequencies

##### 1. Residential data

FREQUENCIES VARIABLES=V2.1 V2.2a V2.2b V2.2c V2.3a V2.3b

/STATISTICS=STDDEV RANGE MINIMUM MAXIMUM MEAN

/ORDER=ANALYSIS.

#### Frequencies

		Statistics					
		V2.1: Socioeconomic date: Number of persons in household	V2.2a: How many adults in the household are: Self- employed	V2.2b: Employed	V2.2c: Unemployed	V2.3a: Number of males and females in the household:a) Males	V2.3b: Number of males and females in the household:b) Females
N	Valid	71	29	65	24	70	67
	Missing	0	42	6	47	1	4
Mean		3.35	1.03	1.92	1.13	1.74	1.70
Std. Deviation		1.343	.626	.853	.900	.793	.969
Range		6	2	3	4	3	4
Minimum		1	0	1	0	1	0
Maximum		7	2	4	4	4	4

#### Frequency Table

##### V2.1: Socioeconomic date: Number of persons in household

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	4	5.6	5.6	5.6
	2	18	25.4	25.4	31.0
	3	17	23.9	23.9	54.9
	4	18	25.4	25.4	80.3
	5	10	14.1	14.1	94.4
	6	3	4.2	4.2	98.6
	7	1	1.4	1.4	100.0

Total	71	100.0	100.0
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**V2.2a: How many adults in the household are: Self-employed**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	5	7.0	17.2	17.2
	1	18	25.4	62.1	79.3
	2	6	8.5	20.7	100.0
	Total	29	40.8	100.0	
Missing	System	42	59.2		
Total		71	100.0		

**V2.2b: Employed**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	22	31.0	33.8	33.8
	2	30	42.3	46.2	80.0
	3	9	12.7	13.8	93.8
	4	4	5.6	6.2	100.0
	Total	65	91.5	100.0	
Missing	System	6	8.5		
Total		71	100.0		

**V2.2c: Unemployed**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	5	7.0	20.8	20.8
	1	13	18.3	54.2	75.0
	2	5	7.0	20.8	95.8
	4	1	1.4	4.2	100.0
	Total	24	33.8	100.0	
Missing	System	47	66.2		
Total		71	100.0		

**V2.3a: Number of males and females in the household:a) Males**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	30	42.3	42.9	42.9
	2	31	43.7	44.3	87.1
	3	6	8.5	8.6	95.7
	4	3	4.2	4.3	100.0
	Total	70	98.6	100.0	
Missing	System	1	1.4		
Total		71	100.0		

**V2.3b: Number of males and females in the household:b) Females**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	3	4.2	4.5	4.5
	1	31	43.7	46.3	50.7
	2	20	28.2	29.9	80.6
	3	9	12.7	13.4	94.0
	4	4	5.6	6.0	100.0
	Total	67	94.4	100.0	
Missing	System	4	5.6		
Total		71	100.0		

FREQUENCIES VARIABLES=V2.4 V2.5 V2.6

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

		V2.4: Tenure	V2.5: Type of dwelling	V2.6: Length of stay
N	Valid	71	70	71
	Missing	0	1	0

**Frequency Table**

**V2.4: Tenure**

	Frequency	Percent	Valid Percent	Cumulative Percent

Valid	Owner	47	66.2	66.2	66.2
	Rental	19	26.8	26.8	93.0
	Leasehold	4	5.6	5.6	98.6
	Other(please specify)	1	1.4	1.4	100.0
	Total	71	100.0	100.0	

#### V2.5: Type of dwelling

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Single storey	37	52.1	52.9	52.9
	Double storey	30	42.3	42.9	95.7
	Outbuilding(garage,etc)	1	1.4	1.4	97.1
	Other (please specify)	2	2.8	2.9	100.0
	Total	70	98.6	100.0	
Missing	System	1	1.4		
Total		71	100.0		

#### V2.6: Length of stay

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less than one year	9	12.7	12.7	12.7
	1 - 5 years	37	52.1	52.1	64.8
	6 - 10 years	11	15.5	15.5	80.3
	11 - 15 years	5	7.0	7.0	87.3
	16 - 20 years	4	5.6	5.6	93.0
	More than 20 years	5	7.0	7.0	100.0
	Total	71	100.0	100.0	

FREQUENCIES VARIABLES=V3.1 V3.2

/ORDER=ANALYSIS.

#### Frequencies

#### Statistics

		V3.1: Have you experienced a water leakage / burst pipe while living in this complex	V3.2: How often do you experience burst pipes
N	Valid	71	70
	Missing	0	1

### Frequency Table

#### V3.1: Have you experienced a water leakage / burst pipe while living in this complex

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	59	83.1	83.1	83.1
	No	12	16.9	16.9	100.0
	Total	71	100.0	100.0	

#### V3.2: How often do you experience burst pipes

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Once a month	3	4.2	4.3	4.3
	Once every 3 months	17	23.9	24.3	28.6
	Once every 6 months	23	32.4	32.9	61.4
	Once a year	12	16.9	17.1	78.6
	Once in two years	8	11.3	11.4	90.0
	Never	5	7.0	7.1	97.1
	Other (please specify)	2	2.8	2.9	100.0
	Total	70	98.6	100.0	
Missing	System	1	1.4		
Total		71	100.0		

MULT RESPONSE GROUPS=\$MRQ3.3 (v3.3b v3.3c v3.3d v3.3e v3.3f v3.3g v3.3h v3.3i v3.3j v3.3k v3.3l

v3.3m v3.3n v3.3o (1,15))

/FREQUENCIES=\$MRQ3.3.

### Multiple Response

### Case Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ3.3 <sup>a</sup>	71	100.0%	0	0.0%	71	100.0%

a. Group

### \$MRQ3.3 Frequencies

		Responses		Percent of Cases
		N	Percent	
\$MRQ3.3 <sup>a</sup>	Broken pipe seals	40	14.0%	56.3%
	Corrosion	29	10.2%	40.8%
	Damaged pipe joints	43	15.1%	60.6%
	Loose water pipe connectors	29	10.2%	40.8%
	Rapid air temperature changes	11	3.9%	15.5%
	Runoff	5	1.8%	7.0%
	Earth movements	12	4.2%	16.9%
	Negligence by local authority and government	41	14.4%	57.7%
	Strikes / demonstrators	11	3.9%	15.5%
	Malicious intent	20	7.0%	28.2%
	Political sabotage	18	6.3%	25.4%
	Pressure differences	15	5.3%	21.1%
	Soil composition, characteristics	9	3.2%	12.7%
	Other	2	0.7%	2.8%
Total		285	100.0%	401.4%

a. Group

FREQUENCIES VARIABLES=V3.3\_Other

/ORDER=ANALYSIS.

V3.3: If you answered "other" to question 3.3 above please specify your answer below

N	Valid	71
	Missing	0

**V3.3: If you answered "other" to question 3.3 above please specify your answer below**

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	69	97.2	97.2	97.2
new construction or developments	1	1.4	1.4	98.6
new development construction in the area	1	1.4	1.4	100.0
Total	71	100.0	100.0	

MULT RESPONSE GROUPS=\$MRV3.4 (v3.4a v3.4b v3.4c v3.4d v3.4e v3.4f v3.4g v3.4h v3.4i v3.4j (1,10))

/FREQUENCIES=\$MRV3.4.

**Multiple Response**

**Case Summary**

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRV3.4 <sup>a</sup>	69	97.2%	2	2.8%	71	100.0%

a. Group

**\$MRV3.4 Frequencies**

	Responses	Percent of Cases	
		N	Percent
\$MRV3.4 <sup>a</sup> Weakening of road surfaces leading to potholes	33	14.6%	47.8%
Damage to underground piping	11	4.9%	15.9%
Damage to foundations of buildings	18	8.0%	26.1%
Cost implications(buying water, paying for no water, not going to work)	33	14.6%	47.8%
Time wastage	33	14.6%	47.8%
Health impacts (resulting from dirty water)	25	11.1%	36.2%

Mould, fungi and algae bloom growth	8	3.5%	11.6%
Water shortages and loss of water	41	18.1%	59.4%
Paying for lost water	23	10.2%	33.3%
Other	1	0.4%	1.4%
Total	226	100.0%	327.5%

a. Group

## Frequencies

### Statistics

MULT RESPONSE GROUPS=\$MRQ3.5 (v3.5a v3.5b v3.5c v3.5d (1,4))

/FREQUENCIES=\$MRQ3.5.

## Multiple Response

### Case Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ3.5 <sup>a</sup>	68	95.8%	3	4.2%	71	100.0%

a. Group

### \$MRQ3.5 Frequencies

	Responses	Percent of Cases	
		N	Percent
\$MRQ3.5 <sup>a</sup> Change in the colour of water	53	35.3%	77.9%
Change in the odour of the water	30	20.0%	44.1%
Change in the taste of water	37	24.7%	54.4%
Sediments found in the water resulting in higher turbidity levels	30	20.0%	44.1%
Total	150	100.0%	220.6%

a. Group

FREQUENCIES VARIABLES=V3.6 V3.7 V3.8 V3.9

/ORDER=ANALYSIS.

**Frequencies**

		<b>Statistics</b>			
		V3.6: Do you think the number of water leakages will increase over time	V3.7: Are your water burst problems serious enough to warrant you to move from this locality	V3.8: If your answer to 3.7 is yes, then where would you move to	V3.9: Please give reasons for your answer in 3.8
N	Valid	70	69	11	71
	Missing	1	2	60	0

**Frequency Table**

**V3.6: Do you think the number of water leakages will increase over time**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	68	95.8	97.1	97.1
	No	2	2.8	2.9	100.0
	Total	70	98.6	100.0	
Missing	System	1	1.4		
Total		71	100.0		

**V3.7: Are your water burst problems serious enough to warrant you to move from this locality**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	11	15.5	15.9	15.9
	No	58	81.7	84.1	100.0
	Total	69	97.2	100.0	
Missing	System	2	2.8		
Total		71	100.0		

**V3.8: If your answer to 3.7 is yes, then where would you move to**

		Frequency	Percent	Valid Percent	Cumulative Percent

Valid	Another area within the affected area	4	5.6	36.4	36.4
	Another area outside the affected area	4	5.6	36.4	72.7
	Another town	1	1.4	9.1	81.8
	Another province	2	2.8	18.2	100.0
	Total	11	15.5	100.0	
Missing	System	60	84.5		
Total		71	100.0		

**V3.9: Please give reasons for your answer in 3.8**

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	64	90.1	90.1	90.1
1	3	4.2	4.2	94.4
2	2	2.8	2.8	97.2
3	1	1.4	1.4	98.6
We are moving anyway	1	1.4	1.4	100.0
Total	71	100.0	100.0	

MULT RESPONSE GROUPS=\$MRQ3.10 (v3.10a v3.10b (1,17))

/FREQUENCIES=\$MRQ3.10.

**Multiple Response**

**Case Summary**

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ3.10 <sup>a</sup>	49	69.0%	22	31.0%	71	100.0%

a. Group

**\$MRQ3.10 Frequencies**

	Responses		Percent of Cases
	N	Percent	
\$MRQ3.10 <sup>a</sup> Safe here	8	14.8%	16.3%

Water leakages & potholes get fixed quickly	8	14.8%	16.3%
Unable to move due to kids schooling	3	5.6%	6.1%
Expensive to move	5	9.3%	10.2%
Live close to work	5	9.3%	10.2%
Just bought here	1	1.9%	2.0%
Centrally located	3	5.6%	6.1%
It happens once in a while	4	7.4%	8.2%
Things will improve	1	1.9%	2.0%
Safe here	4	7.4%	8.2%
Home is spacious	1	1.9%	2.0%
Good community environment	5	9.3%	10.2%
Adequate water supply	1	1.9%	2.0%
Water leakages are inevitable	1	1.9%	2.0%
Just moved here	1	1.9%	2.0%
It is home	2	3.7%	4.1%
Lazy to move	1	1.9%	2.0%
<b>Total</b>	<b>54</b>	<b>100.0%</b>	<b>110.2%</b>

a. Group

FREQUENCIES VARIABLES=V3.11a V3.11b V3.11c V3.11d V3.11e V3.11f V3.11g V3.11h V3.11i

/ORDER=ANALYSIS.

## Frequencies

### Statistics

		V3.11a: Cost of water	V3.11b: Cost of driving to source of water	V3.11c: Time spent	V3.11d: Paying a contractor to fix the problem	V3.11e: Cost of calling a service provider	V3.11f: Cost of not working/ reporting for work	V3.11g: Cost of not having water at my business premises	V3.11h: Cost of cleaning up	V3.11i: Cost of paying for lost water
N	Valid	65	60	63	61	61	59	56	60	62
	Missing	6	11	8	10	10	12	15	11	9

**Frequency Table**

=

**V3.11a: Estimate the cost incurred to you by burst water pipes by crossing low, medium or high: a) Cost of water**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	9	12.7	13.8	13.8
	Medium	23	32.4	35.4	49.2
	High	33	46.5	50.8	100.0
	Total	65	91.5	100.0	
Missing	System	6	8.5		
Total		71	100.0		

**V3.11b: Cost of driving to source of water**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	24	33.8	40.0	40.0
	Medium	20	28.2	33.3	73.3
	High	16	22.5	26.7	100.0
	Total	60	84.5	100.0	
Missing	System	11	15.5		
Total		71	100.0		

**V3.11c: Time spent**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	7	9.9	11.1	11.1
	Medium	22	31.0	34.9	46.0
	High	34	47.9	54.0	100.0
	Total	63	88.7	100.0	
Missing	System	8	11.3		
Total		71	100.0		

**V3.11d: Paying a contractor to fix the problem**

		Frequency	Percent	Valid Percent	Cumulative Percent

Valid	Low	13	18.3	21.3	21.3
	Medium	12	16.9	19.7	41.0
	High	36	50.7	59.0	100.0
	Total	61	85.9	100.0	
Missing	System	10	14.1		
Total		71	100.0		

**V3.11e: Cost of calling a service provider**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	22	31.0	36.1	36.1
	Medium	17	23.9	27.9	63.9
	High	22	31.0	36.1	100.0
	Total	61	85.9	100.0	
Missing	System	10	14.1		
Total		71	100.0		

**V3.11f: Cost of not working/ reporting for work**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	11	15.5	18.6	18.6
	Medium	17	23.9	28.8	47.5
	High	31	43.7	52.5	100.0
	Total	59	83.1	100.0	
Missing	System	12	16.9		
Total		71	100.0		

**V3.11g: Cost of not having water at my business premises**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	15	21.1	26.8	26.8
	Medium	14	19.7	25.0	51.8
	High	27	38.0	48.2	100.0
	Total	56	78.9	100.0	
Missing	System	15	21.1		
Total		71	100.0		

**V3.11h: Cost of cleaning up**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	18	25.4	30.0	30.0
	Medium	23	32.4	38.3	68.3
	High	19	26.8	31.7	100.0
	Total	60	84.5	100.0	
Missing	System	11	15.5		
Total		71	100.0		

**V3.11i: Cost of paying for lost water**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	11	15.5	17.7	17.7
	Medium	12	16.9	19.4	37.1
	High	39	54.9	62.9	100.0
	Total	62	87.3	100.0	
Missing	System	9	12.7		
Total		71	100.0		

FREQUENCIES VARIABLES=V4.1 V4.2 V4.3

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

		V4.1: Cost implication: What do you think is the approximate cost of fixing a water leakage for the water supplier	V4.2: Who should take responsibility for reducing and mitigating the impact of burst water pipes	V4.3: Have you taken any steps to mitigate the impact of water leakages
N	Valid	71	71	69
	Missing	0	0	2

**Frequency Table**

**V4.1: Cost implication: What do you think is the approximate cost of fixing a water leakage for the water supplier**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	R20 000 or less	12	16.9	16.9	16.9
	R20 001 - R40 000	17	23.9	23.9	40.8
	R40 001 - R60 000	13	18.3	18.3	59.2
	R60 001 - R80 000	12	16.9	16.9	76.1
	R80 001 - R100 000	10	14.1	14.1	90.1
	More than R100 000	7	9.9	9.9	100.0
	Total	71	100.0	100.0	

**V4.2: Who should take responsibility for reducing and mitigating the impact of burst water pipes**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Residents	13	18.3	18.3	18.3
	Local authority/ municipality	37	52.1	52.1	70.4
	Central government	16	22.5	22.5	93.0
	Water provider	5	7.0	7.0	100.0
	Total	71	100.0	100.0	

**V4.3: Have you taken any steps to mitigate the impact of water leakages**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	48	67.6	69.6	69.6
	No	21	29.6	30.4	100.0
	Total	69	97.2	100.0	
Missing	System	2	2.8		
Total		71	100.0		

FREQUENCIES VARIABLES=V4.4a V4.4b V4.4c V4.4d V4.4e V4.4f V4.4g V4.4h V4.4i V4.4j V4.4k V4.4\_Other V4.4.1\_Electronic

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

	V4.4a : If "yes" what steps did you take and indica te the total cost there of:	V4.4b : If "yes" what steps did you take and indica te the total cost there of	V4.4c : If "yes" what steps did you take and indica te the total cost there of:	V4.4d : If "yes" what steps did you take and indica te the total cost there of:	V4.4e : If "yes" what steps did you take and indica te the total cost there of:	V4.4f: If "yes" what steps did you take and indica te the total cost there of:	V4.4g : If "yes" what steps did you take and indica te the total cost there of:	V4.4h : If "yes" what steps did you take and indica te the total cost there of:	V4.4i: If "yes" what steps did you take and indica te the total cost there of:	V4.4j: If "yes" what steps did you take and indica te the total cost there of:	V4.4k : If "yes" what steps did you take and indica te the total cost there of:	If you answ ered "other " to questi on 4.4 above pleas e specif y your answ er below	V4.4. 1_Ele ctroni c
N	24	5	14	33	15	4	15	15	5	6	8	71	71
Valid													
Missing	47	66	57	38	56	67	56	56	66	65	63	0	0

**Frequency Table**

**V4.4a: If "yes" what steps did you take and indicate the total cost thereof:**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Water storage tank	24	33.8	100.0	100.0
Missing	System	47	66.2		
Total		71	100.0		

**V4.4b: If "yes" what steps did you take and indicate the total cost thereof**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Dug a borehole/well	5	7.0	100.0	100.0
Missing	System	66	93.0		
Total		71	100.0		

**V4.4c: If "yes" what steps did you take and indicate the total cost thereof:**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Rainwater harvesting	14	19.7	100.0	100.0
Missing	System	57	80.3		
Total		71	100.0		

**V4.4d: If "yes" what steps did you take and indicate the total cost thereof:**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Bought water from shop	33	46.5	100.0	100.0
Missing	System	38	53.5		
Total		71	100.0		

**V4.4e: If "yes" what steps did you take and indicate the total cost thereof:**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Water filter	15	21.1	100.0	100.0
Missing	System	56	78.9		
Total		71	100.0		

**V4.4f: If "yes" what steps did you take and indicate the total cost thereof:**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Stackable Water Brick Containers	4	5.6	100.0	100.0
Missing	System	67	94.4		
Total		71	100.0		

**V4.4g: If "yes" what steps did you take and indicate the total cost thereof:**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Contact with Johannesburg Water	15	21.1	100.0	100.0
Missing	System	56	78.9		
Total		71	100.0		

**V4.4h: If "yes" what steps did you take and indicate the total cost thereof:**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Contact with plumbers	15	21.1	100.0	100.0
Missing	System	56	78.9		
Total		71	100.0		

**V4.4i: If "yes" what steps did you take and indicate the total cost thereof:**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Involved in awareness campaigns	5	7.0	100.0	100.0
Missing	System	66	93.0		
Total		71	100.0		

**V4.4j: If "yes" what steps did you take and indicate the total cost thereof:**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Avoidance during leakages	6	8.5	100.0	100.0
Missing	System	65	91.5		
Total		71	100.0		

**V4.4k: Other(Please specify)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Other	8	11.3	100.0	100.0
Missing	System	63	88.7		
Total		71	100.0		

**If you answered "other" to question 4.4 above please specify your answer below**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		64	90.1	90.1	90.1
	5- R400	1	1.4	1.4	91.5
	N/A	1	1.4	1.4	93.0
	None	4	5.6	5.6	98.6
	R250	1	1.4	1.4	100.0
Total		71	100.0	100.0	

**V4.4.1\_Electronic**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		61	85.9	85.9	85.9
	1. R2000	1	1.4	1.4	87.3
	Borehole- R10 000	1	1.4	1.4	88.7

bottled water for drinking and washing - R45	1	1.4	1.4	90.1
It costed me R2500 to install a Jojo tank with a p	1	1.4	1.4	91.5
N/A	1	1.4	1.4	93.0
R10	1	1.4	1.4	94.4
R100	1	1.4	1.4	95.8
R1000	1	1.4	1.4	97.2
R3000	1	1.4	1.4	98.6
Water storage tank: R2000	1	1.4	1.4	100.0
Total	71	100.0	100.0	

MULT RESPONSE GROUPS=\$MRQ4.5 (v4.5a v4.5b v4.5c (1,16))

/FREQUENCIES=\$MRQ4.5.

### Multiple Response

#### Case Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ4.5 <sup>a</sup>	46	64.8%	25	35.2%	71	100.0%

a. Group

#### \$MRQ4.5 Frequencies

	Responses	Percent of Cases		
		N	Percent	
\$MRQ4.5 <sup>a</sup>	Maintenance & upgrading infrastructure	36	58.1%	78.3%
	Monitoring	4	6.5%	8.7%
	planning by local authorities	5	8.1%	10.9%
	Awareness	1	1.6%	2.2%
	Repairs should be done properly & promptly by efficient staff	8	12.9%	17.4%
	Move trees & maintain them	2	3.2%	4.3%
	Use meters	1	1.6%	2.2%

Use meters	1	1.6%	2.2%
Improved management	1	1.6%	2.2%
Insulate water pipes	1	1.6%	2.2%
Budget for maintenance	2	3.2%	4.3%
Total	62	100.0%	134.8%

a. Group

FREQUENCIES VARIABLES=V4.5\_Electronic

/ORDER=ANALYSIS.

## Frequencies

### Statistics

V4.5\_Electronic: Suggest how the present water leakages and bursts in your area could be minimised?

N	Valid	71
	Missing	0

### V4.5\_Electronic: Suggest how the present water leakages and bursts in your area could be minimised?

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	50	70.4	70.4	70.4
"due diligence by contractors to ensure that location of pipes if known to minimize damage. Regular maintenance of pipes"	1	1.4	1.4	71.8
"Local authorities need to be more involved in planned maintenance and monitoring of all infrastructure around the estate. We pay high levies, what are they used for? "	1	1.4	1.4	73.2
"Maintained infrastructure	1	1.4	1.4	74.6
"Stop water wastage Check water bill "	1	1.4	1.4	76.1
Better management of the resource	1	1.4	1.4	77.5

Consistent monitoring and maintenance	1	1.4	1.4	78.9
Don't waste water	1	1.4	1.4	80.3
Fix all pipelines	1	1.4	1.4	81.7
Fix the problem faster	1	1.4	1.4	83.1
Maintain trees	1	1.4	1.4	84.5
Monitor the system more frequently and send out teams to investigate leakages	1	1.4	1.4	85.9
normal check up need to be done at least once in a year	1	1.4	1.4	87.3
Replace joints that are broken quickly and send out staff that are specialised	1	1.4	1.4	88.7
Replace old pipes, get rid of asbestos	1	1.4	1.4	90.1
Replace the damaged joints and pipes	1	1.4	1.4	91.5
Reporting them	1	1.4	1.4	93.0
Residents can invest in alternative water purification systems	1	1.4	1.4	94.4
Stop new developments causing extra impact on the infrastructure	1	1.4	1.4	95.8
The local municipality should monitor our water supply and check regularly for any faults in the system	1	1.4	1.4	97.2
Upgraded infrastructure and quicker response times	1	1.4	1.4	98.6
we have not experienced any so no mitigation	1	1.4	1.4	100.0
Total	71	100.0	100.0	

FREQUENCIES VARIABLES=V4.6

/ORDER=ANALYSIS.

## Frequencies

### Statistics

V4.6 Are you aware of other areas with a similar problem of water bursts and leakages?

N	Valid	71
	Missing	0

**V4.6 Are you aware of other areas with a similar problem of water bursts and leakages?**

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	51	71.8	71.8	71.8
1	2	2.8	2.8	74.6
1&3	1	1.4	1.4	76.1
12	1	1.4	1.4	77.5
13	1	1.4	1.4	78.9
14	1	1.4	1.4	80.3
15	1	1.4	1.4	81.7
16	1	1.4	1.4	83.1
2	4	5.6	5.6	88.7
2&1	1	1.4	1.4	90.1
5	5	7.0	7.0	97.2
6	1	1.4	1.4	98.6
9	1	1.4	1.4	100.0
Total	71	100.0	100.0	

FREQUENCIES VARIABLES=V5.1 V5.2 V5.3 V5.4 V5.5

/ORDER=ANALYSIS.

**Frequencies**

[DataSet] G:\My Drive\2019\Pillay T18087 Ms D\SPSS datasets\Pillai Residents 16 September 2019.sav

**Statistics**

V5.1: Notifications of pipe bursts: Are you aware of any burst water pipe alerts within your community	V5.2: Who conveyed the alert of the burst pipe	V5.3: How was the alert conveyed	V5.4: What was your response when the alert was conveyed	V5.5: Do you consider the burst pipe alert to be efficient
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N	Valid	71	67	68	67	67
	Missing	0	4	3	4	4

### Frequency Table

#### V5.1: Notifications of pipe bursts: Are you aware of any burst water pipe alerts within your community

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	48	67.6	67.6	67.6
	No	16	22.5	22.5	90.1
	Uncertain	7	9.9	9.9	100.0
	Total	71	100.0	100.0	

#### V5.2: Who conveyed the alert of the burst pipe

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Town/board council	11	15.5	16.4	16.4
	Water supplier	13	18.3	19.4	35.8
	Media	9	12.7	13.4	49.3
	Friends/ relatives	25	35.2	37.3	86.6
	Other (please specify)	9	12.7	13.4	100.0
	Total	67	94.4	100.0	
Missing	System	4	5.6		
Total		71	100.0		

#### V5.3: How was the alert conveyed

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	SMS	19	26.8	27.9	27.9
	WhatsApp group	32	45.1	47.1	75.0
	Radio advert	3	4.2	4.4	79.4
	Newspapers	4	5.6	5.9	85.3
	Television	1	1.4	1.5	86.8
	Notices	4	5.6	5.9	92.6
	Other (please specify)	5	7.0	7.4	100.0

	Total	68	95.8	100.0
Missing	System	3	4.2	
	Total	71	100.0	

**V5.4: What was your response when the alert was conveyed**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Waited for the pipe to be fixed and water to be restored	32	45.1	47.8	47.8
	Contacted my water supplier to report the problem	8	11.3	11.9	59.7
	Changed my working hours around the water leakage and shortage	3	4.2	4.5	64.2
	Left my house for the duration of the leakage and shortage	5	7.0	7.5	71.6
	Communicated to household members to conserve water	9	12.7	13.4	85.1
	Stored the little water from taps that are left prior to complete closure	10	14.1	14.9	100.0
	Total	67	94.4	100.0	
Missing	System	4	5.6		
	Total	71	100.0		

**V5.5: Do you consider the burst pipe alert to be efficient**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	51	71.8	76.1	76.1
	No	16	22.5	23.9	100.0
	Total	67	94.4	100.0	
Missing	System	4	5.6		
	Total	71	100.0		

MULT RESPONSE GROUPS=\$MRQ6.1 (v6.1.a v6.1.b v6.1.c v6.1.d (1,23))

/FREQUENCIES=\$MRQ6.1.

**Multiple Response**

**Case Summary**

Cases

	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ6.1 <sup>a</sup>	58	81.7%	13	18.3%	71	100.0%

a. Group

### \$MRQ6.1 Frequencies

	Responses	Percent of Cases	
		N	Percent
\$MRQ6.1 <sup>a</sup>			
Reduce washing cars & excessive garden watering	9	12.7%	15.5%
Better alerting methods	2	2.8%	3.4%
Better reaction & maintenance by local authorities & competent staff	24	33.8%	41.4%
Improved infrastructure	4	5.6%	6.9%
Awareness	2	2.8%	3.4%
Mitigation measures & monitoring	5	7.0%	8.6%
Better drainage	1	1.4%	1.7%
Build more reservoirs & water towers	4	5.6%	6.9%
Maintain water pressure	2	2.8%	3.4%
Use grey water for toilets, irrigation, etc.	2	2.8%	3.4%
Water harvesting	1	1.4%	1.7%
Water supply increased	1	1.4%	1.7%
Leakage detection devices	1	1.4%	1.7%
Use stronger material when building pipes	1	1.4%	1.7%
It is not common at this stage	1	1.4%	1.7%
Annual budget must be in place	1	1.4%	1.7%
Contingent plans in place during water shortages	2	2.8%	3.4%
Improved management	1	1.4%	1.7%
Local government initiatives	1	1.4%	1.7%
Fix leakages & bursts	4	5.6%	6.9%
Water restrictions	1	1.4%	1.7%

Stop further development	1	1.4%	1.7%
Total	71	100.0%	122.4%

a. Group

FREQUENCIES VARIABLES=V6.1.a V6.1.b V6.1.c V6.1.d

/ORDER=ANALYSIS.

## Frequencies

		Statistics			
		V6.1.a: Impact of water shortages: Suggest how the present water shortages in your area could be minimised	V6.1.b: Impact of water shortages: Suggest how the present water shortages in your area could be minimised	V6.1.c: Impact of water shortages: Suggest how the present water shortages in your area could be minimised	V6.1.d: Impact of water shortages: Suggest how the present water shortages in your area could be minimised
N	Valid	49	9	7	6
	Missing	22	62	64	65

## Frequency Table

### V6.1.a: Impact of water shortages: Suggest how the present water shortages in your area could be minimised

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Reduce washing cars & excessive garden watering	7	9.9	14.3	14.3
	Better alerting methods	1	1.4	2.0	16.3
	Better reaction & maintenance by local authorities & competent staff	16	22.5	32.7	49.0
	Improved infrastructure	2	2.8	4.1	53.1
	Awareness	2	2.8	4.1	57.1
	Mitigation measures & monitoring	3	4.2	6.1	63.3
	Build more reservoirs & water towers	2	2.8	4.1	67.3
	Maintain water pressure	2	2.8	4.1	71.4

	Use grey water for toilets, irrigation, etc	1	1.4	2.0	73.5
	Water harvesting	1	1.4	2.0	75.5
	Water supply increased	1	1.4	2.0	77.6
	Leakage detection devices	1	1.4	2.0	79.6
	It is not common at this stage	1	1.4	2.0	81.6
	Contingent plans in place during water shortages	1	1.4	2.0	83.7
	Improved management	1	1.4	2.0	85.7
	Local government initiatives	1	1.4	2.0	87.8
	Fix leakages & bursts	4	5.6	8.2	95.9
	Water restrictions	1	1.4	2.0	98.0
	Stop further development	1	1.4	2.0	100.0
	Total	49	69.0	100.0	
Missing	System	22	31.0		
Total		71	100.0		

**V6.1.b: Impact of water shortages: Suggest how the present water shortages in your area could be minimised**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Better alerting methods	1	1.4	11.1	11.1
	Better reaction & maintenance by local authorities & competent staff	5	7.0	55.6	66.7
	Mitigation measures & monitoring	1	1.4	11.1	77.8
	Build more reservoirs & water towers	1	1.4	11.1	88.9
	Use grey water for toilets, irrigation, etc	1	1.4	11.1	100.0
	Total	9	12.7	100.0	
Missing	System	62	87.3		
Total		71	100.0		

**V6.1.c: Impact of water shortages: Suggest how the present water shortages in your area could be minimised**

		Frequency	Percent	Valid Percent	Cumulative Percent
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Valid	Reduce washing cars & excessive garden watering	1	1.4	14.3	14.3
	Better reaction & maintenance by local authorities & competent staff	1	1.4	14.3	28.6
	Improved infrastructure	1	1.4	14.3	42.9
	Mitigation measures & monitoring	1	1.4	14.3	57.1
	Build more reservoirs & water towers	1	1.4	14.3	71.4
	Use stronger material when building pipes	1	1.4	14.3	85.7
	Annual budget must be in place	1	1.4	14.3	100.0
	Total	7	9.9	100.0	
Missing	System	64	90.1		
Total		71	100.0		

**V6.1.d: Impact of water shortages: Suggest how the present water shortages in your area could be minimised**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Reduce washing cars & excessive garden watering	1	1.4	16.7	16.7
	Better reaction & maintenance by local authorities & competent staff	2	2.8	33.3	50.0
	Improved infrastructure	1	1.4	16.7	66.7
	Better drainage	1	1.4	16.7	83.3
	Contingent plans in place during water shortages	1	1.4	16.7	100.0
	Total	6	8.5	100.0	
Missing	System	65	91.5		
Total		71	100.0		

FREQUENCIES VARIABLES=V6.2

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

V6.2: How frequently is your property affected by water shortages

N	Valid	71
	Missing	0

**V6.2: How frequently is your property affected by water shortages**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never	2	2.8	2.8	2.8
	Less than once a year	9	12.7	12.7	15.5
	1-2 times a year	21	29.6	29.6	45.1
	3-4 times a year	22	31.0	31.0	76.1
	5 or more times	17	23.9	23.9	100.0
	Total	71	100.0	100.0	

MULT RESPONSE GROUPS=\$MRQ6.3 (v6.3a v6.3b v6.3c v6.3d v6.3e v6.3f v6.3g v6.3h v6.3i v6.3j v6.3k

(1,11))

/FREQUENCIES=\$MRQ6.3.

**Multiple Response**

**Case Summary**

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ6.3 <sup>a</sup>	70	98.6%	1	1.4%	71	100.0%

a. Group

**\$MRQ6.3 Frequencies**

	Responses	Percent of Cases		
		N	Percent	
\$MRQ6.3 <sup>a</sup>	Climate change(droughts)	42	15.6%	60.0%
	Water leakages	57	21.1%	81.4%
	Theft of water	22	8.1%	31.4%
	Overuse of water	21	7.8%	30.0%

Water pollution	24	8.9%	34.3%
Water wastage	49	18.1%	70.0%
Conflict	5	1.9%	7.1%
Destruction of water catchment areas	18	6.7%	25.7%
Restriction by government	18	6.7%	25.7%
Water rationing	13	4.8%	18.6%
Other	1	0.4%	1.4%
<b>Total</b>	<b>270</b>	<b>100.0%</b>	<b>385.7%</b>

a. Group

MULT RESPONSE GROUPS=\$MRQ6.4 (v6.4a v6.4b v6.4c v6.4d (1,17))

/FREQUENCIES=\$MRQ6.4.

### Multiple Response

#### Case Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
<b>\$MRQ6.4<sup>a</sup></b>	60	84.5%	11	15.5%	71	100.0%

a. Group

#### \$MRQ6.4 Frequencies

		Responses		Percent of Cases
		N	Percent	
<b>\$MRQ6.4<sup>a</sup></b>	Repair damaged infrastructure, attend to water leakage sin time, maintenance	23	31.5%	38.3%
	Better management of funds & resources	9	12.3%	15.0%
	Improve town planning & infrastructure incl. storm water	8	11.0%	13.3%
	Water conservation	6	8.2%	10.0%
	Monitoring	1	1.4%	1.7%
	Awareness & communication	6	8.2%	10.0%

Address pollution	1	1.4%	1.7%
Research & alternative sources of water	2	2.7%	3.3%
Stop malicious intent	3	4.1%	5.0%
Provide water tanks	1	1.4%	1.7%
More water supplies	1	1.4%	1.7%
Educate & train staff	4	5.5%	6.7%
Keep proper records	1	1.4%	1.7%
Transparency & communication with residents	3	4.1%	5.0%
Fines for water wastage	1	1.4%	1.7%
Take initiative	2	2.7%	3.3%
Run surveys for upgrading infrastructure	1	1.4%	1.7%
<b>Total</b>	<b>73</b>	<b>100.0%</b>	<b>121.7%</b>

a. Group

MULT RESPONSE GROUPS=\$MRQ6.5 (v6.5a v6.5b v6.5c v6.5d v6.5e v6.5f v6.5g v6.5h v6.5i v6.5j (1,10))

/FREQUENCIES=\$MRQ6.5.

### Multiple Response

#### Case Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ6.5 <sup>a</sup>	62	87.3%	9	12.7%	71	100.0%

a. Group

#### \$MRQ6.5 Frequencies

	Responses	Percent of Cases	
		N	Percent
\$MRQ6.5 <sup>a</sup>	Signed petition	9	9.8%
	Attended local authority meetings	12	13.0%

Attended community meetings	13	14.1%	21.0%
Reported to member of committee concerned with service delivery	8	8.7%	12.9%
Reported to Johannesburg Water	35	38.0%	56.5%
Created a street group to pressurise service delivery	2	2.2%	3.2%
Reported malicious individuals	6	6.5%	9.7%
Joined a protest group on the streets	1	1.1%	1.6%
Other	6	6.5%	9.7%
<b>Total</b>	<b>92</b>	<b>100.0%</b>	<b>148.4%</b>

a. Group

FREQUENCIES VARIABLES=V7.1 V7.2 V7.3

/ORDER=ANALYSIS.

### Frequencies

#### Statistics

		V7.1: Billing systems: Have you ever received an inaccurate bill	V7.2: What was the cause of the inaccurate bill	V7.3: Do you think using smart meters are good for billing accuracy(including water leakages)
N	Valid	70	61	71
	Missing	1	10	0

### Frequency Table

#### V7.1: Billing systems: Have you ever received an inaccurate bill

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	60	84.5	85.7	85.7
	No	10	14.1	14.3	100.0
	Total	70	98.6	100.0	
Missing	System	1	1.4		

Total	71	100.0		
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**V7.2: What was the cause of the inaccurate bill**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Meter inaccuracy	25	35.2	41.0	41.0
	Human error	18	25.4	29.5	70.5
	Water leakages	4	5.6	6.6	77.0
	Average water readings	10	14.1	16.4	93.4
	Inaccurate rates	4	5.6	6.6	100.0
	Total	61	85.9	100.0	
Missing	System	10	14.1		
Total		71	100.0		

**V7.3: Do you think using smart meters are good for billing accuracy(including water leakages)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	67	94.4	94.4	94.4
	No	4	5.6	5.6	100.0
	Total	71	100.0	100.0	

MULT RESPONSE GROUPS=\$MRQ7.4 (v7.4a v7.4b v7.4c v7.4d (1,3))

/FREQUENCIES=\$MRQ7.4.

**Multiple Response**

**Case Summary**

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ7.4 <sup>a</sup>	3	4.2%	68	95.8%	71	100.0%

a. Group

**\$MRQ7.4 Frequencies**

Responses		Percent of Cases
N	Percent	

\$MRQ7.4 <sup>a</sup>	Monthly & consistent actual meter readings	1	33.3%	33.3%
	Pre-paid	1	33.3%	33.3%
	Only pay for water that comes into the house	1	33.3%	33.3%
Total		3	100.0%	100.0%

a. Group

FREQUENCIES VARIABLES=V7.4\_Electronic

/ORDER=ANALYSIS.

## Frequencies

### Statistics

V7.4\_electronic

N	Valid	71
	Missing	0

### V7.4\_electronic

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	68	95.8	95.8	95.8
Current one works, smart meters are inconvenient t	1	1.4	1.4	97.2
Fix what we use already	1	1.4	1.4	98.6
Keep current meters- new meters will inconvenience	1	1.4	1.4	100.0
Total	71	100.0	100.0	

FREQUENCIES VARIABLES=V7.5

/ORDER=ANALYSIS.

## Frequencies

### Statistics

V7.5: Do you think unauthorised consumption of water occurs

N	Valid	71
	Missing	0

**V7.5: Do you think unauthorised consumption of water occurs**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	34	47.9	47.9	47.9
	No	37	52.1	52.1	100.0
	Total	71	100.0	100.0	

**Water suppliers: Initial Frequencies**

FREQUENCIES VARIABLES=V2.1

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

V2.1: Socioeconomic data: What is your highest completed level of education

N	Valid	2
	Missing	0

**V2.1: Socioeconomic data: What is your highest completed level of education**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Tertiary (College/ University/ Post-Secondary)	2	100.0	100.0	100.0

COMPUTE Work\_Months\_Dec=V2.2b / 12.

EXECUTE.

COMPUTE Work\_Years\_Months=V2.2a + Work\_Months\_Dec.

EXECUTE.

FREQUENCIES VARIABLES=Work\_Years\_Months

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

Work\_Years\_Months

N	Valid	2
	Missing	0

**Work\_Years\_Months**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	8.50	1	50.0	50.0	50.0
	10.75	1	50.0	50.0	100.0
Total		2	100.0	100.0	

FREQUENCIES VARIABLES=V3.1 V3.2 V3.3

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

		V3.1: Water leakages: How often do you get alerted of burst pipes/leakages	V3.2: To your knowledge, in which part of Midrand to water leakages occur most frequently	V3.3: Which of the following components has the highest water losses choose one
N	Valid	2	2	2
	Missing	0	0	0

**Frequency Table**

**V3.1: Water leakages: How often do you get alerted of burst pipes/leakages**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Once every month	2	100.0	100.0	100.0

**V3.2: To your knowledge, in which part of Midrand to water leakages occur most frequently**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Others (please specify)	2	100.0	100.0	100.0

**V3.3: Which of the following components has the highest water losses choose one**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Distribution mains	1	50.0	50.0	50.0
	Connections	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

MULT RESPONSE GROUPS=\$MRQ3.4 (v3.4a v3.4b v3.4c v3.4d v3.4e v3.4f v3.4g v3.4h v3.4i v3.4j v3.4k v3.4l v3.4m v3.4n v3.4o (1,15))  
 /FREQUENCIES=\$MRQ3.4.

**Multiple Response**

**Case Summary**

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ3.4 <sup>a</sup>	2	100.0%	0	0.0%	2	100.0%

a. Group

**\$MRQ3.4 Frequencies**

		Responses		Percent of Cases
		N	Percent	
\$MRQ3.4 <sup>a</sup>	Intruding tree roots	1	20.0%	50.0%
	Rapid temperature changes	1	20.0%	50.0%
	Pressure differences	1	20.0%	50.0%
	Other	2	40.0%	100.0%
Total		5	100.0%	250.0%

a. Group

FREQUENCIES VARIABLES=V3.5 V3.6

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

V3.5: Do you expect that more water leakages will occur in Midrand within the next few months

V3.6: Please state the reason/s for your answer to 3.5

N	Valid	2	0
	Missing	0	2

**Frequency Table**

**V3.5: Do you expect that more water leakages will occur in Midrand within the next few months**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	1	50.0	50.0	50.0
	No	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V3.6: Please state the reason/s for your answer to 3.5**

		Frequency	Percent
Missing	System	2	100.0

FREQUENCIES VARIABLES=V4.2 /ORDER=ANALYSIS.

**Frequencies**

**Statistics**

V4.2: What is the approximate cost of fixing a water leakage(This includes all equipment and travel)

N	Valid	2
	Missing	0

**Frequency Table**

**V4.2: What is the approximate cost of fixing a water leakage(This includes all equipment and travel)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	R20 000 or less	1	50.0	50.0	50.0
	R20 001 - R40 000	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

FREQUENCIES VARIABLES=V4.3a V4.3b V4.3c V4.3d V4.3e

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

		V4.3a: Please state the approximate expenditure during a burst pipe call out: Equipment costs (in Rands)	V4.3b: Distance to burst pipe in (Rand/km)	V4.3c: Time spent (in hours or part of an hour)	V4.3d: Labour costs (in Rands/hour)	V4.3e: Personal Protective Equipment (in Rands)
N	Valid	2	2	2	2	2
	Missing	0	0	0	0	0

**Frequency Table**

**V4.3a: Please state the approximate expenditure during a burst pipe call out: Equipment costs (in Rands)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	R250/hour	1	50.0	50.0	50.0
	R3000	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V4.3b: Distance to burst pipe in (Rand/km)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		1	50.0	50.0	50.0
	10 km	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V4.3c: Time spent (in hours or part of an hour)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3 hours	2	100.0	100.0	100.0

**V4.3d: Labour costs (in Rands/hour)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	R1000	1	50.0	50.0	50.0
	R120/hour	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V4.3e: Personal Protective Equipment (in Rands)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	R1000	1	50.0	50.0	50.0
	R8/hour	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

QUENCIES VARIABLES=V4.4 V4.5

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

		V4.4: Which leakage intervention interval would have the highest cost	V4.5: How do you track water supply
N	Valid	2	2
	Missing	0	0

**Frequency Table**

**V4.4: Which leakage intervention interval would have the highest cost**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Every 0.5 years (6 months)	1	50.0	50.0	50.0
	Every 2 years (24 months)	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V4.5: How do you track water supply**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Software	1	50.0	50.0	50.0
	Manually in field	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

FREQUENCIES VARIABLES=V4.2 V4.3a V4.3b V4.3c V4.3d V4.3e

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

		V4.2: What is the approximate cost of fixing a water leakage(This includes all equipment and travel)	V4.3a: Please state the approximate expenditure during a burst pipe call out: Equipment costs (in Rands)	V4.3b: Distance to burst pipe in (Rand/km)	V4.3c: Time spent (in hours or part of an hour)	V4.3d: Labour costs (in Rands/hour)	V4.3e: Personal Protective Equipment (in Rands)
N	Valid	2	2	2	2	2	2
	Missing	0	0	0	0	0	0

**Frequency Table**

**V4.2: What is the approximate cost of fixing a water leakage(This includes all equipment and travel)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	R20 000 or less	1	50.0	50.0	50.0
	R20 001 - R40 000	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V4.3a: Please state the approximate expenditure during a burst pipe call out: Equipment costs (in Rands)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	R250/hour	1	50.0	50.0	50.0
	R3000	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V4.3b: Distance to burst pipe in (Rand/km)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		1	50.0	50.0	50.0
	10 km	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V4.3c: Time spent (in hours or part of an hour)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3 hours	2	100.0	100.0	100.0

**V4.3d: Labour costs (in Rands/hour)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	R1000	1	50.0	50.0	50.0
	R120/hour	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V4.3e: Personal Protective Equipment (in Rands)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	R1000	1	50.0	50.0	50.0
	R8/hour	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

FREQUENCIES VARIABLES=V5.1 V5.2

/ORDER=ANALYSIS.

### Frequencies

#### Statistics

V5.1: Water shortages: Do you think water shortages cause people to move

V5.2: Do you send out water shortage alerts to residents

N	Valid	Missing
	2	0
	2	0

### Frequency Table

#### V5.1: Water shortages: Do you think water shortages cause people to move

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	2	100.0	100.0	100.0

#### V5.2: Do you send out water shortage alerts to residents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	2	100.0	100.0	100.0

MULT RESPONSE GROUPS=\$MRQ5.3 (v5.3a v5.3b v5.3c v5.3d v5.3e v5.3f v5.3g (1,7))

/FREQUENCIES=\$MRQ5.3.

### Multiple Response

#### Case Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ5.3 <sup>a</sup>	2	100.0%	0	0.0%	2	100.0%

a. Group

### \$MRQ5.3 Frequencies

		Responses		Percent of Cases
		N	Percent	
\$MRQ5.3 <sup>a</sup>	Radio alert	2	50.0%	100.0%
	Newspapers	1	25.0%	50.0%
	Notices	1	25.0%	50.0%
Total		4	100.0%	200.0%

a. Group

FREQUENCIES VARIABLES=V5.4

/ORDER=ANALYSIS.

### Frequencies

#### Statistics

V5.4: How effective do you consider the alerts to be

N	Valid	2
	Missing	0

### V5.4: How effective do you consider the alerts to be

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Moderately effective	1	50.0	50.0	50.0
	Effective	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

MULT RESPONSE GROUPS=\$MRQ6.1 (v6.1.a v6.1.b v6.1.c v6.1.d v6.1.e v6.1.f v6.1.g v6.1.h v6.1.i v6.1.j v6.1.k v6.1.l v6.1.m v6.1.n v6.1.o v6.1.p v6.1.q (1,17))

/FREQUENCIES=\$MRQ6.1.

**Multiple Response**

**Case Summary**

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ6.1 <sup>a</sup>	2	100.0%	0	0.0%	2	100.0%

a. Group

**\$MRQ6.1 Frequencies**

		Responses		Percent of Cases
		N	Percent	
\$MRQ6.1 <sup>a</sup>	Cost implications	2	14.3%	100.0%
	Water wastage	2	14.3%	100.0%
	Consumer complaints/ Strikes	2	14.3%	100.0%
	Health impacts	1	7.1%	50.0%
	Sedimentation at point of leakage	1	7.1%	50.0%
	Reduction in system capacity	2	14.3%	100.0%
	Negative pressures	2	14.3%	100.0%
	Low velocities	1	7.1%	50.0%
	Dirty water with grit	1	7.1%	50.0%
Total		14	100.0%	700.0%

a. Group

FREQUENCIES VARIABLES=V6.3a V6.3b V6.3c V6.3d V6.3e V6.3f V6.3g V6.3h V6.3i

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

N	
Valid	Missing

V6.3a: Specific reference to water shortages, how would you rate/respond to the following factors in attempting to reduce severity of water leakage impacts: Pressure management to reduce leakages	2	0
V6.3b: Using meters to monitor water usage	2	0
V6.3c: Using meters to monitor water demand	2	0
V6.3d: Upgrading old infrastructure to reduce water leakages	2	0
V6.3e: Implementing models to help identify and mitigate costs of water leakages	2	0
V6.3f: Increase the frequency of maintenance of infrastructure	2	0
V6.3g: Construct more water towers and reservoirs	2	0
V6.3h: Dig boreholes on sites	2	0
V6.3i: Other (please specify)	0	2

### Frequency Table

**V6.3a: Specific reference to water shortages, how would you rate/respond to the following factors in attempting to reduce severity of water leakage impacts: Pressure management to reduce leakages**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly agree	2	100.0	100.0	100.0

**V6.3b: Using meters to monitor water usage**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly agree	2	100.0	100.0	100.0

**V6.3c: Using meters to monitor water demand**

		Frequency	Percent	Valid Percent	Cumulative Percent
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Valid	Agree	1	50.0	50.0	50.0
	Strongly agree	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V6.3d: Upgrading old infrastructure to reduce water leakages**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	1	50.0	50.0	50.0
	Strongly agree	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V6.3e: Implementing models to help identify and mitigate costs of water leakages**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Disagree	1	50.0	50.0	50.0
	Strongly agree	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V6.3f: Increase the frequency of maintenance of infrastructure**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	1	50.0	50.0	50.0
	Strongly agree	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V6.3g: Construct more water towers and reservoirs**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Agree	1	50.0	50.0	50.0
	Disagree	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V6.3h: Dig boreholes on sites**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Agree	1	50.0	50.0	50.0
	Agree	1	50.0	50.0	100.0

Total	2	100.0	100.0
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**V6.3i: Other (please specify)**

		Frequency	Percent
Missing	System	2	100.0

MULT RESPONSE GROUPS=\$MRQ6.4 (v6.4a v6.4b v6.4c v6.4d v6.4e v6.4f v6.4g v6.4h v6.4i (1,9))

/FREQUENCIES=\$MRQ6.4.

**Multiple Response**

**Case Summary**

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ6.4 <sup>a</sup>	2	100.0%	0	0.0%	2	100.0%

a. Group

**\$MRQ6.4 Frequencies**

		Responses		Percent of Cases
		N	Percent	
\$MRQ6.4 <sup>a</sup>	Local authority meetings:	1	8.3%	50.0%
	Community meetings	2	16.7%	100.0%
	Water conservation information distributed	2	16.7%	100.0%
	Television advertisements	1	8.3%	50.0%
	Government campaigns	1	8.3%	50.0%
	Notices	1	8.3%	50.0%
	Incentives/rewards	2	16.7%	100.0%
	Penalties/fine	2	16.7%	100.0%
Total		12	100.0%	600.0%

a. Group

FREQUENCIES VARIABLES=V6.7

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

V6.7: How effective have these strategies been

N	Valid	0
	Missing	2

**V6.7: How effective have these strategies been**

		Frequency	Percent
Missing	System	2	100.0

FREQUENCIES VARIABLES=V6.7

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

V6.7: How effective have these strategies been

N	Valid	2
	Missing	0

**V6.7: How effective have these strategies been**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Moderately effective	1	50.0	50.0	50.0
	Very effective	1	50.0	50.0	100.0
Total		2	100.0	100.0	

REQUENCIES VARIABLES=V7.1

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

V7.1: Do you use smart meters for identifying leakages

N	Valid	2
	Missing	0

**V7.1: Do you use smart meters for identifying leakages**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	2	100.0	100.0	100.0

FREQUENCIES VARIABLES=V7.3 V7.4

/ORDER=ANALYSIS.

**Frequencies**

**Statistics**

		V7.3: On average how long does it take to repair a burst pipe	V7.4: How are unreported bursts detected
N	Valid	2	2
	Missing	0	0

**Frequency Table**

**V7.3: On average how long does it take to repair a burst pipe**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0.5 - 1 day	2	100.0	100.0	100.0

**V7.4: How are unreported bursts detected**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Alerted by someone	2	100.0	100.0	100.0

MULT RESPONSE GROUPS=\$MRQ7.5 (v7.5a v7.5b v7.5c v7.5d v7.5e v7.5f v7.5g (1,7))

/FREQUENCIES=\$MRQ7.5.

**Multiple Response**

**Case Summary**

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
\$MRQ7.5 <sup>a</sup>	2	100.0%	0	0.0%	2	100.0%

a. Group

### \$MRQ7.5 Frequencies

		Responses		Percent of Cases
		N	Percent	
\$MRQ7.5 <sup>a</sup>	Field work	2	28.6%	100.0%
	Water consumption patterns	2	28.6%	100.0%
	Invoiced bills	1	14.3%	50.0%
	Meter readings	2	28.6%	100.0%
Total		7	100.0%	350.0%

a. Group

FREQUENCIES VARIABLES=V7.6 V7.7 V7.9

/ORDER=ANALYSIS.

### Frequencies

#### Statistics

		V7.6: How are water loss interventions and checks undertaken	V7.7: How effective is your leakage detection method	V7.9: Would you consider implementing a model that determines the Economic loss of water leakages and suggests an active leakage control frequency which is at a suitable cost
N	Valid	2	2	2
	Missing	0	0	0

### Frequency Table

**V7.6: How are water loss interventions and checks undertaken**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Every 6 months	2	100.0	100.0	100.0

**V7.7: How effective is your leakage detection method**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Somewhat effective	1	50.0	50.0	50.0
	Moderately effective	1	50.0	50.0	100.0
	Total	2	100.0	100.0	

**V7.9: Would you consider implementing a model that determines the Economic loss of water leakages and suggests an active leakage control frequency which is at a suitable cost**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	2	100.0	100.0	100.0

**Addendum 7B: Results from cross tabulations**

**Length of stay of residents and frequency of burst pipes**

CROSSTABS

/TABLES=V2.6 BY V3.1

/FORMAT=AVALUE TABLES

/STATISTICS=CHISQ

/CELLS=COUNT EXPECTED COLUMN SRESID

/COUNT ROUND CELL

/METHOD=EXACT TIMER(5).

**Crosstabs**

**Case Processing Summary**

		Cases					
		Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent	
<hr/>							

V2.6: Length of stay * V3.1: Have you experienced a water leakage / burst pipe while living in this complex	71	100.0%	0	0.0%	71	100.0%
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**V2.6: Length of stay \* V3.1: Have you experienced a water leakage / burst pipe while living in this complex Crosstabulation**

		V3.1: Have you experienced a water leakage / burst pipe while living in this complex		Total	
		Yes	No		
V2.6: Length of stay	Less than one year	Count	7	2	9
		Expected Count	7.5	1.5	9.0
		Column %	11.9%	16.7%	12.7%
		Standardized Residual	-.2	.4	
	1 - 5 years	Count	31	6	37
		Expected Count	30.7	6.3	37.0
		Column %	52.5%	50.0%	52.1%
		Standardized Residual	.0	-.1	
	6 - 10 years	Count	8	3	11
		Expected Count	9.1	1.9	11.0
		Column %	13.6%	25.0%	15.5%
		Standardized Residual	-.4	.8	
	11 - 15 years	Count	5	0	5
		Expected Count	4.2	.8	5.0
		Column %	8.5%	0.0%	7.0%
		Standardized Residual	.4	-.9	
	16 - 20 years	Count	4	0	4
		Expected Count	3.3	.7	4.0
		Column %	6.8%	0.0%	5.6%
		Standardized Residual	.4	-.8	
More than 20 years	Count	4	1	5	
	Expected Count	4.2	.8	5.0	
	Column %	6.8%	8.3%	7.0%	
	Standardized Residual	-.1	.2		
Total	Count	59	12	71	
	Expected Count	59.0	12.0	71.0	

Column %	100.0%	100.0%	100.0%
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### Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	2.901 <sup>a</sup>	5	.715	.779		
Likelihood Ratio	4.284	5	.509	.685		
Fisher's Exact Test	2.522			.800		
Linear-by-Linear Association	.324 <sup>b</sup>	1	.569	.648	.342	.084
N of Valid Cases	71					

a. 8 cells (66.7%) have expected count less than 5. The minimum expected count is .68.

b. The standardized statistic is -.569.

### CROSSTABS

/TABLES=V2.6 BY V3.2

/FORMAT=AVALUE TABLES

/STATISTICS=CHISQ

/CELLS=COUNT EXPECTED COLUMN SRESID

/COUNT ROUND CELL

/METHOD=EXACT TIMER(5).

### Crosstabs

#### Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
V2.6: Length of stay * V3.2: How often do you experience burst pipes	70	98.6%	1	1.4%	71	100.0%

#### V2.6: Length of stay \* V3.2: How often do you experience burst pipes Crosstabulation

	V3.2: How often do you experience burst pipes							Total
	Once a month	Once every 3 months	Once every 6 months	Once a year	Once in two years	Never	Other (please specify)	
Count	0	2	3	1	1	1	0	8

V2.6: Length of stay	Less than one year	Expected Count	.3	1.9	2.6	1.4	.9	.6	.2	8.0
		Column %	0.0%	11.8%	13.0%	8.3%	12.5%	20.0%	0.0%	11.4%
		Standardized Residual	-.6	.0	.2	-.3	.1	.6	-.5	
	1 - 5 years	Count	2	12	11	4	4	3	1	37
		Expected Count	1.6	9.0	12.2	6.3	4.2	2.6	1.1	37.0
		Column %	66.7%	70.6%	47.8%	33.3%	50.0%	60.0%	50.0%	52.9%
		Standardized Residual	.3	1.0	-.3	-.9	-.1	.2	-.1	
	6 - 10 years	Count	1	2	4	2	1	1	0	11
		Expected Count	.5	2.7	3.6	1.9	1.3	.8	.3	11.0
		Column %	33.3%	11.8%	17.4%	16.7%	12.5%	20.0%	0.0%	15.7%
		Standardized Residual	.8	-.4	.2	.1	-.2	.2	-.6	
	11 - 15 years	Count	0	1	1	2	0	0	1	5
		Expected Count	.2	1.2	1.6	.9	.6	.4	.1	5.0
		Column %	0.0%	5.9%	4.3%	16.7%	0.0%	0.0%	50.0%	7.1%
		Standardized Residual	-.5	-.2	-.5	1.2	-.8	-.6	2.3	
	16 - 20 years	Count	0	0	3	1	0	0	0	4
Expected Count		.2	1.0	1.3	.7	.5	.3	.1	4.0	
Column %		0.0%	0.0%	13.0%	8.3%	0.0%	0.0%	0.0%	5.7%	
Standardized Residual		-.4	-1.0	1.5	.4	-.7	-.5	-.3		
More than 20 years	Count	0	0	1	2	2	0	0	5	
	Expected Count	.2	1.2	1.6	.9	.6	.4	.1	5.0	
	Column %	0.0%	0.0%	4.3%	16.7%	25.0%	0.0%	0.0%	7.1%	
	Standardized Residual	-.5	-1.1	-.5	1.2	1.9	-.6	-.4		
Total	Count	3	17	23	12	8	5	2	70	
	Expected Count	3.0	17.0	23.0	12.0	8.0	5.0	2.0	70.0	
	Column %	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	

### Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	24.129 <sup>a</sup>	30	.766	. <sup>b</sup>	
Likelihood Ratio	24.194	30	.763	.893	
Fisher's Exact Test	22.267			.858	
Linear-by-Linear Association	1.278	1	.258	. <sup>b</sup>	. <sup>b</sup>
N of Valid Cases	70				

a. 39 cells (92.9%) have expected count less than 5. The minimum expected count is .11.

b. Cannot be computed because there is insufficient memory.

<https://www.ibm.com/support/pages/mantel-haenszel-test-trend-available-crosstabs>

### Relationship between type of dwelling and the cost implications:

#### V2.5: Type of dwelling \* V3.4d: Burst pipes have cost implications Crosstabulation

		V3.4d: Burst pipes have cost implications		Total	
		No	Yes		
V2.5: Type of dwelling	Single storey	Count	17	20	37
		Expected Count	19.6	17.4	37.0
		Column %	45.9%	60.6%	52.9%
		Standardized Residual	-.6	.6	
	Double storey	Count	20	10	30
		Expected Count	15.9	14.1	30.0
		Column %	54.1%	30.3%	42.9%
		Standardized Residual	1.0	-1.1	
	Outbuilding(garage,etc)	Count	0	1	1
		Expected Count	.5	.5	1.0
		Column %	0.0%	3.0%	1.4%
		Standardized Residual	-.7	.8	
	Other (please specify)	Count	0	2	2
		Expected Count	1.1	.9	2.0
		Column %	0.0%	6.1%	2.9%
		Standardized Residual	-1.0	1.1	
Total		Count	37	33	70

Expected Count	37.0	33.0	70.0
Column %	100.0%	100.0%	100.0%

### Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	6.369 <sup>a</sup>	3	.095	.047		
Likelihood Ratio	7.572	3	.056	.045		
Fisher's Exact Test	5.890			.051		
Linear-by-Linear Association	.235 <sup>b</sup>	1	.628	.675	.370	.100
N of Valid Cases	70					

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is .47.

b. The standardized statistic is .485.

### CROSSTABS

/TABLES=V2.5 BY V3.4e

/FORMAT=AVALUE TABLES

/STATISTICS=CHISQ

/CELLS=COUNT EXPECTED COLUMN SRESID

/COUNT ROUND CELL

/METHOD=EXACT TIMER(5).

### Relationship between residents waiting for the pipe to be fixed and water to be restored and attending community meetings.

**V5.4: What was your response when the alert was conveyed: Waited for the pipe to be fixed & water to be restored \* V6.5c: Become involved in management of water shortages: Attended community meetings Crosstabulation**

			V6.5c: Become involved in management of water shortages: Attended community meetings		Total
			No	Yes	
V5.4: What was your response when the alert was conveyed: Waited for the pipe to be fixed & water to be restored	No	Count	32	3	35
		Expected Count	28.2	6.8	35.0
		Column %	59.3%	23.1%	52.2%
		Standardized Residual	.7	-1.5	
	Yes	Count	22	10	32

	Expected Count	25.8	6.2	32.0
	Column %	40.7%	76.9%	47.8%
	Standardized Residual	-.7	1.5	
Total	Count	54	13	67
	Expected Count	54.0	13.0	67.0
	Column %	100.0%	100.0%	100.0%

#### Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2- sided)	Exact Sig. (1- sided)	Point Probability
Pearson Chi-Square	5.498 <sup>a</sup>	1	.019	.029	.020	
Continuity Correction <sup>b</sup>	4.143	1	.042			
Likelihood Ratio	5.705	1	.017	.029	.020	
Fisher's Exact Test				.029	.020	
Linear-by-Linear Association	5.416 <sup>c</sup>	1	.020	.029	.020	.017
N of Valid Cases	67					

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.21.

b. Computed only for a 2x2 table

c. The standardized statistic is 2.327.

#### CROSSTABS

/TABLES=V5.4a BY V6.5d

/FORMAT=AVALUE TABLES

/STATISTICS=CHISQ

/CELLS=COUNT EXPECTED COLUMN SRESID

/COUNT ROUND CELL

/METHOD=EXACT TIMER(5).