TAMPERE UNIVERSITY OF TECHNOLOGY

ARTO LÖPPÖNEN

WATER LOSS MANAGAMENT IN KEETMANSHOOP, NAMIBIA

Master of Science thesis

Examiners: DSc Pekka Pietilä
Doc. Tapio Katko
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ABSTRACT

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Deteriorating water distribution networks are commonly causing trouble for water utilities worldwide. PLDDSI (Partnership for Local Democracy, Development and Social Innovation) is a Finnish-Namibian cooperation project which provides engineering assistance for addressing those problems in Namibian municipalities. In Keetmanshoop, which is one of the counterpart municipalities, more than one third of all water entering the network is counted as non-revenue water. One of the targets of the project in Keetmanshoop is reducing non-revenue water to financially sustainable level.

The main objective of this study was to analyze the major problems in the municipality of Keetmanshoop and give suggestions how to deal with them. Based on the suggestions, a development strategy was built up for reducing non-revenue water. Literature survey was used to explain tools that are internationally used for non-revenue water reduction and to introduce how they could be applied in Keetmanshoop. Analysis in Keetmanshoop was done mainly by interviewing staff at the municipality and making observations and measurements in the field. The water network was also analyzed with computer simulations. In addition, a number of other municipalities and their water departments were analyzed as a comparison. The additional municipalities referred to were Windhoek, Swakopmund, Walvis Bay, Lüderitz and Ondangwa in Namibia and the PLDSSI counterparts Kangasala and Lempäälä in Finland. It seems that all of the reviewed municipalities have acknowledged the importance of systematic plan for non-revenue water reduction but the methods how this problem is tackled differ a lot. Only the Finnish municipalities and Lüderitz have a clear long-term plan to renovate their water networks.

This research showed that the financial losses caused by non-revenue water in Keetmanshoop are alarming. The percentage of lost water has been on increase for at least past five years and it is not probable that the situation will improve without changes in the management methods. Water is presently lost due to a number of factors but the most significant ones are leaking pipe network and apparent losses due to illegal consumption and non-functioning water meters. With the knowledge gained during the research period, a programme was introduced to show the importance of non-revenue water reduction. Since there are still a lot of vital data missing, some financial calculations are based on estimates. However, as the programme suggested, in the beginning additional data will be collected to verify assumptions and justify needed actions. Likewise with many investments in the business world, the profits will come with a delay. The first few years of the programme will be unprofitable but more and more savings will be achieved in the future.

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO
Ympäristö- ja energiatekniikan koulutusohjelma
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Rappeutuvat vesijohtoverkostot aiheuttavat merkittäviä ongelmia vesilaitoksille maailmanlaajuisesti. PLDDSI (Partnership for Local Democracy, Development and Social Innovation) on suomalais-namibialainen kehitysyhteistyöprojekti, joka tarjoaa insinööriapua vesijohtoverkoston ongelmien ratkaisuun kahdessa namibialaisessa kunnassa. Keetmanshoopissa, joka on yksi projektin kunnista, yli kolmasosa verkostoon johdetusta vedestä häviää ja jää laskuttamatta. Projektin yhtenä tavoitteena Keetmanshoopissa on vähentää laskuttamattoman veden määrä taloudellisesti kestävälle tasolle.

Tämän tutkimuksen keskeinen tavoite oli analysoida vesijohtoverkoston hallintaan liittyviä ongelmia Keetmanshoopissa ja etsiä keinoja niiden ratkaisemiseksi. Kirjallisuusselvityksen avulla esiteltiin kansainvälisesti käytössä olevia keinoja verkostohäviöiden vähentämiseksi sekä tarkasteltiin niiden käyttökelpoisuutta Keetmanshoopissa. Itse Keetmanshoopin vesijohtoverkoston hallinta analysoitiin pääasiassa haastatteluilla, kenttätyöskentelyä havainnoimalla sekä kenttämittauksilla. Vesijohtoverkosto myös mallinnettiin sekä analysoitiin tietokonesimuloinneilla.

Keetmanshoopin lisäksi vertailutarkoituksessa analysoitiin seitsemän muun kunnan verkostonhallintaa. Namibiassa analyysi tehtiin Windhoekissa, Swakopmundissa, Walvis Bayssa, Lüderitzissa ja Ondagwassa sekä Suomessa PLDDSI-yhteistyökunnissa Kangasalassa ja Lempäälässä. Vertailuanalyysissa kävi selvästi ilmi, että kaikissa kunnissa tiedostetaan suunnitelmallisen vesihäviöiden pienentämisen merkitys, mutta ongelmaan puututaan eri tavoin. Ainoastaan suomalaisissa kunnissa sekä Lüderitzissa on selkeä pitkän tähtäimen suunnitelma vesijohtoverkostojen saneeraamiseksi.

Tämä tutkimus osoitti, että laskuttamattoman veden aiheuttamat taloudelliset tappiot Keetmanshoopissa ovat hälyttävän suuria. Vesihävikki on ollut selvässä nousussa viimeiset viisi vuotta eikä tilanteen parantuminen ole todennäköistä nykyisellään. Suurimmat laskuttamattoman veden aiheuttajat ovat vuotava vesijohtoverkosto, luvaton vedenkäyttö sekä toimimattomat vesimittarit. Tutkimusjakson aikana kerätyn aineiston pohjalta laadittiin ohjelma, joka tähtää vesihävikin vähentämiseen systemaattisesti. Koska paljon elintärkeää tietoa puuttuu edelleen, taloudellisuusanalyysia varten jouduttiin tekemään muutamia arvioita. Ohjelman ensimmäisessä osassa kerätään tietoa, jonka pohjalta ohjelman toinen osa toteutetaan. Kuten on monissa liike-elämän investoinneissa, myös verkostoinvestointien voitot tulevat viiveellä. Muutamat ensimmäiset vuodet ovat tappiollisia, mutta voitot tulevat olemaan kiistattomia tulevaisuudessa.

PREFACE AND ACKNOWLEDGEMENTS

The fieldwork for this thesis was carried out in the municipality of Keetmanshoop and the research was compiled at Tampere University of Technology. Big share of the input into this research was collected in meetings and interviews with numerous people in Keetmanshoop as well as in seven other municipalities in Namibia and Finland.

This research was made possible by many individuals and organizations. First, I wish to thank the supervisor of my thesis, DSc Pekka Pietilä, for giving useful suggestions to develop my approach to the topic and for letting me be part of this project in the first place. Special gratitude goes also to Docent Tapio Katko for professional assistance. I also wish to thank RIL (Suomen Rakennusinsinöörien Liitto) and MVTT (Maa- ja vesitekniikan tuki ry.) for supporting finance my thesis.

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Tampere, 18th of April 2011

Arto Löppönen

ABBREVIATIONS AND NOTATIONS

C	leakage coefficient [no unit]
H	water head [m]
L_m	length of mains in water distribution system [m]
L_p	length of service pipes [m]
MF	minimum hour demand factor [no unit]
N_c	number of service connection in water distribution system
P	average operating pressure [m]
PF	peak factor [no unit]
q	water flow through an opening in a pipe [m^3/s]
q_o	original water flow through an opening in a pipe [m^3/s]
q_r	reduced water flow through an opening [m^3/s]
Q_{avg}	average hour demand [m^3/s]
Q_{max}	maximum hour demand [m^3/s]
Q_{min}	minimum hour demand [m^3/s]
Q_{in}	input volume of water [m^3/s]
$Q_{revenue}$	billed volume of water [m^3/s]
AC	asbestos cement
CAD	computer aided design
CARL	current annual real losses
DMA	district metering area
ILI	Infrastructure Leakage Index
ITS	Keetmanshoop municipality: Department of Infrastructure and Technical Services
IWA	International Water Association
NamWater	Namibia Water Corporation Ltd
NRW	non-revenue water
PLDDSI	Partnership for Local Democracy, Development and Social Innovation
PMA	pressure management area
PRV	pressure reducing valve
PVC	Polyvinyl Chloride
uPVC	Unplasticized Polyvinyl Chloride
UARL	unavoidable annual real losses [l/d]
VAT	Value Added Tax (Namibia 15 %, Finland 23 %)
WPI	Water Poverty Index

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1. INTRODUCTION

1.1. Background

Water is a basic human need and throughout the history people have moved to areas where abundant water resources are available. Water has been used for drinking, livestock needs, irrigation and presently tens of other purposes such as industry and power plants. Yet, the future availability of water is uncertain and some of this is due to uncontrollable factors such as weather. However, there are various factors that can be influenced by choices made by the people. These factors include population growth, investment in water infrastructure, the allocation of water to various uses, reform in water management, and technological changes in agriculture. It is mainly up to the actions of millions of individuals and policy decisions that determine which is the path to the future of water. Already in 2010 many areas especially in developing economies are suffering from severe water shortages. Without effective actions, already scarce water storages are diminishing even faster in the future due to increasing demand for water. It is estimated that by 2025 the total water demand in developing countries will increase by 27 % compared with the demand in 1995. (Rosegrant et al. 2002, pp. 1-5)

Namibia, which is one of the driest countries in Africa, suffers from severe water shortages. Rainfalls are irregular taking place only for short periods. This creates a challenge for managing water resources effectively. Namibia has, however, succeeded in this matter quite well by constructing large dams around the country and taking advantage of borehole water wherever the quality of water is suitable and the use is economically feasible. In large areas in many other African countries water must be carried with buckets from kilometers away, while the most Namibian built-up areas have piped systems serving water to all points of the towns. The biggest problem that urban parts of Namibia are facing presently is deteriorating water network infrastructure. Keetmanshoop and many other Namibian municipalities suffer from fragile and constantly bursting pipes, non-functional shut valves and pumps etc. These issues cause problems such as huge amounts of water losses in water distribution systems as well as unsatisfied residents due to water cut-offs and water shortages. Water utilities' management of network infrastructure is thus playing a major role in improving the condition of the networks and avoiding massive financial losses now and in the future.

PLDDSI (Partnership for Local Democracy, Development and Social Innovation) is a cooperation project between four municipalities in Finland and Namibia. The Finnish counterparts are the municipalities of Lempäälä and Kangasala and Namibian partners are the municipalities of Ondangwa and Keetmanshoop. One of the objectives of the project is the water service development in both Namibian municipalities by providing engineering assistance. (PLDDSI 2010) Such assistance has been provided by cooperation partners Tampere University of Technology and Polytechnic of Namibia along with Kangasala and Lempäälä. Students from those two educational institutes have spent time in both Namibian municipalities doing fieldwork in order to gain experience and to compile their final thesis or final projects. The project has been going on since 2007 and the outcomes for Keetmanshoop's needs has been the new water distribution system map and a broad survey of the problems that municipality is encountering in 2008. Also in mid 2009 a wide-scale survey on the condition of shut valves was performed. In 2010, a water engineering student from Finland and a civil engineering student from Namibia spent almost two months from the beginning of July till the end of August in Keetmanshoop to explore the possibilities to manage municipality's water distribution network more effectively.

1.2. Objectives

The main aim of this research is to achieve one of the targets stated by PLDDSI-project: reduce economical losses caused by water losses in Keetmanshoop. This research is a follow-up work for Risto Seppänen's Master of Science thesis: "Water network management in Keetmanshoop, Namibia." Seppänen compiled his thesis in 2008 by making a wide-scale survey on water network management issues and gave a lot of recommendations on how to improve the management issues in Keetmanshoop. Generally speaking this survey is dedicated to update some knowledge already collected by Seppänen and to show more detailed ways for cutting down high amounts of water losses which are financially extremely harmful for the municipality already and even more in the future, if no actions are taken.

This study seeks answers to following questions:

- How much water is being lost nowadays?
- From where is it being lost?
- Why is it being lost?
- What kind of strategies can be introduced to reduce losses?
- What is the cost for water loss reduction programme?
- What are the achievable savings with water loss reduction programme?

1.3. Structure and scope of the research

This research focuses mainly on reducing water losses in Keetmanshoop leaving other water services such as sewerage and storm water channeling out of the scope. However, five other Namibian municipalities, namely Lüderitz, Swakopmund, Walvis Bay, Ondangwa and Windhoek were chosen to be analyzed for their ways of managing water losses as a comparison to Keetmanshoop's current practice. First four of the above mentioned municipalities have roughly same population as Keetmanshoop which gives a good reference. However, Windhoek, the capital city of Namibia, is much larger and was chosen to give an idea of very well managed water department. Comparison is also made with the Finnish counterparts, Kangasala and Lempäälä municipalities.

This research is divided into six chapters. Chapters 2 and 3 are mainly literature surveys. Chapter 2 explains which are the sources and factors that cause losses in water distribution networks. Chapter 3 seeks tools for reducing losses caused by the factors discussed in Chapter 2. Water loss management has been a major topic worldwide in recent decades and thus it is relatively easy to find literature about it. Research, both theoretical and practical, has been done in developed and developing countries and a lot of good results have been achieved in many cases.

Chapter 4 analyses the current situation in Keetmanshoop. Many of the research topics discussed in this chapter have already been dealt with in Seppänen's report, but the current study will explain how the situation has developed since then. It also gives suggestions on how the analyzed topics could be improved with tools explained in previous chapters. The other five selected Namibian municipalities are analyzed in that chapter as a comparison. Analysis is based on field observations, field measurements and interviews. Chapter 5 focuses on explaining the current situation in Finnish counterparts, Kangasala and Lempäälä municipalities, and it also involves Keetmanshoop to make continuous comparisons. Chapter 6 introduces a development strategy that aims to reduce water losses remarkably from the current volume. Chapter 7 discusses the research period, the achieved results and their significance and gives predictions for the future. Since economics plays a big role in this research and there are Finnish and Namibian municipalities discussed side by side, the currency of Finland (Euro) is converted to Namibian Dollars. Conversion is done in accordance of the Bank of Finland and the average value in 2010 is used. In this report, the exchange rate used is 1 € = 9,7 N$.

2. SOURCES AND FACTORS AFFECTING NON-REVENUE WATER

2.1. Definition of water balance

It is suggested that discussion on water losses must be preceded by a clear definition of water balance components. Water balance is based on measurements or estimations of water produced, water imported and exported, water consumed and water lost. The water balance calculation provides a tool for water utility to estimate how much water is being lost due to number of reasons. It is wise to determine the water balance over a 12-month period. The components of water balance should be calculated in volumes of water. (Liemberger & Farley 2004) IWA (International Water Association) represents "the best practice water balance" with accepted terminology which is illustrated in Figure 2.1. (Lambert & Mckenzie 2002).

System Input Volume (corrected for known errors)	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption (including water exported)	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water (NRW)
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorised Consumption	
			Customer Metering Inaccuracies	
		Real Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to point of Customer metering	

Figure 2.1. *The IWA "best practice" water balance (Lambert & Mckenzie 2002).*

The definitions of the principal components of the IWA water balance are as follows (Farley & Trow 2007):

- System input volume is the annual volume input to that part of the water supply system.
- Authorized consumption is the annual volume of metered and/or non-metered water taken by registered customer, the water supplier and other who are

implicitly or explicitly authorized to do so. It includes water exported, and leaks and overflows after the point of customer metering.

- Non-revenue water (NRW) is the difference between system input volume and billed authorized consumption. NRW consists of:
  - unbilled authorized consumption
  - water losses
- Water losses are the difference between system input volume and authorized consumption, and consists of apparent losses and real losses.
- Apparent losses consist of unauthorized consumption and all types of metering inaccuracies
- Real losses are the annual volume of lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

The components of the water balance can be measured, estimated or calculated using a number of techniques. Ideally most of the components are measured. Unfortunately, the reality is often very different. However, it is always useful to establish the water balance even if some key elements are based on estimates. (Liemberger & Farley 2004) The elements of the water balance are discussed more broadly in Chapter 2.2.

2.2. Non-revenue water

NRW is a volume of water which enters the distribution system but gives no revenue to the utility. NRW includes the real losses (physical) and apparent losses (commercial) as well as the unbilled authorized consumption. (Liemberger & Farley 2004) Term unaccounted-for water is also widely used but IWA Task Force does not recommend its use because of varying interpretations of the term. (Farley & Trow 2007, p. 13) NRW is often represented as a percentage of annual system input volume. It can be calculated simply:

$$NRW(\%) = {Q_{in} - Q_{revenue}}\Big/{Q_{in}} \cdot 100\% \tag{1}$$

with Q_{in} the annual system input volume
$Q_{revenue}$ the annual billed volume

A high NRW level is often a surrogate for a poorly run water utility. It is one of the major issues affecting water utilities especially in developing countries. The reasons for reducing NRW levels are fairly well-understood world-wide, but still the causes are hard to be tackled down. This is common because the reduction of NRW is not just a technical issue, but it also relates to management and financial frameworks. Many water utilities in developing economies face multiple political and economic constraints and they lack the proper incentives, specialist management and technical expertise necessary to carry out effective NRW programmes. Although it is widely acknowledged that NRW levels in developing countries are very high, very few data are available in the literature regarding the actual figures, largely because most water utilities do not have proper monitoring systems. However, WHO estimates that average NRW percentage in developing countries is approximately 27 %. (Kingdom et al. 2006) The components of NRW will be discussed next.

2.2.1. Unbilled authorized consumption

A part of unbilled authorized consumption is the water used by the utility for operational purposes. This usage includes items such as fire fighting, network flushing, cleaning of tanks and reservoirs, street cleaning and watering of municipal gardens. These may be metered or unmetered according to local practice. (Farley & Trow 2007, p.13) Normally unbilled authorized consumption is a fairly small component of the water balance. However, sometimes when the documentation of such usages exists, it shows that the consumption is unnecessarily high. It can be reduced to lower annual volumes without influencing operation efficiency of customer service standards. Because of this, such volumes should always be metered, whenever feasible. (Liemberger & Farley 2004)

Components of unbilled unmetered consumption should be individually estimated. The utility can base its estimates on records from the field. For example, how many times per month mains are flushed and for how long. Similarly demands for firefighting can be estimated by knowing the average number of big fires per year and how much water is used to put off the fire. (Liemberger & Farley 2004)

2.2.2. Apparent losses

Not all water losses in water distribution systems consist of leakages in mains, reservoirs etc. There are always some apparent losses like illegal water use (unauthorized consumption) and inaccuracies with water meters and billing. They all relate to water that is being consumed but not paid for. Figure 2.2. illustrates how apparent losses can be separated into four components. Yet, it is nearly impossible to determine the exact annual volume of apparent losses due to their nature. Water meters usually have some degree of uncertainty and they are often not calibrated nor replaced at regular intervals. (Rizzo et al. 2007)

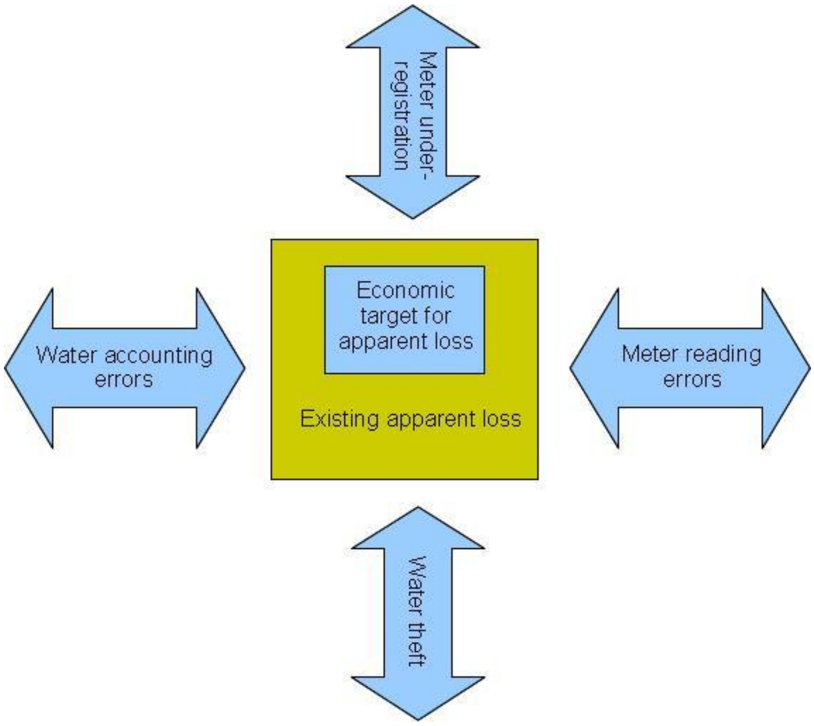

Figure 2.2. *Sources of apparent losses* (Rizzo et al. 2007).

The four components of apparent losses can act and interact interchangeably. For example, meter under-registration consists of the inability of a water meter to accurately measure flows, especially lower flows. But reverse can also be true, thus the registration water meter error is positive (over-recording). The problem of under-registration tends to increase with time as the meter degenerates. Under-registration of water meters may cause a big portion of apparent losses. (Rizzo et al. 2007)

Water theft is easy to conceptualize and it usually consists of by-passes to a water meter, illegal connections or intentional damage to a water meter. Illegal consumption takes place especially in locations of low income. Meter reading errors consist of mistaken or intentionally incorrect meter readings. Water accounting errors include billing anomalies such as computer-based estimations that do not reflect actual consumption values. (Rizzo et al. 2007)

2.2.3. Real losses

Real losses usually sum up the biggest fraction of NRW especially in developed countries. Real losses consist of leakages in distribution and transmission mains, leakage and overflows in utility’s reservoirs and leakage on service connections up to customer metering point. Water loss through leakages is acknowledged as one of the main challenges that water network operators are facing. Leakages from distribution and transmission mains can again be divided into three components; reported, unreported bursts and background leakage. (Giustolisi et al. 2008) Reported bursts are usually large and visible and therefore quickly found and repaired. (Liemberger & Farley 2004)

Unreported bursts can be active for a long period of time and even having only a small leak rate, the total leakage volume can be significant. Unreported bursts are often hard to be determined without step testing and using high-tech equipment such as noise correlators. Even then, some elements of the background losses cannot be located because it is not technically or economically feasible (Liemberger & Farley 2004)

Background losses are individual events such as small leaks and weeps with too low flow rates to be detected even by active leakage control methods. They remain active unless detected either by chance or until they gradually grow up to a point that they can be detected. (Liemberger & Farley 2004)

2.3. Factors affecting non- revenue water in distribution systems

2.3.1. Deterioration of water network infrastructure

Water meters

The under-registration of water meters often comprises the biggest part of apparent losses. Meters sometimes fail in recording flow accurately for many reasons such as normal deterioration in the aging process, damaged registers, solid materials that clog the meter mechanism or broken seals that allow water damaging certain parts. Sometimes bypass lines are built or meters are damaged by construction activities. Improperly sized meters can also cause apparent losses especially due to the incapability to record certain flow rates (usually low flows in the case of larger meters). (Buie 2000)

Buie (2000) made a study in DeKalb County in Georgia to test-drive all sizes of water meters to check their accuracies. Water meters were tested at a minimum of three flow rates. As the researcher expected, the results indicated that larger diameter meter had higher error than smaller ones. For example, 100 mm meters were under-recording by 6,8 % and 20 mm meters by 2,4 % on average respectively. The study highlighted especially the significance of the correct sizing of water meters.

Pipes

Deterioration of pipes is the main cause of bursts in mains and these bursts usually comprise the biggest part of real losses. The deterioration of pipes can be classified into structural, external and internal deterioration. Structural deterioration diminishes pipe ability to withstand various types of stress and internal deterioration results in diminishing hydraulic capacity and even structural resiliency in cases of severe internal corrosion. Structural deterioration mechanisms are affected by many factors including the characteristics of pipe and surrounding environment. External deterioration is a function of the interaction between the pipeline and the surrounding soil. Soil properties that are most prone to affect the external deterioration process are resistivity and pH. Internal deterioration is largely dependent on water quality. (Kleiner 1997; Doyle et al. 2003)

Iron-based mains have high structural strength but are the most prone to destructive corrosion processes. Corrosion is an electrochemical reaction between two materials in contact with each other that have a difference in potential. Cement-based mains may also undergo a chemical reaction internally and externally due to leaching process. (Engelhardt et al. 2000)

The correlation between **pipe age** and burst rate has been studied broadly. Presently, the correlation is not straight forward and thus there are discrepancies between the variables. For example, Kettler & Goulter (1985) found a strong correlation between the age and burst rates. However, a newer research by Herbert (1994) concluded that age is actually a secondary factor and must be combined with knowledge of the network and weak points to allow accurate assessment. According to Boxall et al. (2007) it is obvious that pipe age indicates the time that pipe has been in operation and exposed to loading and the surrounding environment which again increases the probability of bursting. Also, given the date when pipe has been laid may be a surrogate for design and construction practice. Quality of materials used for pipes is another surrogate.

Pipe diameter has been shown to affect burst rates significantly. The burst rate increases exponentially with decreasing diameter. This behavior can be explained by the increase in structural strength of larger cross-sectional profile. The relationship between **pipe length** and burst rate is slightly curved. This means that the rate of increase in bursts decreases with length of a pipeline. (Boxall et al. 2007.)

2.3.2. Effect of pressure

Traditionally, it was believed that leakages from water distribution network are fairly insensitive to pressure. However, several researches done in recent decades have proved this assumption wrong and pressure actually has a big effect on leakage rates. (Van Zyl 2004) Pressure in the water network affects the rate of leakages in two ways. First, excessive pressure causes pipe bursts more frequently. In other words, the lower the pressure the lower the pipe burst frequency. The same applies to both mains and service pipes. (Pearson et al. 2005) Thornton & Lambert (2007) introduced a data set consisting of 112 systems from 10 countries and concluded that an average of 37 % drop in pressure in these systems resulted in 53 % reduction in pipe bursts on average.

Secondly, rate of discharge from an opening of a pipe is proportional to the pressure level in that particular pipe line. Theoretically, the flow rate from such opening is proportional to the square root of pressure differential across the opening. The theoretical pressure-leakage relationship can be represented with equation commonly known as orifice equation (Shammas & Ai-Dwohalia 1992):

$$q = CH^{0,5} \tag{1}$$

with q the flow through an opening
C the coefficient dependent on pipe material and conditions in surroundings
H the water head in meters

If the pressure in the pipeline doubles, the leakage through an opening increases by 40 % according to the equation. However, studies done for real water networks in the UK and South Africa revealed that the leakage rate can be much higher than theoretically predicted, thus the exponent is nowadays replaced by a common exponent α. For example field study by McKenzie & Wegelin (2009) in South Africa revealed that the exponent can be as high as 2,5. Using this value for orifice equation doubling the pressure will increase leakages by 570 %. Also, a significant factor is that openings in AC and uPVC pipes tend to enlarge with increasing pressure making leaks greater again.

There are various mechanisms that can explain the alteration of the exponent in the equation. Most important factors are leak hydraulics, pipe material and soil conditions. These determine the behavior of the flow which can be either laminar or turbulent and thus different in magnitude for different cases. (Van Zyl 2004)

Pressure management not only reduces the rate and frequency of leakage in pipelines but also prevents post meter leakage and has an effect on water demand. Waldron et al. (2009) found a significant correlation between operating pressure and toilet leaks. The bench test of that study revealed a 5 % reduction in flow rate when pressure was dropped by 10 %. Water demand is not classified as leakage but increased pressure has an impact on water consumption since, for example, irrigation is usually time-based rather than volume-based. Thus, the demand increases with increasing pressure and the volume of consumed water might be in excess of what is needed. (Van Zyl & Clayton 2007)

2.3.3. Management issues

Insufficient management of water distribution systems forms a huge problem especially in developing countries. This problem is compounded by lack of orientation and human resources. Water utilities often do not have any strategy on how to develop the operational level of their water network and have inadequate levels of data to allow adequate evaluation and monitoring. Many of them never collect any data to enable improvements to the performance of the system. As a result of these problems, many water utilities find themselves in a cycle of poor corporate performance with low coverage of services, huge amounts of NRW and insufficient funding for maintenance and expansion. (Mugabi et al. 2007)

Other management related issues causing water losses are due to the insufficient leadership and educational level of employees. Pipes can be stored poorly such as plastic pipes in direct sunlight which causes them to become fragile already before the installation. Wrong choices can be made when selecting materials which may not be suitable for local soil conditions. Employees may be low-skilled and make poor installations which increase the tendency of failures in pipelines. Also low skill levels may cause pressure peaks such as “water hammer” when opening shut valves too quickly and harming the pipes.

3. METHODS OF CONTROLLING NON-REVENUE WATER

For successfully reducing NRW the utility needs to identify priority areas of the network as well as pay attention to operating policies. Utility also needs to introduce policies to assess, monitor and control elements of NRW – real losses, apparent losses and unbilled consumption. (Liemberger & Farley 2004)

In passive leakage control, only evident leakages are repaired. This means that actions are taken to fix problems only when there is a clear evidence of them. The evidence usually comes from the residents who complain about insufficient pressure or a visible leak on the ground. (Shammas & Ai-Dwohalia 1992) This method is actually always in use in every town and city. Yet, in those ones which lack resources and proper management, it is usually unfortunately the only one.

It is clear that reduction of non-revenue water is beneficial for every water utility. Benefits of cutting down water losses include at least the following matters (Kingdom et al. 2006):

- reduces volume of water purchased
- reduces losses of water already treated
- reduces potential liability due to property losses associated with leaks
- reduces public health hazard due to contamination of water supply
- improves pressure to customers with no increase in pumping
- improves water supply reliability and drought security
- provides additional capacity for expanding demand
- improves knowledge of distribution system
- brings more efficient use of existing supplies.

A proper water network management in terms of active leakage control can be categorized in the following methods: (a) quantifying the total water loss in whole distribution system, (b) monitoring of leakage in smaller subdivisions of the network, (c) managing pressure, (d) locating and repairing pipes or other leaking components and (e) data collection and NRW reduction policy. Quantifying total water loss can be done by establishing a water balance and determining its components. (Hunaoidi et al. 2004) The methods described above will be explained next.

3.1. Water metering

3.1.1. Consumer water meters

Absolute accuracy of water metering is in reality impossible to achieve, since meters always have some degree of uncertainty. Usually new water meters record flow quite accurately but they become more and more unreliable as time goes by. All meters, especially the older ones, should be tested for accuracy on a regular basis. It should also be made sure that the meters are appropriately sized since the meters that are too large for a customer’s level of use will tend to under-register water use. Meters should be able to record the full range of expected flow rates accurately. (EPD 2007)

After the accuracy of metering is determined, a schedule of activities necessary to correct metering inaccuracies should be compiled. Meters should be calibrated on a regular basis to ensure accurate water accounting. Replacing meters after a certain period of time would also be feasible since similar meters usually have equal lifespan if they are handled properly and are under the same conditions. (EPD 2007)

3.1.2. District metering areas

Implementation of district metering areas (DMAs) is an effective tool for determining the most problematic areas in terms of NRW. DMA is an area of distribution network that is specifically defined whether by natural hydraulic boundaries or the closure of boundary valves. Bulk water meters are then installed at entry and exit points to record the quantities of water entering and leaving the area. The concept of water balance can thereafter be applied to each separate DMA. (Morrison 2004)

Night flow analysis is the best practice analysis of DMA as customer demand is at its minimum and therefore the leakage component is at its largest percentage of the flow. This method may emphasize problematic areas with a high percentage of NRW in real time especially if night consumption is expected to be fairly small. Use of DMAs also reveals the occurrence of new big pipe bursts which are not visible on the ground. When recordings from the bulk water meter are compared with consumer meter readings in longer time period, the utility gets a better estimate of background leakages (invisible leaks) within the DMA. (Morrison 2004)

Water utilities often want to see the impact of their renovation work on water demand. Repairing a leak will definitely reduce NRW, but if the leak was small compared with the whole system input volume, repair may not meet the visibility threshold, and thus the success of the project is not ensured for utility. However, by dividing the whole system into a number of DMAs, it will be easier to measure the impact of repair on water demand. Generally, the water distribution system should be divided into as small DMAs as technically and economically feasible. (Carteado & Vermersch 2009)

All in all, DMA analysis helps the utility to identify which parts of the network are experiencing the highest level of leakage to ensure that resources are targeted to the greatest effect. (Morrison 2004) There are many modern tools which practitioners can use to locate a pipe burst from suspected DMA. These leak localization tools and techniques will be discussed in Chapter 3.3.

3.2. Pressure management

An increasing number of countries worldwide recognize pressure management as an important part of any effective leakage management strategy. Although it is important to control pressure in order to keep losses as low as possible, enough pressure is needed to meet the demand of consumers. Water supply systems are generally designed to provide water for consumers at some agreed level of service which is often defined as a minimum level of pressure at the critical point which is the point of lowest pressure in the system. This critical pressure usually occurs during the period of peak demand which is normally only a short period of the day. Thus, the remainder of the time the systems often operate at pressures significantly higher than required. (Mckenzie & Wegelin 2009)

Managing water pressure in a supply area is not a simple task because there are various factors to be considered. Same pressure management scheme cannot be applied to all water supply systems since they all differ from each other. It must be kept in mind that when reducing leakage through pressure management it is necessary to sustain the level of service for customers as well as demand for fire-fighting. (Mckenzie & Wegelin 2009)

Desired pressure level can be obtained in various ways. Thornton (2003) describes following as the most common tools and methods for pressure control:

- zonal boundaries
- pump and reservoir level control
- fixed outlet control valves
- time modulated control valves
- flow modulated control valves

Zonal boundaries determine the pressure management areas (PMAs.) Managing pressure with fixed outlet control valve is the simplest and most straightforward form of pressure management as it normally involves only a pressure reducing valve (PRV). PRV is used to control the maximum pressure entering a zone. Use of time modulated control valve is more advanced method since it uses additional device to provide further reduction to off-peak periods – typically during the night. Flow modulated pressure control is even more advanced because it reacts to the water demand which can vary a great deal for example when the fire breaks out. The more advanced form of these three pressure control methods is used, the bigger savings can be achieved. However, more advanced method is also more complex and more expensive. (Mckenzie & Wegelin 2009)

It is clear that pressure control does not reduce the number of existing leaks in the water distribution network. Because of this, many water utilities still do not recognize pressure control as a solution to manage water losses. If the water pressure in a certain area can be reduced even for a short period, the level of leakage will be reduced no matter which approach is selected. In addition, water utilities can prevent further damages in the water distribution network caused by excessive pressure levels. (Mckenzie & Wegelin 2005) Parker (2009) points out that pressure control will not eliminate the need to replace mains but it will increase the life of pipes and perhaps allow major capital investments to be delayed.

According to Morrison (2004) the planning of PMAs and DMAs should be undertaken as one overall concept although the implementation of one stage may come before the other. The common thing between them is the requirement to define the area of the network and close the boundaries.

3.3. Leak localization with sound detecting

Listening based methods of locating leaks in water distribution networks are old techniques used already some 100 years by water engineers. The earliest tools were simple wooden listening sticks placed on the main or fitting such as valves and hydrants to allow the inspector to listen to the sound of escaping water from a supply line. The leak noise was transmitted from the fitting to the engineer's ear through the listening stick. This method was reasonably cheap but sensible to pipe material. Sound travels fairly long distances in metallic materials but considerably poorer in non-metallic materials. However, no matter which pipe material was under investigation, this method was time-consuming and not very effective. Inspectors did often try to locate leaks from areas where they did not exist. This problem gave a boost to two activities: leak localizing and leak locating. Leak localizing identifies and priorities the areas with the biggest problems in terms of leaks to make a pinpoint search (leak locating) much easier. (Pilcher 2003)

Today, many water utilities use sophisticated methods that are based on leak localizing and leak location activities. These include the use of sound loggers, leak noise correlators and leak noise listening. All of them use the same principle as the primitive listening sticks decades ago: the transmission of sound. These devices will be next explained more broadly.

3.3.1. Leak noise listening

An old method of leak noise listening is the use of listening rods which can be either mechanical or electronic. Use of mechanical listening stick relies on the operator's ability to interpret the noise, and if he has any hearing difficulties, this ability will be greatly reduced. An improved method is the use of electronic listening stick with a measurement device incorporated which reduces the reliance of the operator's abilities. Popularity of listening rods is still as great as ever, and the technique is invariably used to confirm a leak site identified by a correlator. General surveys, which are performed by listening only components attached to the network such as fire hydrant or a stop valve, are usually designed to detect big leaks. The effectiveness of this listening based leak survey depends on the size of leaks, ambient noise and the experience of the user. (Hunaiodi et al. 2004; Farley 2007)

Ground microphone is used for pinpointing leaks by listening to a leak noise on the ground surface above the pipe. Minor leaks can usually be detected only directly above the leaking spot of a pipeline. This practice should be done at night when there is as little ambient noise as possible. To make survey as effective as possible employees should be assisted by professionals. When there is a leak in a pipe, it gives out a signal that is traceable by the signal amplifier and noise filter of the device. (Hunaiodi et al. 2004) There are a number of factors affecting the ability to locate a leak from the surface, such as the operating pressure within the pipe, the size and type of leak and the degree of leak noise transferability through the ground material to the surface. (Hamilton 2007)

3.3.2. Leak noise correlator

Flow meter data from DMAs is useful for indicating most problematic zones in terms of unreported bursts or an accumulation of leaks, but the area of leakages must still be reduced within the zone and finally the exact leak position must be determined. A widely used technique is the use of leak noise correlators. (Farley 2003) Leak noise correlator can be used either to leak survey or pinpointing modes. It is a data-based device where data unit records sound with different frequencies to reveal leaks. The sensors are placed in two locations of a pipeline (usually integrated into shut valves) to measure leaking sound simultaneously. Measured noise signals are then wirelessly transmitted to the correlator device which reveals the position of the leak based on time shift of two signals, propagation velocity of leak noise and distance between sensors. The theory of the correlator can be seen in Figure 3.1. The correlator needs some initial information, basically pipe material and size in order to determine the exact point of leak accurately. (Hunaiodi et al. 2004)

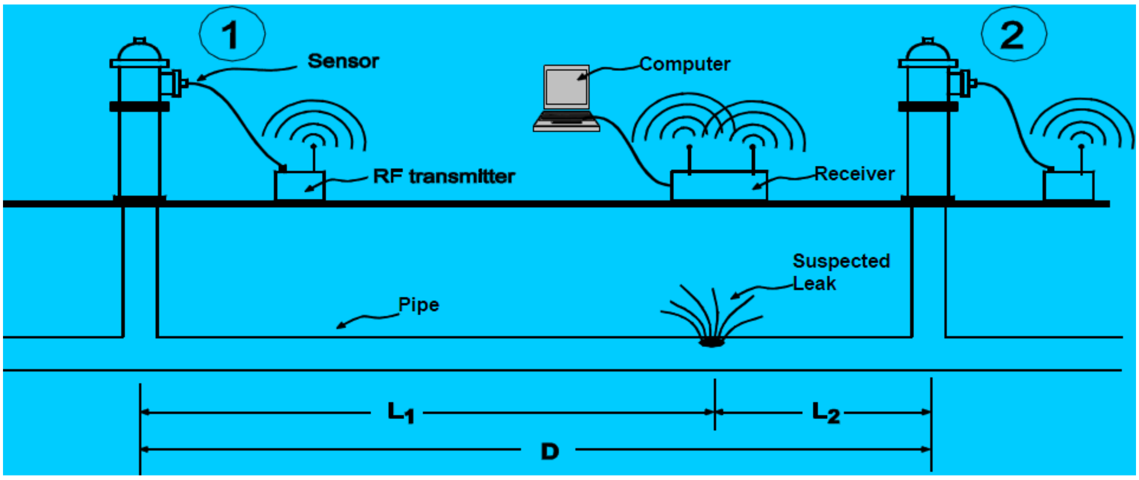

Figure 3.1. *Principle of leak noise correlator. The leak emits a sound wave which is transmitted through the pipeline to the sensors 1 and 2* (Hunaiodi et al. 2004).

Leak noise correlators can give out reliable results if the data entered is correct. They can operate distances over 500 m on metallic pipes but considerably less on non-metallic pipes and locate a leak within one meter. The accuracy depends on three critical entries: pipe length, pipe material and pipe diameter. Thus, if any of these parameters is incorrect, the location calculation can be out by many meters. (Hamilton 2007) The efficiency of locating leaks with correlators depends most on pipe material. The sound wave slows down in pipes and the pipes with higher elasticity slow the wave down more. Metallic pipes transfer the noise signals much better than non-metallic pipes such those made of plastic which makes the survey with the correlators in metallic pipes much more reliable. (Hamilton & Hartley 2008)

3.3.3. Noise logger

Noise loggers are units composed of a vibration sensor and a programmable data logger. They are not suitable for pinpointing leaks like ground microphones but are used to survey large areas. Loggers are attached to pipe fittings, fire hydrants or shut valves some 200 to 500 m apart and left there overnight. The units are normally programmed to collect data between hours of small consumption for instance between 2 am and 4 am. In the next day, the loggers are collected and the stored data by the loggers is downloaded to a computer database. Then loggers are deployed at the next location. Some newer noise loggers also allow downloading data just by driving past each logger with a van-mounted receiver to pick up the noise signals. The presence of leaks is analyzed statistically with the data of leak noise levels. Data loggers can also be deployed permanently. Then leak noise is processed by using onboard electronics and the result is transmitted wirelessly to a roaming receiver. (Hunaoidi et al. 2004; Farley 2007)

There are variances in the tones and sounds of the flow when the usage is normal customer-based. On the other hand, leakages usually have a constant sound and this difference reveals the suspect of a leak. Noises that are suspected to be leaks can be confirmed, and the leak located using location equipment such as a leak noise correlator, a ground microphone or an acoustic sounding stick. (Farley 2007)

3.4. Managing water network with appropriate data and policy

3.4.1. Collecting data

Parker (2009) explains that collecting information of pipe failures will give utilities possibility to choose whether pipes in some area should be replaced instead of repairing. The most important pieces of information are; which type of pipe failed, when it failed, how it failed and what was the location. This information can then be analyzed to identify the pipes that have the highest risk of failure in the future. Some utilities use sophisticated statistical methods to analyze the data, but a simple spreadsheet system such as excel can also help to identify trends in failures. For example, failures may occur more frequently at certain times, in certain locations or for certain ages or materials of pipes. Study by Goultier & Kazemi (1988) found that time to the next burst close to the previous point of failure decreases exponentially. Also, the next burst was found to take place within only 20 m away from the previous burst in 46 % of cases.

Utilities need to record data continuously, consistently and accurately in order to get the most out of it. Data should be collected to cover all breaks to ensure that it represents the state of the whole system. If some records are missing, it may create a level of uncertainty regarding the records that are collected. The standard operating practices should be adopted as well as training of those who collect data to ensure that data is recorded in a consistent manner. (Wood & Lence 2006)

Data may be collected by many different departments such as laboratory, maintenance, technical and financial departments or response teams. In such cases it is vital that data is stored and shared effectively between the departments and then put together for analysis. (Wood & Lence 2006) Generally, the data collecting programme does not increase utility’s expenses much and it is thus financially easy to be implemented for water utilities of any size.

3.4.2. Water network management policy

It should be borne in mind that operation of any corporation cannot be effective without proper policy and management. The same applies with operators of water networks. The problem of NRW must be recognized to justify any actions. Then a strategy for reducing these losses must be established if it does not already exist. Even if there is a strategy it may need to be updated or modified to serve today's needs.

To develop an effective strategy for managing water networks, an extensive level of data is required. Nevertheless, the problem with NRW can be severe and it may take several years to collect detailed data to support analyses and so forth come up with a strategy. Meanwhile, the level of NRW gets worse. (Liemberger & Farley 2004) Lambert et al. (1999) introduced a performance indicator Infrastructure Leakage Index (ILI) to be used with much less initial data. One of the biggest advantages using ILI as an indicator is its need of minimum level of data. Thus, actions to manage NRW can be carried out much faster than with traditional methods. ILI is the ratio of current annual real losses (CARL) derived from water balance and unavoidable annual real losses (UARL) which is the part of CARL that cannot be eliminated. In other words, it is the lowest technically achievable annual volume of CARL for well maintained and well-managed systems. (Lambert et al. 1999) Value of UARL can be calculated using the following equation for systems consisting of more than 3 000 service connections (Liemberger & McKenzie 2005):

$$UARL\ (liters\ /\ day) = (18 \cdot L_m + 0{,}8 \cdot N_c + 25 \cdot L_p) \cdot P \qquad (2)$$

with L_m the length of mains (in km)
N_c the number of service connections
L_p the length of private pipes (in km)
P the average operating pressure (in meters)

ILI is an indicator of how well a distribution network is being maintained at the current operating pressure. In equation form ILI is presented as (Liemberger & McKenzie 2005):

$$ILI\ (no\ unit) = \frac{CARL}{UARL} \qquad (3)$$

For accurate calculations of ILI, the level of apparent losses should be known but in absence of such level, NRW can be used for rough calculations to represent CARL. In recent years, ILI has proved to be a very useful performance indicator when benchmarking leakage in water distribution systems. However, it has still not been taken into broad use among water utilities. One reason for this, especially in developing countries, is that sufficient data is not available initially. For example, information of the length of mains, the number of connections or average pressure does not exist. (Liemberger & McKenzie 2005)

4. ANALYSIS ON KEETMANSHOOP

4.1. Namibia and Keetmanshoop: general information

4.1.1. Namibia

Namibia is one of the most sparsely populated countries in the world having a surface area of 825 418 km^2 and a population of 2 030 000 (2010). The country is located in the South-West Africa (see Figure 4.1. for the map of Namibia). It is situated along the coast line of Africa between 17 and 29 degrees south of the equator. Namibia, which was previously known as South West Africa, is bordered by South Africa in the south, Angola and Zambia in the north and Botswana and Zimbabwe in the east. Despite rapid urbanization, 67 % of population still lives in rural areas. (Namibian Government 2010)

Namibia is the driest country in sub-Saharan Africa. Roughly 80 % of its surface area consists of desert, arid and semi-arid land. Rainfall is not only low, but also extremely variable over much of the country as the total annual rainfall varies a lot throughout the country. (Lange 1998) During 2008-2009, the annual rainfall ranged between 80-650 mm with the northern part receiving significantly more water than the south (Namibian Meteorological Service 2010). Of the total rainfall, some 83 % evaporates, 14 % is used up by vegetation, one percent recharges groundwater and only two percent becomes surface runoff (Encyclopedia of Earth 2010).

Namibia is divided into 13 political regions, each headed by a Regional Council. There are 45 local authorities, who are divided into four different categories: Part 1 Municipalities, Part 2 Municipalities, Towns and Villages. The division of local authorities is made according to the ability to exercise and perform the powers and duties. (Holtzhausen 2003, p. 8)

Figure 4.1. *The map of Namibia (Source: Wordtravels 2011). Note: The Namibian counterpart municipalities are marked with rectangles.*

In Namibia water is obtained from three natural sources: groundwater, perennial surface water supplied by the rivers (situated on the southern and northern borders) and ephemeral surface water from rivers within the country that flow only after especially heavy rains. (Lange 1998) Ephemeral surface water is collected in several dams, for example Von Bach Dam for Windhoek, the capital city of Namibia. Because of only 2 % of rainfall becoming surface runoff water, it is important to take effective advantage of it. About half of all water supplied in Namibia is groundwater. A state owned bulk water supplier, NamWater Ltd, is responsible for distributing most of urban water demand. In rural areas potable water is usually supplied either by NamWater or small-scale localized water sources, mainly boreholes. (Lange 1998). According to the 2002 Population and Housing Census, National Report (2003) 87 % of all households in Namibia have access to safe water. More than half of the households have piped water within their compounds while another 35 % of them get their water from public standpipes and boreholes. Total water consumption in Namibia was 300 million m^3 in 2000 and about two thirds of it was used by agriculture.

Namibia suffers from extreme water scarcity, but the water sources are managed fairly effectively. With Water Poverty Index (WPI) the country ranks one of the best in Africa with 60 points in 2002 (World Resources Institute 2010.). WPI is built up of five components: resources, access, capacity, use and environment. The index is an effective tool in integrating the wide variety of information related to water issues. (Sullivan et al. 2003)

4.1.2. Keetmanshoop

Keetmanshoop is the capital of the Karas region and is situated in the southern part of Namibia approximately 500 km south from Windhoek and 400 km from the border to South Africa. According to the 2003 Census statistics, Keetmanshoop is a host to approximately 25 000 people (both rural and urban) which is about 36 % of the total population of the Karas region. (PLDDSI 2010) The accurate population of urban part of Keetmanshoop is presently unknown, but it is estimated to be around 17 000. Town is divided into five suburbs: Westdene, Noordhoek, Tseiblaagte, Krönlein and Town Center (see Appendix 1 for the town layout of Keetmanshoop). Population is still mostly divided as it was during the colonial administration. Tseiblaagte is the zone of the black and low income people. Krönlein is populated by colored who were considered second after whites during that time. Noordhoek is the area of the middle income whereas Westdene is for both middle and high income. Town Center is populated by high incomes, but this area comprises mostly of buildings related to the business sector.

Keetmanshoop is blessed with retail industry and services that are the biggest employment factors. One can find almost anything in terms of shopping but manufacturing industry is not evident except for the agricultural industry that produces Karakul and quality meat for both local and international markets. Town is surrounded by mountains and dry areas of sheep grazing; it has got beautiful scenes for tourists (see Photo 4.1. for the view of Keetmanshoop). There are proper schools, a state hospital, a good telecommunication infrastructure as well as a rail network from Karasburg through to Windhoek. (PLDDSI 2010) Keetmanshoop is classified as Part 2 municipality. Of the surveyed municipalities Lüderitz and Ondangwa also belong to Part 2 whereas Windhoek, Swakopmund and Walvis Bay belong to Part 1 municipalities.

Photo 4.1. *View over the municipality of Keetmanshoop. The town is very dry for most of the year. The annual rainfall in 2009 was approximately 160 mm (Namibian Meterological Service 2010). © Arto Löppönen*

The organization of Keetmanshoop municipality is divided into three departments, which are Departments of Corporate Affairs and Human Resources (CAHR), Finance and Economic Development (FED) and Infrastructure and Technical Services (ITS). Above these three departments is the Chief Executive Officer's (CEO) office. Municipality's organization has been under development for many years and has been struggling to find employees for certain critical positions. There have also been alterations to the organizational chart, and according to Seppänen (2008), new plan was supposed to be approved by town council in September 2008. Still, in the mid 2010 it has not yet been approved.

Department of ITS has the biggest number of employees with the total number of 85 people. There are 18 employees working with water and wastewater maintenance who are divided into four groups and the groups are mainly working separately. The teams consist of plumbers and general workers. ITS lacks employees on two key positions; strategic executive and chief technician. Building inspector is an active chief technician which is not an ideal situation because understandably water issues are not getting enough focus.

4.2. Water network infrastructure

4.2.1. Pipe network

The water network of Keetmanshoop started to build up in the early 1940s. Growth started in the Town Center and followed by Westdene. Tseiblaagte and Krönlein were the next suburbs getting their water infrastructure in the 1960s. For the first decades pipes installed were asbestos cement (AC) for mains and galvanized steel for house connections. They were basic pipe materials until the 1980s when polyethylene (PE) replaced galvanized steel in house connections. Unplastized Polyvinyl Chloride (uPVC) was taken into use in mains in 2004. Since then no AC-pipes have been installed even though some of them still exist in municipality's store. The sizes of mains range from 50 mm to 200 mm. According to the map of water distribution network, length of mains is approximately 150 km.

Extract of municipality store's logbooks from the beginning of 2004 till July 2010 reveals that only about two and a half kilometers of new uPVC pipes has been installed into the network. However, some pipes are installed without being recorded in store's book keeping, but these have mainly been used for new built-up areas. So, considering that only those pipes that appear in the logbooks have been used for pipe replacements (AC → uPVC), the rate of replacement has been approximately 400 m per year which is only 0,25 % of the total length of mains.

The pipelines are full of mixtures of AC and uPVC pipes because of maintenance practices (discussed more broadly in Chapter 5.4.1.). Presently some 90 % of the mains are still AC. Figure 4.2. shows an estimate for the length of the pipe network in different age groups. The estimate is based on the water network maps from 1962, 1975 and 2007 and already mentioned rate of pipe replacements per year which is assumed to have been the same over the decades. It is also assumed that pipe replacements have been evenly distributed in the water network.

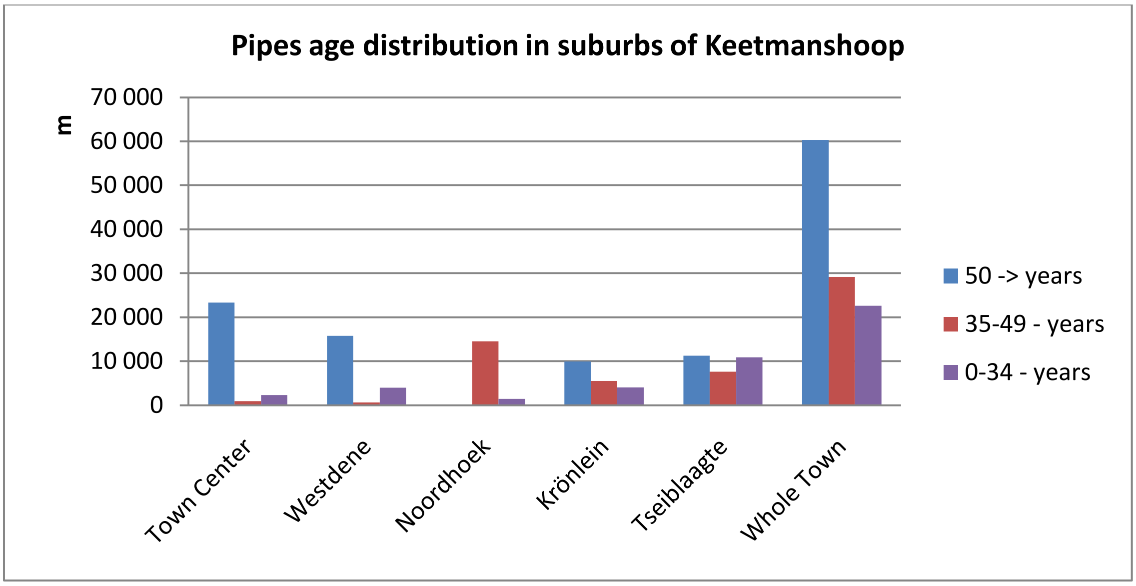

Figure 4.2. *The age distribution of pipes in Keetmanshoop's suburbs. Lengths have been estimated from old water network maps and replacements done in previous decades.*

As discussed in chapter 3.3.2. pipe age can be considered as at least a secondary factor for burst rates. Overall, in Keetmanshoop about half of the pipes are more than 50 years old which makes the situation far from ideal. In addition to this, the fact that only about 400 meters of pipes are replaced annually these days, makes the situation worse and worse in the future. The rate of replacement is once in every 400 years and it is obvious that pipes will not last that long. Estimated ages of mains is one important parameter when making decisions which areas should be given the highest priority in terms of renovation.

4.2.2. Shut valves and fire hydrants

There are some 450 confirmed shut valves and 250 fire hydrants in the network according to the water network map which was last updated in 2009. Just by taking a look at the map of water distribution system, the operation of the network seems to be fairly convenient in terms of shut valves because of the ample number of them. However, a closer approach reveals that shut valves are missing in number of critical locations. Thus, many valves are made useless when a valve in such critical location is missing. This problem occurs especially in those parts of the town where there is a distribution pipeline on both sides of a wide street.

The condition of the existing shut valves is another story. There has never been a systematic plan to go through shut valves to check their condition. When a shut valve stands many years without anyone touching it, sealings tend to dry. Afterwards when a valve is finally closed when needed, dried sealings start leaking. In June 2010 PLDDSI workers did a research checking the condition of the most critical valves in the network. It was noted that the biggest part of the valves were decades old and have never been replaced. About 50 % of the valves under that research were either leaking or could not be closed (see Photo 4.2. for some problematic shut valves). Non-functioning valves make a big problem when some part of the network should be isolated in case of a pipe burst. According to the town plumbers, sometimes maintenance teams need to isolate whole suburb because of non-functioning or missing valves in critical locations.

Photo 4.2. *Photos of some shut valves in Keetmanshoop. The coverage of left valve has been stolen and the right valve could not be closed at all. © Arto Löppönen*

Fire hydrants which are tested on a monthly basis by the fire brigade are in fairly good condition. According to Mr. George Josephs, the Chief of fire brigade, only one or two leaking or non-functioning fire hydrants are reported monthly. This is mainly because of active check-up practice and relatively young age of the hydrants.

A common problem with shut valves and fire hydrants is that many of them lack proper coverage and are buried underground due to that. Steel is the material for most covers of valves and fire hydrants which make them attractive for thieves to be sold as scrap metal. Even though the coverage exists, sometimes the metal cover box is full of sand and trash making it impossible to close the valve without digging it out first.

4.2.3. Water sources and reservoirs

NamWater pumps water from the treatment plant in Naute Dam some 50 km away to the three reservoirs located at Oxpass Hill next to Westdene. Before water enters these reservoirs, it is re-chlorinated. From these reservoirs, water flows through NamWater's own water meter and fills municipality's reservoir at Oxpass Hill (volume of 2 800 m^3) and Donkiedraie (volume of 1 500 m^3) near the golf course. The reservoir at Oxpass Hill supplies water mainly to Westdene and Town Center and the one at Donkiedraie supplies mainly Krönlein and Tseiblaagte. The quality of water is Class A (the best class in NamWater classification) likewise in all related municipalities under this study.

There are also smaller reservoirs in three locations but those are no more in use. The other reservoir at Oxpass Hill has not been in use since late 1950s except at the beginning of 2008 when water from town borehole was pumped into it to be used for irrigation purposes. However, pressure was not enough for the sprinkler system so this practice was given up soon. At Donkiedraie near the golf course there are four reservoirs which were also taken out of use in the 1950s. Two reservoirs in town were built as early as 1920s but they have been out of use for decades. These old reservoirs are in very bad shape and contaminated, thus they are not suitable for storing water without massive renovation and purification.

Nowadays, there are three boreholes in use in Keetmanshoop of which two are in Tseiblaagte and one close to Town Centre. One of Tseiblaagte's boreholes known as Ileni Borehole is supplying water only to the nearby fish farm and the other one to Tseiblaagte stadium. The borehole at Town Center is supplying water for town's swimming pool and to the tank next to the borehole. Water from the tank is used for fire fighting and watering the streets.

A research was done for the Town borehole to see if it can provide water for potable use as well. Research by Aqua Services & Engineering (2009) suggested that a mixture of 20 % borehole water and 80 % NamWater's water could be used. This 20:80 mixture of water still remains in Class A according to laboratory analysis. Only chlorification and polyphosphate dosing will be needed as treatment before leading borehole water into the reservoir. This plan would save a lot of money by decreasing the demand to purchase water from NamWater. However, no test pumping has been done to prove that borehole capacity is enough to fill the demand of this plan in every season. At the end of 2010, the plan is still waiting for approval from the town council.

NamWater is the main potable water supplier also for all other reviewed Namibian municipalities except Windhoek, which has 50 own boreholes and takes advantage of use of reclaimed water. The direct potable reuse of waste water started in 1968 and still in 2011 Windhoek is the only town worldwide where it is applied in a large scale. All together reclaimed and borehole water accompany almost 45 % of potable water supplied in Windhoek. Semi-purified waste water is also used for irrigation purposes in Swakopmund and Walvis Bay. Use of borehole water in Atlantic coast where Swakopmund, Walvis Bay and Lüderitz are located is problematic especially because of salinity. Uranium mining north from Swakopmund demands a lot of treated water which makes the area even more vulnerable to water shortages. However, this problem will be at least partially solved with the desalination plant, which will produce water for mining purposes. The plant is supposed to be in operation in 2011.

4.2.4. Water meters

In Keetmanshoop, every private water consumer has a water meter installed in the service pipe. Altogether there are approximately 3 800 water meters in the municipality. Municipality’s meter readers take readings once a month for billing. However, not all municipality’s own premises have a water meter or it is broken. Even if there is a functioning one, meter reading is taken only once a year or randomly. Only a few readings were available from previous years in 2010.

Water meters’ accuracy is not tested on a regular basis but only in case of a total failure or clear error in recording they are either flushed or replaced by a new meter. Errors are usually observed when meter reading books are revised before billing. The same meter reading and maintenance practice is used in all other reviewed Namibian municipalities as well. Swakopmund has taken a step forward by introducing a water meter that has “a smart valve” integrated into it. This type of valve is remote controlled and allows only a certain volume of water through the meter per day or per month. For those residents who have a history of problems in paying their water bills, the valve can be adjusted to allow a volume of eight cubic meters per month which is provided free for a single household in Swakopmund.

According to the logbooks in the municipality store of Keetmanshoop, 360 water meters were installed between January 2009 and June 2010. Thus, about 240 meters are replaced per year, which is 6,5 % of the total number of meters. Thus, the replacement rate is once in every 15 years. This figure is not poor after all since AWWA (1999) recommends replacing customer meters at least in every 15 years.

In the past, municipality had serious problems with theft regarding water meters. Nowadays the situation has improved a lot, since most of the currently installed water meters are made of plastic, which makes them a lot less attractive for theft because of small value in scrap markets.

Seppänen (2008) made a field study on consumers' water meters in mid 2008. This study revealed that the water meters were recording fairly accurately having only an error of -1.9 % (over-recording) on average. However, study concentrated on small residential water meters (≤20 mm) only and tests were made too few to reveal the real situation. The testing procedure was neither done with different flow rates.

4.3. Management of Keetmanshoop's water distribution network

4.3.1. Water distribution system maintenance

Municipality is maintaining its water network on an ad-hoc basis and there is no long-term development plan. Maintenance work is done only in case of a failure in the water network. This means that only evident (customer reported) leaks are repaired by the maintenance teams. Evidence usually comes from residents who complain about deficit in water pressure or even total water cut-off. Another way of getting evidence-based information is visible leakages. Residents inform the ITS's office and orders are given to maintenance teams. This way all residents carry big responsibility in terms of network maintenance. However, in order to get evidence of a burst, it must take place in a location where people saunter.

Each water team is on a standby every fourth month for a period of month. It means that employees on standby are doing the needed maintenance work after regular working hours and on the weekends. During regular working hours alarm calls from the residents go to ITS's office where each call is recorded. After regular working hours, complaints are directed to the private guarding office which then informs the water team in reserve. Frequency of daytime complaints has been four to five times per day permanently and up to seven to eight times during winter time when old and fragile asbestos cement pipes are more likely to burst. The private standby office receives 3-4 calls per day on average.

When the water team gets a call from the foreman of water and sewerage they go up to the location of the burst to realize the situation. Shut valves are then shut in order to prevent further water losses and to isolate the pipeline. Then they go to the municipality store to get necessary spare parts. In case of a small burst with a minor leak, the pipe is usually fixed with water proof tighten. If there is a big crack which is often the case with AC pipes, whole pipe is replaced (see Photo 4.3. for a big crack in AC pipe and a large leak).

Photo 4.3. *On the left there is a typical crack in an AC pipe. The length of the crack is about 20 mm. On the right there is a large leak due to a pipe burst in Krönlein. Photos do not relate to the same incidence. © Arto Löppönen*

AC pipes are replaced so that three pieces are replaced by two uPVC pipes because of the lengths; AC pipes are four meters long and uPVC pipes are six meters long. This is a common practice because it is not wise or cost-efficient to cut uPVC into smaller lengths. A big problem is that since the water network map is not updated on a regular basis, teams cannot know beforehand which spare parts are needed to fix the leak without digging the leaking pipe out.

The same ad-hoc maintenance culture is in Ondangwa and Walvis Bay. Windhoek and Swakopmund allocate some money for network renovation in the most problematic areas but this is always done for one year at the time. However, Windhoek would eagerly like to establish a long-term plan but so far it has not been possible due to financial issues. Lüderitz is the only one of the reviewed municipalities having a clear long-term plan. In Lüderitz, all old AC pipes should be replaced by new uPVC pipes by 2015 according to the plan.

A good example of a success story with a water loss management programme in Namibia took place in Rehoboth at the beginning of the 2000s. Before the implementation of the programme, the annual volume of non-revenue water was 598 000 m^3 (around the same than in Keetmanshoop presently) which was due to a number of leaks and non-functioning water meters. After the leaks were fixed and the meters were replaced, the NRW was reduced to 160 000 m^3. The reduction represented savings of 2,1 million Namibian dollars. (The Namibian 5.11.2004)

4.3.2. Record keeping

As written before, a new water distribution map layout was made by two Finnish and two Namibian students in 2007 using computer aided design (CAD). Mapping was done using old plans and manually locating hidden shut valves and fire hydrants. The map includes pipe diameters and materials and locations of fire hydrants and shut valves. Some updating has been made during 2008, 2009 and 2010, and newly developed areas have been added during the course of last few years. However, there is no practice in Keetmanshoop to update the map on a regular basis for example when pipes have been replaced or new shut valves have been installed. Neither are there records on consumer’s water meters except the numbers of meters purchased by the municipality store.

The office responsible of taking complaint calls records every call and informs the water maintenance teams. Nevertheless, the information what has been completed in the field is not submitted to any data base. This information would be very useful for two reasons. First, to keep the map layout updated, and second, give tools for decision making for example when complete replacement of a section could be justified because of numerous bursts detected. In addition, if the frequency of leak occurrence as well as time and crew required to repair bursts is recorded, work performance standards could be established.

The record-keeping practices vary a lot in related municipalities under this study. However, all of them have an Auto-CAD soft copy of their water distribution system. In Ondangwa the situation is nearly similar to Keetmanshoop where the map was drawn by PLDDSI workers in 2007. Yet, the map drawing in Ondangwa was much more challenging, since there was no map covering the whole area but only a number of drawings for new residential areas. Another difficulty was that valve and fire hydrant boxes were buried under the streets and thus were occasionally impossible to be located even with the help of a metal detector and long-served staff members. Consequently the map still lacks a lot of valves and fire hydrants. Likewise in Keetmanshoop, the map of water distribution system is not updated regularly in Ondangwa. However, in Swakopmund, Windhoek and Lüderitz the map layouts are updated whenever there are changes to them but Swakopmund is the only one keeping record on the installation dates of the pipes. In Walvis Bay there is intend to update the map on a regular basis but the municipality is struggling with time and personnel commitment to do so.

4.4. Water balance

Water balance components for Keetmanshoop are based on municipality meter reading books (authorized consumption), Namwater billing (system input volume) and some estimates. Authorized consumption is extracted from meter reading books between

January 2009 and November 2009 because there were no such data available to cover financial year 2009/2010. However, to make this analysis more comfortable, the period of 11 months is extended to correspond to whole year of 2009 by multiplying the consumption figure by 1,091 (=12/11). See the water balance components in Figure 4.3.

<table>
<tr><td rowspan="4">System input volume
1 593 000 m^3/year</td><td rowspan="2">Authorized consumption
1 059 000 m^3/year</td><td>Billed Authorized consumption
984 000 m^3/year</td><td>Revenue Water
984 000 m^3/year</td></tr>
<tr><td>Unbilled Authorized consumption
75 000 m^3/year</td><td rowspan="3">Non-Revenue Water
609 000 m^3/year</td></tr>
<tr><td rowspan="2">Water losses
534 000 m^3/year</td><td>Apparent Losses 10-20 % of water losses</td></tr>
<tr><td>Real Losses 80-90 % of water losses</td></tr>
</table>

Figure 4.3 *Keetmanshoop water balance 2009.*

Keetmanshoop's water balance is a simplified form of IWA's best practice water balance (Figure 2.2.) since there is inadequate data to calculate, for example, the division of real losses into its component. Portion of apparent losses is roughly estimated and it is not based on any measurements. The balance does not include the use of borehole water but the amount is considerably small compared to NamWater's supply. Revenue water and non-revenue water will be discussed in next.

4.4.1. Revenue water

The annual billed authorized consumption in Keetmanshoop in 2009 was 984 000 m^3. This volume is divided into two categories: domestic consumption and non-domestic consumption. Domestic consumption means residential use including personal hygiene, drinking water, laundry and irrigation. Non-domestic consumption means the use in shops, schools, hostels, industry etc. The industry is located south from the Town Center and the rest of non-domestic consumption is distributed between the four suburbs. Town Center comprises mostly of buildings related to business sector so the consumption is mainly non-domestic whereas in the other four suburbs almost all consumption is domestic. All authorized consumption which is billed is also metered.

Per capita domestic consumptions vary a lot in different suburbs. As discussed in Chapter 4.1.2., people are divided into suburbs mainly based on their level of income. Water consumption per capita seems to be straightly proportional to the level of income. Table 4.1. represents the population and consumption in each suburb in 1992 and 2008.

Table 4.1. *Populations and average domestic consumption per area in 1992 and 2008.*

	Population		**Domestic consumption per capita (l/d)**	
	1992	**2008**	**1992**	**2008**
Town Center	372	1116	550	264
Westdene	2070	1453	425	374
Noordhoek	2016	1874	330	147
Krönlein	3162	3100	110	99
Tseiblaagte	8580	8234	80	51
Total	**16200**	**15777**		

Source: Namhindo 1992
Seppänen 2008

The populations in 1992 are based on estimates of number of residents per household in each area. However, the estimates correspond quite well with the actual total population of 16 000 in 1992. Back then the municipality predicted that Keetmanshoop's total population will rise up to 26 000 by 2010. As can be seen from Table 4.1., the number of residents has actually decreased by a couple of hundred people till 2008. Also, the average consumption per capita has decreased in every area. This can be best explained by a significant increase in water tariffs. Other possible explanations can be developed shower and toilet facilities using less water than previously. All together, domestic consumption measures about 65 % of the total billed consumption in Keetmanshoop. The rest, about 35 % of the billed consumption, is industrial and other non-domestic usage. The biggest such consumers are hospital, schools, hostels, hotels, police station and prison. In 2009 total revenue water was around 1 000 000 m^3 and this comprises about 61,8 % of the total volume supplied by NamWater.

4.4.2. Non-revenue water

Total volume of NRW in 2009 was over 600 000 m^3 which is 38,2 % of the total input volume. Keetmanshoop has a history of serious problems in terms of high NRW. Figure 4.4. demonstrates the NRW development between 2006 and 2010.

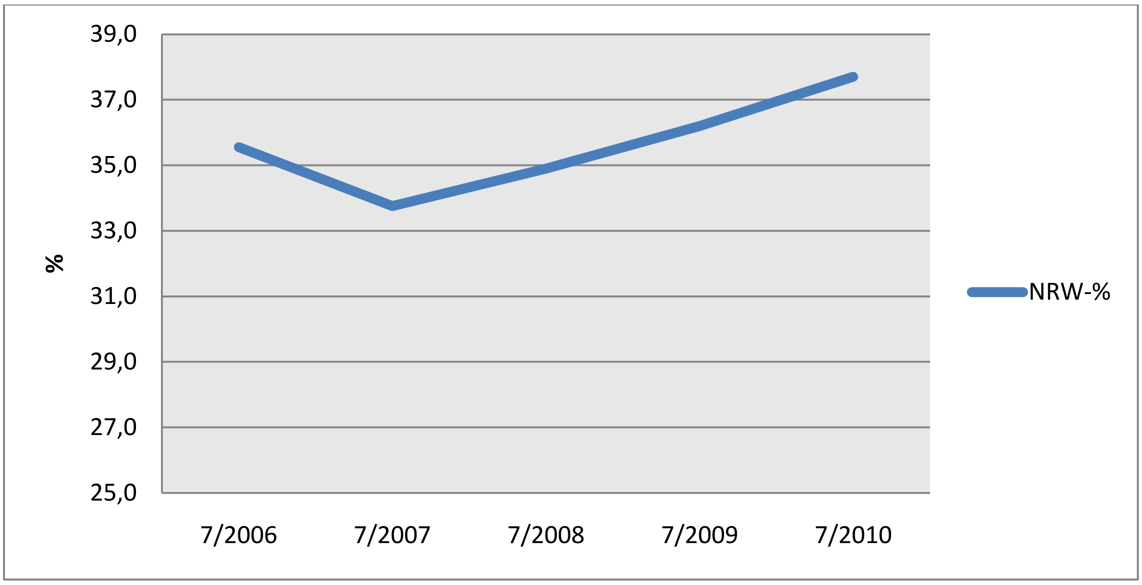

Figure 4.4. *Development of NRW percentage between 2006-2010.*

Estimate on municipality's own usage of NamWater's supply (unbilled metered consumption and unbilled unmetered consumption) was 75 000 m^3 in 2008 according to Seppänen (2008). This volume includes water consumption in municipality's own premises, town swimming pool, irrigation of parks, fire fighting demands and use at public taps in grave yards. When the current research was done, no newer meter readings were available. However, the usage is likely the same than in 2008, thus the same figure is used in this research and it comprises approximately 4,7 % of the total system input volume. The rest of Keetmanshoop's consumption, about 33,5 % of total system input volume in 2009, is actual water losses. Table 4.2. summarizes annual system input volumes and non-revenue water percentages in reviewed Namibian municipalities.

Table 4.2. *System input volumes in Namibian municipalities in cubic meters and annual non-revenue water percentages. Volumes are NamWater supplies only, thus own borehole use is not included.*

Town	**Annual System Input Volume [m^3]**	**NRW [%]**
Keetmanshoop	1 593 000	38,2
Lüderitz	959 848	10-15
Swakopmund	3 908 870	12-15
Walvis Bay	4 903 843	20
Ondangwa	800 404	15
Windhoek	Unknown	17

Note: System input volumes correspond to calendar year 2009, but non-revenue water percentages are figures from financial year 2009/2010 except that of Keetmanshoop which represent the calendar year as well.

The main reasons for such high water losses in Keetmanshoop are constantly leaking pipe network and apparent losses. Because of the nature of apparent losses, it is really hard to estimate how big portion of total water losses they comprise. However, in this survey the apparent losses are estimated to comprise about 10-20 % of total water losses. It is known that some water is stolen by making by-passes to water meters and other illegal connections but according to the staff of ITS, this is not a major issue today. However, public standpipes in grave yards have been used to steal water from during night time. Another form of apparent losses is customer metering inaccuracies, but the amount is presently uncertain. As described in Chapter 5.3.4., residential water meters under test survey in 2008 were more likely over-recording according to the experiment. However, the number of meters tested was too small and the survey focused on testing small diameter meters only, thus it does not give a reliable overall picture. One major issue, especially with big premises such as schools, is leaking toilets. During night when there is no real consumption in these premises, leaking toilets may sustain little flow which might not be recorded by the water meter causing apparent losses. Other sources of apparent losses are network flushing (which is not often done in Keetmanshoop) and firefighting, but use for firefighting from the water supply network is quite small as the fire truck uses mainly water from the borehole in the Town Center.

During the field work period of this research in July 2010, a survey was made to reveal the situation of water flow at night time between 11 pm and 5 am. During this period, all water into the Keetmanshoop water distribution system flowed through NamWater’s meter at Oxpass Hill. NamWater’s meter records flows continuously and during that night the minimum flow was 100 m^3/h. This flow can be separated into four components:

1) water filling up the municipality reservoirs at Oxpass Hill and Donkie Draai
2) water consumed by private households and public premises
3) water losses due to leakages and meter recording errors
4) water thefts.

There are several public premises that are suspected to be consuming water during night hours. Eight of them were picked including prison, police station, hospital, clinic, train station and three hotels to read their water meters every hour. Also, the water levels of the reservoirs during that night were measured every hour to reveal their fluctuation. A simple measuring tape was used for this purpose and the procedure was repeated several times to avoid error in measurements.

The result was that the levels remained about the same whole night (as much water was entering and escaping the reservoirs). Water meter reading at the surveyed premises revealed that combined average consumption during night hours was 3,5 m^3/h. It is hard to make any estimation about how much water was consumed by private households or public premises that were not considered in the research but according to observations, there were very little activities going which gives an idea of very little actual consumption. Again, it is hard to estimate how much water is stolen during night hours. However, minimum night flows in Keetmanshoop differ surprisingly little (within a period of two weeks) which gives an idea that if there were thefts, they would need to take place constantly. Consequently, the night flow analysis somehow justified the idea that biggest part of the minimum night flow is real losses and apparent losses.

4.5. Infrastructure Leakage Index

To calculate UARL from Equation 3 there are four parameters that need to be determined. These parameters are presented below for Keetmanshoop. Gathered data in this study is not sufficient for Lp, so it needs to be estimated.

- Lm = 150 km
- Nc = 3800 conn.
- Lp = 2 m
- P = 59 m

With the actual measured data and estimation for Lp, UARL will be:

$$UARL = (18 \cdot 150 + 0{,}8 \cdot 3800 + 25 \cdot 0{,}002) \cdot 59 \approx 339\, m^3 / day$$

To convert this value into annual UARL, the figure is multiplied by number of days per year. Thus,

$$UARL_{annual} = 339\, m^3 / d \cdot 365 d / y \approx 124\,000 m^3 / y$$

In absence of knowledge about volume of apparent losses, water losses are used to represent CARL which comprises an annual volume of 534 000 m^3 as justified in Chapter 4.4. ILI can then be determined according to Equation 4:

$$ILI = {}^{CARL}\!/_{UARL} = {}^{534\,000\, m^3}\!/_{124\,000\, m^3} = 4{,}3$$

This result means that CARL is assessed as being over four times as high as the UARL. In other words, it is theoretically possible to reduce real losses to around one fourth of current volume if there are no changes in operating pressure. (Pearson 2009)

Additional changes in real losses will result from changes in the pressure management regime because network leakages are straightly proportional to pressure as was discussed in Chapter 2.3.2. Liemberger & McKenzie (2005) propose that water distribution network having an ILI value of 4,3 is classified into Category B. The definition of category B states: “Potential for marked improvements; consider pressure management, better active leakage control practices, and better network maintenance.”

4.6. Water pressures

During the research period in July and August 2010, pressure measurements were carried out throughout Keetmanshoop. Pressures were detected as pinpoint research so that the whole network would be represented. Readings were taken from the yard taps of residential houses with a simple pressure gauge (see Photo 4.4.).

Photo 4.4. *Pressure gauge installed in a yard tap of a residential house. Reading in the picture is about 30 meters of water head (≈3 bars).* *© Arto Löppönen*

The network pressures were detected during hours of low and high consumptions. Measurements representing pressures when consumption is low were carried out 8.00-11.00 and the ones representing time of high consumption 16.00-19.00. See Figure 4.5. for the map of measurement points and reading ranges in the morning and Figure 4.6. for those in the evening. The original plan was to take more measurements to get more reliable data, but since the research team was dependent on residents’ presence at home because of the need to ask permission for the procedure, some measurement points were forced to be left out. Also, it would have been interesting to take the first measurements during night when there is hardly any actual consumption, but this was again impossible because of the need to interact with the residents.

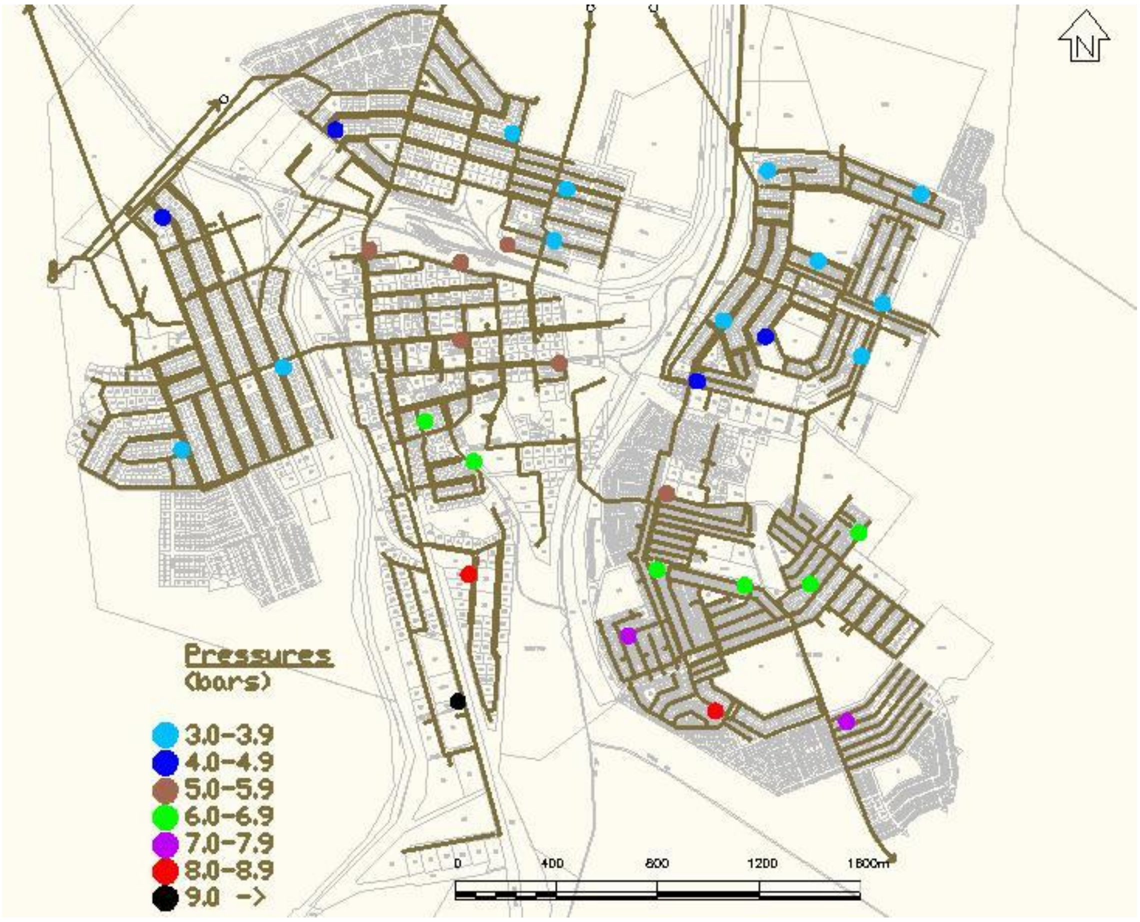

Figure 4.5. *Pressure readings in the morning. Each color of the circular spots in the map represents certain pressure range which is indicated in left side of the map layout.*

Pressures varied a lot throughout Keetmanshoop in the morning. Suburbs of Westdene, Noordhoek and Krönlein had overall pressures of about the same magnitude between 3,0-4,9 bars. On the other hand, in the industrial area and Tseiblaagte, pressures were as high as 8-9 bars. The highest measured pressure was 9.2 bars in industrial area south from Town Center. High pressures in those areas were predictable since elevations drop significantly moving down to those areas. The network model in Figure 4.8 and the simulation data in Appendix 2 will help to understand changes in elevations throughout Keetmanshoop. Minimum pressure demand for normal household and firefighting use is normally around two bars so the pressures can be regarded unnecessarily high especially in industrial area and Tseiblaagte. As discussed earlier these areas also encounter pipe burst most frequently which supports the theory in Chapter 2.3.2.

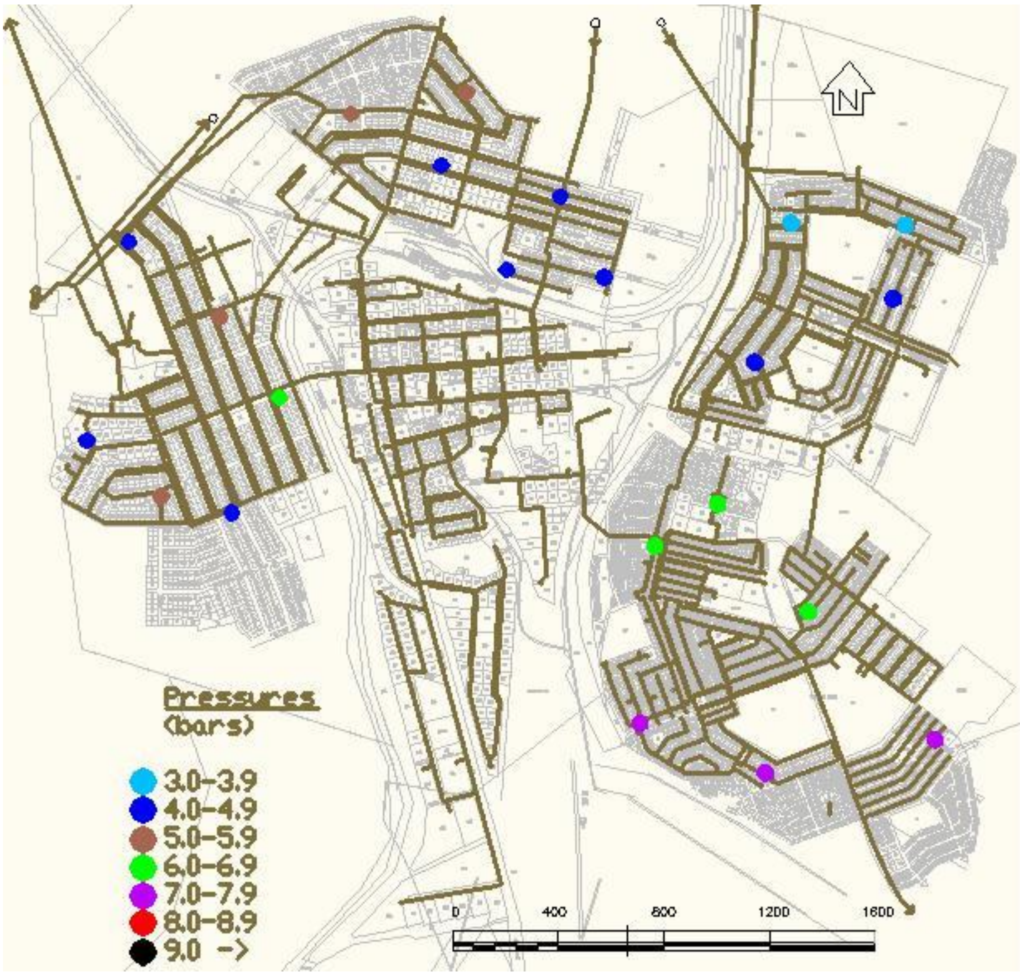

Figure 4.6. *Pressure readings in the evening.*

Pressures dropped a bit in the evening in Tseiblaagte compared with morning but in other areas they were about the same. In Town Center measurements were not done at all in the evening and industrial area because of the time limit which was unfortunate since in those areas the consumption differs significantly thus it is presumable that there is more variation in pressure levels as well. However, pressures of relatively same magnitude between morning and evening indicate that the friction losses in the pipelines are small, and thus the network is fairly loose.

All suburbs are within one pressure zone, thus pressure control cannot be managed effectively in current situation. Isolating different suburbs would be possible by shutting valves that connect two suburbs together but those valves have only been used in case of pipe bursts so far. It is difficult to predict what will happen to water flows and pressures in case that those valves are closed without further investigation. In Chapter 5.8. the results of water network computer simulations are presented to get a rough idea of changes.

In Keetmanshoop where water flows by gravity, no pumping stations are used in the distribution network, thus pressure reduction is obtainable with the installation of PRVs.

According to Meyer et al. (2009) a high percentage of the total obtainable savings can be achieved with a normal PRV and the smaller portion through smart pressure controllers.

Let's take an overview on how significant reductions could be achieved if pressures in Tseiblaagte area are reduced with effective pressure management. First, because of lack of proper information about the division of the leakages inside the network, a few assumptions need to be made. The total length of water mains in Tseiblaagte is approximately 33 000 m which is about one fifth of the total length of the water distribution system in Keetmanshoop. By estimating that leakages distribute evenly in the network, about one fifth of leakages are situated in this area. Also, based on discussions with the staff of the technical sector, around half of all observed pipe bursts take place in Tseiblaagte. Last, let's assume that 80 % of all annual water losses are related to different types of leakages (background leakage, leakage in mains etc.) and the rest is metering inaccuracies and so on. This sums up total of 83 000 m^3 lost water due to leakages in Tseiblaagte. Current average pressure in Tseiblaagte is 75 m and this is considered as the original pressure and desired reduced pressure used in calculations is 45 m.

As discussed in Chapter 2.3.2., there have been many researches trying to determine exponents for the common leakage equation. In theoretical Orifice equation, the exponent is 0,5 but it has been found that the exponent can be as high as 2,5. Figure 4.7. presents the leakage-pressure relationship for exponents 0,5 , 1 and 2,5.

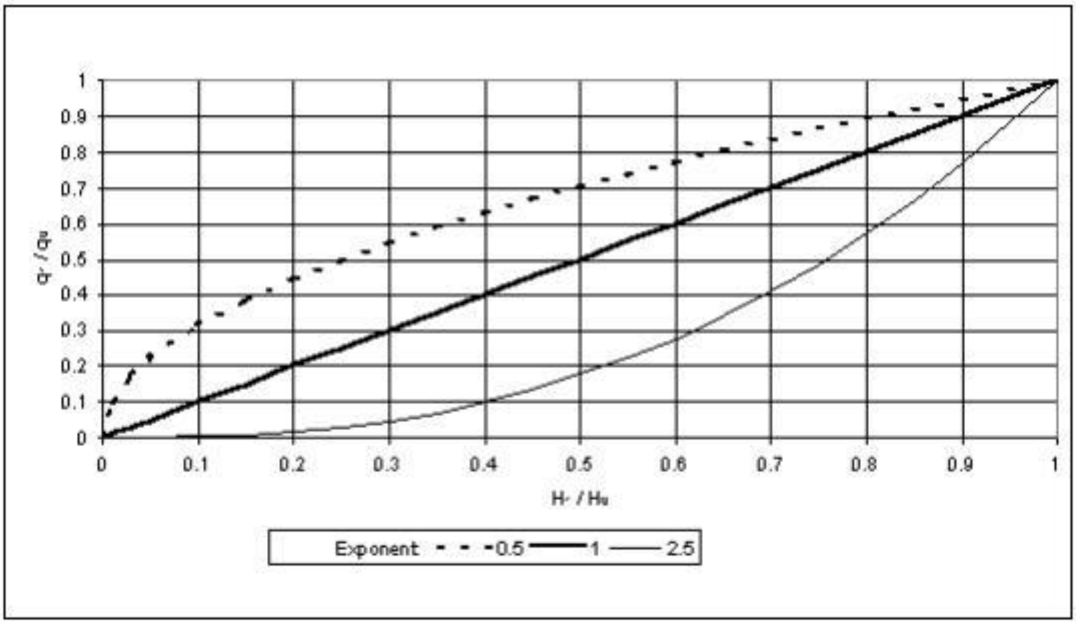

Figure 4.7. *Reduction in leakage for a reduction of pressure for different leakage exponents. On the X axis is reduced pressure over original pressure (H_r/H_o) and on the Y axis is reduced leakage q_r over original leakage q_o (Van Zyl 2004).*

Without any adequate data measured in Keetmanshoop it is impossible to determine what would be the correct exponent. However, Table 4.3. shows calculated parameters for all three exponents.

Table 4.3. *Parameters extracted from Figure 4.7 for different exponents. The last column indicates the achievable annual monetary savings.*

Exp.	q_r/q_o	q_r [m^3]	q_o – qr [m^3]	Savings [N$]*
0,5	0,78	64 740	18 260	117 777
1	0,6	49 800	33 200	214 140
2,5	0,27	22 410	60 590	390 806

* based on NamWater charge 10,26 N$/m^3 (2010)

The q_r value corresponds to annual reduced and q_o value original leakage volumes respectively. The last column in the table shows that reducing pressure from 75 m to 45 m causes remarkable annual monetary savings in leakages for all exponents. Even for the smallest exponent 0,5 the annual savings would be more than 22 % of total annual losses comprising more than a hundred thousand in Namibian Dollars. Field studies by Greyvenstein & Van Zyl (2005) showed that the exponent for AC pipes was in the range of 0,78-1,04, so according to that study the annual savings would roughly be something between 100 000-200 000 N$.

As discussed earlier in Chapter 3.3.1., pressure also has an impact on toilet leaks and water demand. Municipality may either benefit or lose because of these two factors. Surely, bigger consumption means more income but it is only in case that this flow is recorded by water meters which may not be the case especially for toilet leaks during night time when there is no other consumption, and thus the flow is little.

4.7. Water distribution system simulations

4.7.1. Initial data needed for the simulation

Simulation usually refers to a mathematical representation of a real system. Simulations can be used to test the behavior of an existing or designed system. Also, they are commonly used to predict system responses to events under a wide range of conditions without interrupting the actual systems. By simulating processes before any action is taken in a real-world process, a lot of money, time and material can be saved. Simulations are exceptionally important for water utilities due to the complex nature of the distribution networks as the networks can consist of thousands of pipes and junctions. For example, a water utility may want to find out whether a new built-up area can be served with a certain pipeline. The system could be installed and tested directly to see the functionality, but if problems appear, the cost of correction may be outstanding. (Walski et al. 2001, p.4-6)

Because there are hundreds of pipes and connections in Keetmanshoop’s water distribution network including service connections, valves and a number of other components, the model would be a huge undertaking if they all were included. Therefore, only the parts of the hydraulic network that have a significant effect on the behavior of the system are included in the model. Thus, in this case only the biggest transmission mains with diameters of (mainly) 150 mm and 200 mm along with corresponding junctions and reservoirs are included. Figure 4.8. illustrates the simplified (~skeletonized) model of the distribution network.

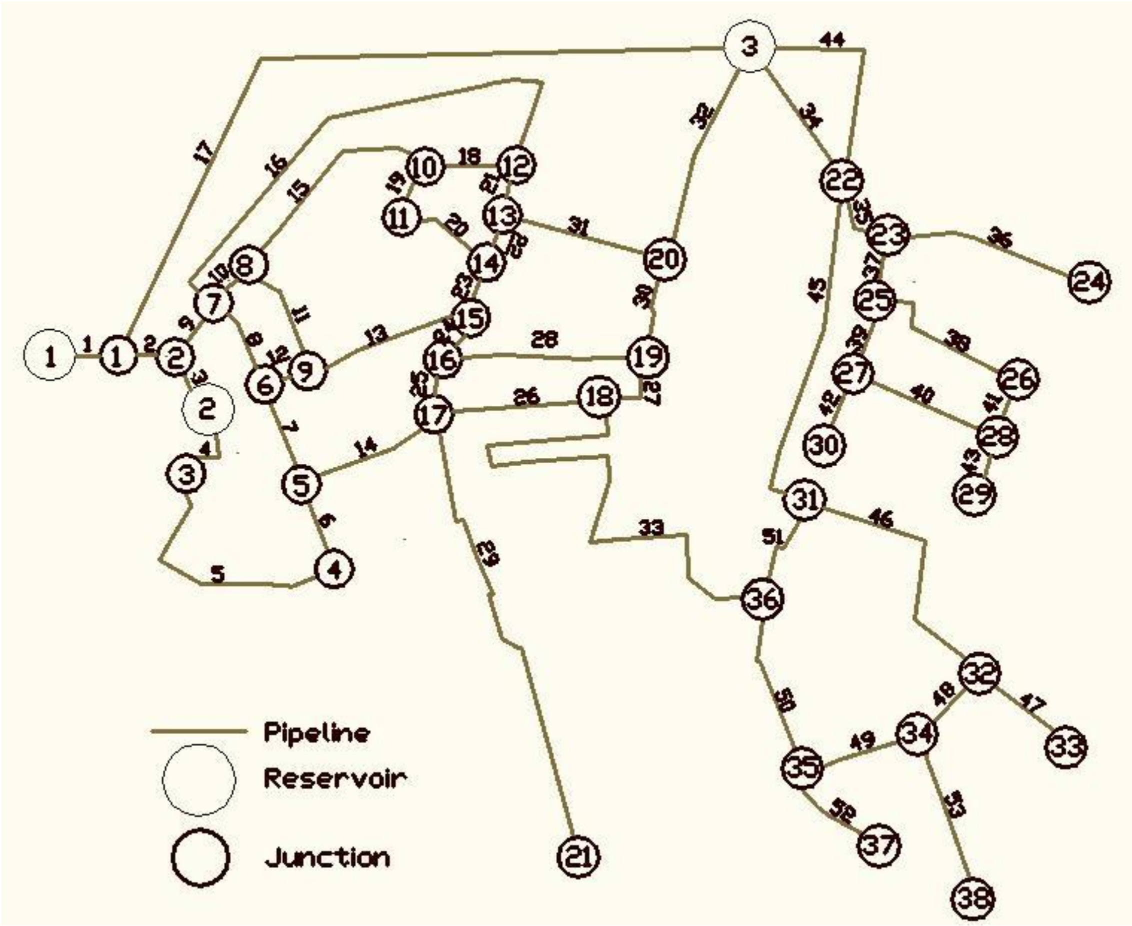

Figure 4.8. *Skeletonized model of Keetmanshoop's water distribution system. Symbols in the sketch are not in scale.*

In the model there are 53 Pipelines, 38 Junctions and three Reservoirs. Reservoir one is NamWater’s reservoir in Oxpass Hill which supplies water directly to the network and to two other reservoirs. The AutoCAD-layout of water distribution provides topological information for the model. The map includes information on pipe diameters, lengths, materials and connections with other pipes. In addition to that data, the model also demands the Hazen-Williams roughness coefficients for the pipes. Computer programme uses these coefficients to calculate friction losses in pipes. All demanded pipe information for simulations is represented in Appendix 2.

Junctions represent a connection point between two or more pipes or a reservoir. Junctions remove water from the system. In order to determine the demand in each junction, the number of plots that the particular junction serves and the consumption in each plot must be calculated. In this simulation it is estimated that the total consumption in each suburb is evenly distributed between the plots in that suburb. Also, NRW must be taken into consideration as demand. Because there is no knowledge how NRW is divided between portions of the system, in the model that demand is distributed evenly to the system. With these simplifications, the consumption per plot is calculated and represented in Table 4.4.

Table 4.4. Data for demand calculations in junctions.

Area	No. of plots	Annual consumption [m^3]	Annual consumption + NRW [m^3]	Consumption per plot [m3]
Town Center	490	270 000	428 571	875
Westdene	424	220 000	349 206	824
Noordhoek	404	110 000	174 603	432
Krönlein	687	190 000	301 587	439
Tseiblaagte	1 856	190 000	301 587	162

Based on this per plot data, the demand for each junction in the model can be calculated. Since the simulations will be done to represent daily maximum and minimum consumptions, a peak factor (PF) and minimum daily factor (MF) are needed. PF and MF are extracted from equations below.

$$PF = {Q_{\max}}/{Q_{avg}}$$

with *PF* the peak factor between maximum hour and average hour demands
Q_{max} the maximum hour demand
Q_{avg} the average hour demand

$$MF = {Q_{\min}}/{Q_{avg}}$$

with MF the minimum hour demand factor
Q_{min} the minimum hour demand

According to NamWater's data during 2009, the demands were Q_{avg} = 180 m^3/h, Q_{max}= 360 m3/h and Q_{min} = 100 m^3/h. Therefore, the factors will be PF = 2,0 and MF = 0,6. In calculations it is assumed that the factors are the same in every location. Lastly each junction needs a level of elevation. This information is provided by a map of Keetmanshoop with couture lines. Data for each junction is represented in Appendix 2.

As discussed in the previous chapter, an excess water pressure in the distribution network causes big problems in terms of leakage and pipe burst rates. The simulation in this study concentrates on determining the response of the system when water pressure is controlled in certain areas. Since there are no pumping stations, water is pressurized by the elevation drop between the distribution system and the reservoirs. Therefore, pressure could be managed by closing the boundary valves between suburbs and installing pressure reducing valves.

4.7.2. Simulation results

Simulation is done with Bentley's WaterCAD V8i software. The pressures calculated in the simulation corresponded fairly well with measured pressures at related junctions throughout the network when simulation was done with average consumption. Because of this, only relatively small adjustments in pressures were needed to calibrate the model. The results of simulations are represented in Appendix 3.

Surprisingly, it seems that Pipe-32 is actually feeding the Reservoir in Donkiedraai (Reservoir 3) under average and minimum consumption conditions, but the flow direction changes under peak demand conditions and the pipe starts supplying water to Noordhoek. One issue where the model differs significantly from field observations is the flow within the reservoirs. As discussed in Chapter 4.4.2., the night flow analysis revealed that the minimum flow from Reservoir-1 was about 100 m^3/h and the levels in the other two reservoirs remained almost unchanged during the night hours. However, the simulation shows that the net outflow in these two reservoirs is actually negative, and thus water is stored in them which make the situation contradictory in this sense.

Flow in Pipe-33, which is the only connection pipe between Town Center and Tseiblaagte, is from Tseiblaagte towards Town Center under peak demand conditions, but the direction changes under minimum and average demand. However, the flow in this particular pipe is very little throughout the day, and thus Tseiblaagte could easily be isolated from Town Center just by closing the (existing) boundary valve in this pipeline with a very little effect on the system behavior. The closure of this valve will mean that Tseiblaagte is supplied only by Pipe-45, but the peak velocity in it will increase a little only (0,48 m/s → 0,54 m/s).

Pressure control

As discussed earlier, the pressures in Tseiblaagte and Industrial Area are the highest and most desperately need pressure control. Thus, a fixed outlet control valve was set to reduce pressure entering the zones. Valves were set to the starting point of pipe-32 and to the end point of Pipe-45 just before Junction-31. Also the boundary valve in Pipe-33 was closed. The ultimate goal was to set the valves to reduce pressure to a fixed value.

Because there is water demand right after the valves, it is also needed to sustain pressure at agreed level of service for customer and firefighting demands so that each point in the network has at least two bars of pressure at any time of the day.

Both PRVs were set to a fixed value of two. This means that the valve prevents the downstream hydraulic grade from exceeding the set value. The valve opens and closes automatically depending on the value of the grade.

The results show that under peak conditions the pressure dropped 2,8 bars in Industrial Area (J-21) and 1,2 bars on average in Tseiblaagte (J-35 - J-41). Under minimum demand, the related pressure drops were 3,5 bars in Industrial Area and 1,6 bars on average in Tseiblaagte. Trials were done to set additional PRVs in Tseiblaagte, but it seems that pressure would not be reduced much more by, for example, PRV in Pipe-46, mainly because the network forms loops, and thus water can enter each junction from two directions.

4.8. Review on economy

According to Seppänen (2008) the municipality of Keetmanshoop was experiencing serious financial problems as a result of large outstanding debt to NamWater in 2006. At the end of financial year 2006, the amount of outstanding debt was more than 10 000 000 N$. In 2008 when Seppänen (2008) compiled his report, municipality owed merely 2 500 000 N$ to NamWater due to unpaid bills. However, according to Andries Kok, NamWater manager of Karas region, in mid 2010 the municipality is up to date with their bills.

According to the budgets (see Appendix 4 for budget for financial year 2010/2011) money on salaries and maintenance work has been pretty well in line with update values in 2005-2010 according to water vote. Maintenance and repair costs have been in the range of 250 000-400 000 N$ and salaries between 350 000-600 000 N$. However, actual overtime costs have been at least double each year compared with the budgeted in last five years. Municipality has also allocated money in development projects in previous years but these lump sums have not been used since 2002.

Water sales are the main source of income for the municipality. However, according to this and previous research by Seppänen (2008), water sales have been remarkably unprofitable for the last seven years. According to NamWater billing and municipality's meter reading books in a period of January 2009-November 2009, the volume of unbilled water has been 545 273 m^3. When this period of eleven months is extended to comprise the whole year, the total volume of unbilled water will be 594 843 m^3 in 2009. Taking taxes into consideration, the cost of unbilled water in 2009 was more than 4 million N$.

So far without any effective actions taken to reduce the volume of unbilled water, the cost of this non-revenue water has been covered by raising municipality's water tariff compared with that of NamWater's. Figure 4.9. illustrates the development of both tariffs in the period 2002-2010.

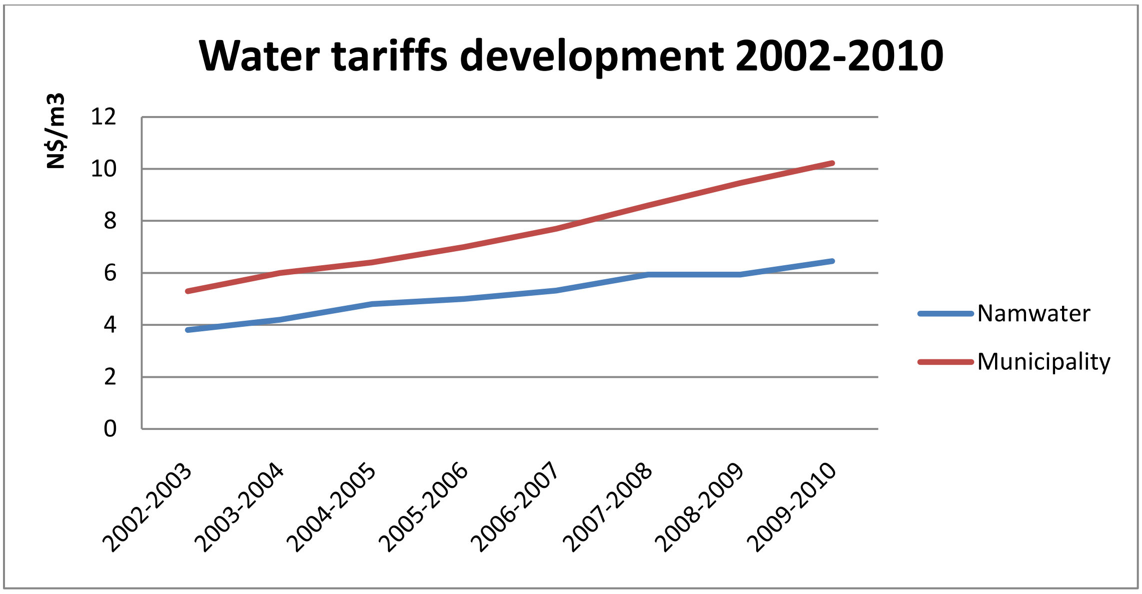

Figure 4.9. *Development of water tariffs in 2002-2010.*

In 2002, the gap between the tariffs was only 1,5 N$, but in 2010 it is already as much as 3,77 N$. NamWater raises its tariff based on e.g. the development of electricity and chemical costs. According to Andries Kok, it is hard to estimate the rate of increase in NamWater's tariff, but it follows the normal inflation rate quite well. Keetmanshoop's current practice to constantly raise their tariffs compared with NamWater to cover the costs of unbilled water is not a recommended solution on its own. This practice could be compared to a company which wastes part of its product and is therefore forced to raise the prices for their products more than is reasonable. Therefore water consumers will face more and more difficulties in paying their water bills. For example, in June 2009, water was cut from 100 houses because of the lacking payments (The Namibian 10.6.2009). The situation will not get better in the future without effective actions.

5. COMPARISON TO FINNISH MUNICIPALITIES

5.1. General information

Finland is easternmost of the Nordic countries known as “the land of thousands of lakes”. There are total of 188,000 lakes and 180,000 islands. The surface area is 338 000 km^2 of which about 10 % is water and 69 % is forests. Finland is populated by 5 300 000 people and it is the most sparsely populated country in the European Union. (Statistics of Finland 2010) At the beginning of 2010, the total number of municipalities in Finland was 342 but the number has been on decrease in recent years due to merging (Local Finland 2010).

The Finnish climate is characterized by irregular rains caused by rapid changes in the weather. The annual mean rainfall in southern and central Finland is 600-700 mm and in northern Finland where about half of the rainfall is snow, the annual mean rainfall is about 600 mm. The least rain falls in March and the most in August and September. Summers are fairly warm (20°C) and winters cold (25-30°C) depending on the location where measured. The mean temperature in Finland is several degrees higher than that of other areas in the same latitudes, e.g. Siberia and south Greenland. This is because of airflows from the Atlantic which are warmed by the Gulf Stream. (FMI 2010)

Kangasala and Lempäälä and medium-sized Finnish towns close to the industrialized city of Tampere. There are many options for housing in both towns consisting of single houses, row houses and apartment buildings. They are rapidly growing towns with the annual growth of population in Lempäälä about 400 people as in Kangasala it is about 300. The towns have beautiful sites for many kinds of activities especially by many lakes located in the areas. See table Table 5.1. for basic information of Namibia, Finland, Keetmanshoop, Kangasala and Lempäälä.

Table 5.1. *Basic information of Namibia, Finland, Kangasala, Lempäälä and Keetmanshoop.*

	Finland	**Namibia**
Population	5 300 000	2 030 000
Surface area [km^2]	338 000	825 418
Population density [inhabitants/km^2]	15,7	2,5
Number of municipalities	342	45

	Kangasala	**Lempäälä**	**Keetmanshoop**
Population	28 623	20 589	17 000
Surface Area [km^2]	649,8	307,6	-
Population density [inhabitants/km^2]	44	66,9	-

Sources: Statistics of Finland 2010
Namibian Government 2010
Municipality of Kangasala
Municipality of Lempäälä
Finnish Ministry of Finance 2010

Kangasala and Lempäälä have been counterparts of PLDDSI-project since the beginning. Staff from Kangasala Water and Lempäälä waterworks have provided engineer consulting for water sector needs in Keetmanshoop and Ondangwa.

5.2. Water services and water sources

5.2.1. Water services

In Finland, local municipalities provide around two thirds of all public services and the state about one third. Non-like in most countries Finnish regional councils have very small role in provision of basic services to the residents. In the provision of water services regional level administration has practically no role. Thus, they have other roles such as enhancing the cooperation between municipalities in water services development and operation. The role of State has always been fairly negligible in the development of water and sewerage systems in Finland, thus municipalities are responsible for the overall development of water services within their jurisdiction. Development of water services and infrastructure is financed mainly through user fees. The central government subsidizes water systems in rural areas and the first such systems were built in the 1950’s. No subsidies for water infrastructure in urban areas have been available from the government. (Pietilä et al. 2006)

Even though municipalities are responsible for providing water services within its area of jurisdiction, there are plenty of housing outside this territory. Those households need to develop their own water supply. Briefly, water services in Finland are arranged in three different ways based on population density (Pietilä et al. 2006):

- in population centers municipal water utilities take care of both water supply and waste water services
- in rural areas user cooperatives or partnerships take care of water supply while wastewater is either treated individually by households or lead to municipal sewerage system.
- in sparsely populated areas people have their own well or boreholes and individual wastewater treatment facilities.

Generally there is no strict rule of which arrangement should be adopted. Usually whichever form is selected depends mainly on the local situation, circumstances and preferences. People in rural areas often wish for municipal utility to extend their water supply network to their area but this may not be cost-effective. The cost of extension per connection would be too high for the municipality to invest and too high for the people to pay for the real connection cost in full. Statistics reveal that water charges of cooperatives are somewhat lower than those of municipal utilities but since water charges vary a lot from one undertaking to another, it may be misleading to draw any firm conclusion of the charges. (Pietilä et al. 2006) Water services in Finland are undoubtedly one of the best in the world and presently about 90 % of population are connected to municipal water distribution network. In 2007, there were about 1 500 local water utilities. About 400 are owned by municipalities and the rest are relatively small mainly customer-owned corporations in rural areas. (Silfverberg 2007)

In both Kangasala and Lempäälä waterworks are units under technical departments. Kangasala Water is a public corporation administered through municipality of Kangasala, but Lempäälä waterworks is a part of the municipality’s organization. In 2011, Kangasala water has 21 permanent employees and Lempäälä waterworks has 13. Lempäälä waterworks supplies water for nearly 17 800 residents. This figure includes direct water sales to residents in Lempäälä as well as sales to ten cooperatives and to Vesilahti municipality. About 83 % of all residents are connected to municipal water network. In Kangasala, about 80 % or the residents are joined into municipal water network. All together, Kangasala Water supplies water to about 4 000 real estates and to 12 cooperatives.

5.2.2. Water sources

Finland has abundant water sources. There are thousands of lakes and they can be found from every part of the country. The surface water pumped from the lakes along with natural and artificial ground water are the water sources in Finland. There are more than 6 000 aquifers in Finland and ground water from those comprises about 60 % of all supplied water. In sparsely populated areas, the population living outside municipal water supply systems use groundwater from dug wells or boreholes in the Precambrian rock. (SYKE 2011)

Kangasala Water has two water treatment plants which receive water from a total of four well which are connected to two aquifers. These treatment plants supply water for the whole town, thus making Kangasala self-sufficient for water delivery. Another water source for Kangasala is connecting pipelines to the water network of Tampere Water but this source is used only in case of an emergency. Municipality of Lempäälä has three ground water intake plants which comprise about 37,5 % of all water demand. The rest is surface water and is purchased from Tampere and Valkeakoski.

5.3. Water distribution networks

5.3.1. Growth, age and materials of pipe network

Ministry of Agriculture and Forestry ordered a research to analyze the situation of pipeline infrastructure in Finland. First version of the research was published in 1992 and updated version was carried out in 2008. At the end of 2006, the total length of Finnish potable water network was approximately 92 000 km. (Ministry of Agriculture and Forestry 2008) As in the early 1960s the total length of Finnish water network was only 10 000 km, in 1980 it had expanded to about fourfold. (Hellsten & Korhonen 2010) There is wide variety of different pipe materials in the network but since the 1970s the main material has been plastic, especially polyethens. Since 2006 the annual growth rate has been about 1 600 km, which means that the total length is about 98 000 km at the end of 2010. About 46 % of water pipes are less than 20 years old and about 30 % are more than 30 years old. Compared with the first version of the research from 1992 the relative portion of less than 20 years old pipes has decreased till 2008. (Ministry of Agriculture and Forestry 2008)

The total length of the water network in Lempäälä is 251 km and 322 km in Kangasala respectively. Kangasala started to build its network in the late 1950s as Lempäälä installed its first potable water pipes in the 1960s. Figure 5.1. represents the age distribution of water networks in those two towns and in Keetmanshoop as comparison.

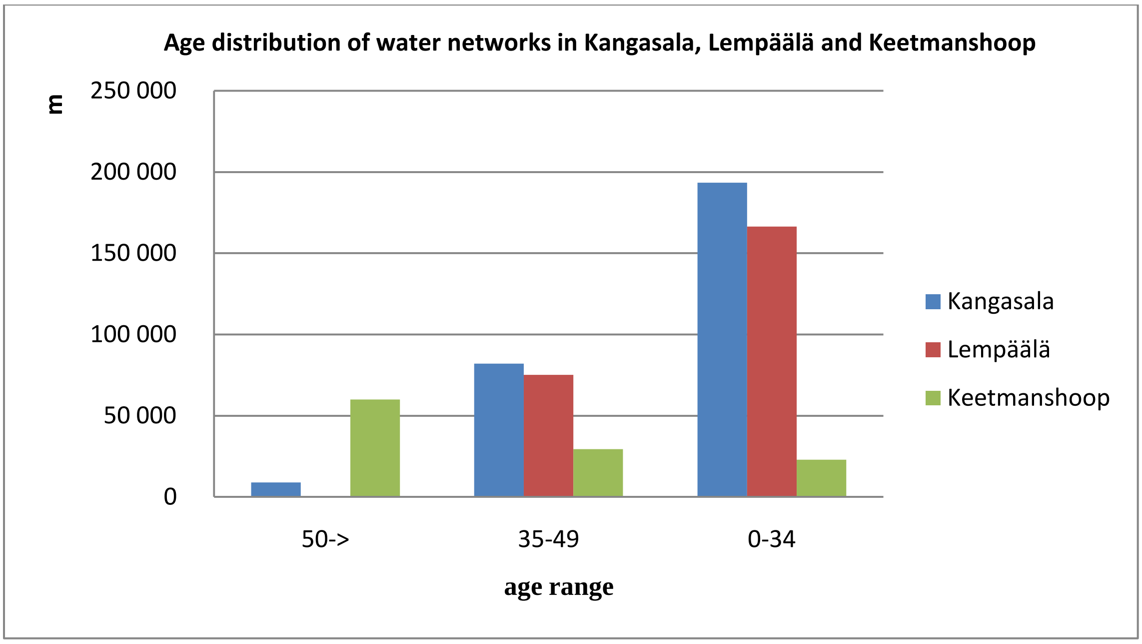

Figure 5.1. *Age distribution of water distribution networks in Kangasala, Lempäälä and Keetmanshoop. X-axis indicates the ages of pipes in three ranges.*

Both Kangasala and Lempäälä have used plastic (PE and uPVC) as their material for new water pipes since the 1970's. In Lempäälä, already about 87 % of the mains are made of plastic. The rest are made of himanite (5 %) and cast iron (8 %). The portions are about the same in Kangasala but in Keetmanshoop plastic is presently a minor pipe material accompanying only about 10 % of the total length. There are two basic reasons for such big difference: first, in Keetmanshoop AC pipe was the material for mains until the third millennium and second, the pipe replacement rate is smaller.

5.3.2. Condition and causes of failures

Pietilä (2006) points out that water utilities in Finland have postponed investments in repair and renewal of pipe networks because of political decisions. Negligence in this matter is not immediately apparent, and thus funds have been used more eagerly for other more visible activities, even though at least 80 % of the assets of water and wastewater consist of pipelines buried underground. Not until presently water utilities have paid enough attention to the problem when concerns of deteriorating pipes and increasing non-revenue water due to leakages have arisen. According to questionnaires to water utilities in Finland, the portion of pipes which are in bad or very bad condition is 6 %. However, the corresponding figure in 1992 was 12 % thus the situation has improved (Ministry of Agriculture and Forestry 2008). The main reason for the deterioration of pipe infrastructure is the poor quality of cast steel from the beginning of "crazy growth" since the 1960s especially in the capital area. (Hellsten & Korhonen 2010).

The survey by Water Institute in 2005 revealed that the average NRW-% in Finnish water networks was 16 and ranged between 8,7 - 25,7. Major part of leakages occurred in mains and service pipes. Grey cast iron seemed to be the most problematic pipe material in terms of failures. Water utilities pointed out several reasons for failures in different pipe materials. Installation and external damage were estimated as the main cause for failure in HDPE and PVC pipes. External stress was the main cause of failures for materials iron and cement group materials. Iron group materials were also noted to have exceeded their technical lifetime in many cases of failures. Freezing also causes failures for all pipe materials. The most common cause of failure for all pipe materials combined was the installation work. (Kekki et al. 2008)

In Kangasala and Lempäälä basically the same reasons causing failures in mains and service pipes were pointed out. Most reasons were related to installation and excavation. Internal corrosion is causing pipes to rust due to the corrosive quality of water but also because of wrong choice of materials in the past. Annual NRW in Kangasala is 15,7 % (2009) and 23 % (2009) in Lempäälä. Table 5.2. summarizes water statistics in Kangasala, Lempäälä and Keetmanshoop.

Table 5.2. *Water statistics of 2009 in reviewed municipalities.*

	Kangasala	Lempäälä	Keetmanshoop
System input volume [m^3/a]	1 833 000	1 168 000	1 593 000
Per capita consumption [l /day]	150	140	94
NRW [%]	15,7	23,0	38,2
NRW per km of mains per year [m^3/km/a]	953	1053	4056
Lenght of water network mains [km]	302	255	150
Portion of population connected to municipal water network [%]	100	83	100

As can be seen in Table 5.2., if NRW is calculated in cubic meters per km of mains per year, losses are about the same in Kangasala and Lempäälä, but about fourfold in Keetmanshoop. This figure explains even better than the percentage alone, how different the situation is in these two Finnish municipalities compared with Keetmanshoop in terms of non-revenue water.

5.3.3. Other infrastructure

In Kangasala there are three water storage facilities which are water towers whose combined capacity is 2 100 m^3. In addition to the water towers, water is pressurized by six pumping stations and municipality is divided into eight pressure zones. Lempäälä has been divided into four pressure zones, pressurized by two pumping stations and two water towers.

Shut valves and fire hydrants can be found in critical locations in both towns and their condition is fairly good, even though the condition is not checked on a regular basis. All single-family houses have their own water meter, but usually multi-storey buildings have only one meter and billing is based on the size of an apartment and number of residents. There are no district water meters in either Kangasala or Lempäälä expect those at pumping stations. Both municipalities have, however, decided to install some of them in the near future.

5.4. Water loss management

5.4.1. Data collection

Water utilities in Finland are actively doing researches to analyze the condition of their water networks. Franssila (2010) states that data collection systems of water utilities presently collect enormous volumes of data, but much of this cannot be utilized because sufficient tools for analyzing the data are not available. Another problem that water utilities are encountering is that research projects are carried out now and then, but they are often not finalized. However, managers of water utilities are in many cases willing to put more focus on researches and analyses, but are incapable to do so because of insufficient resources. Nevertheless, water networks with all its parts are usually fairly well mapped among water utilities in Finland including all the relevant information.

Both Kangasala and Lempäälä are using sophisticated CAD based computer software to store the data of their water networks. The maps contain the whole water network and are kept up-to-date all the time. Software includes information about length, installation year (not for all), material and size of pipes as well as the same information for water meters. Shut valves and fire hydrants can also be located from the map. The same software can store information about pipe bursts for analysis of the condition of the network in different parts of the system. Both municipalities also use a full-time planning assistant who takes care of the layouts. Private consulting companies have produced a model for both municipalities to simulate the network and the model is updated when it seems to be reasonable to collect further information about functionality of the network.

As discussed earlier there are presently only a few district water meters in these municipalities. However, those water meters in that are recording inflow to the pumping station, send online data to the monitoring system in municipal offices. Remarkable fluctuations in this data sometimes give suspect of big leaks in that particular pressure zone. Kangasala Water intends to improve the situation of metering by installing new district meters in the network during the year of 2011. Both municipalities also have several pressure sensors throughout the network to indicate significant pressure fluctuations which occasionally indicate bursts.

Neither Kangasala nor Lempäälä are using a water balance to evaluate NRW division into its components. In Lempäälä it is estimated that leaks formulate some 90 % of NRW and the rest 10 % is apparent losses due to under-registration of water meters and unbilled authorized consumption. Basically both municipalities considered the same reasons as causes for unbilled authorized consumption which were irrigating sport fields, freezing ice-hockey rinks, flushing mains and demands for fire-fighting. Either do not have possibilities to record that usage even though it is acknowledged to be a substantial issue. The recording methods are expensive, however, and the revenue out of this practice would not be enough compared with the costs.

5.4.2. Leak surveys and pressure control

Both municipalities usually act to repair or renovate pipes when there is a clear evidence of a leak, thus leak surveys in general are rarely performed. However, Lempäälä has surveyed some areas with the help of a private company. Lempäälä waterworks has a ground microphone to indicate the exact spots of leaks when a clear evidence of a leakage has been located by other means. Lempäälä also has a plan to install a few data loggers in the network in 2011.

Generally, pressure is controlled by the pumping stations and levels of the water towers. The pressure sensors in the networks give signals to the pumps equipped with frequency converters. If pressures are too low or too high, the pumps are automatically adjusted to sustain pressure at desired levels. Both municipalities are rather struggling with too low pressure levels in many parts of the networks, thus pressure control to cut-down water losses is not a favorable option to be adopted.

5.4.3. Development

On average water utilities in Finland are renovating their water networks 0,4 % (390 km) per year and the amount ranges between 0…2 %. During the last decades, the situation has improved as the renovation volume has been on the increase. Water utilities mainly decide parts of their water networks to be renovated based on observations and researches of network condition and long-term renovation programmes. However, researchers have brought up a claim that some Finnish water utilities’ still react only towards acute renovation needs without paying enough attention to future development demands. (Heikkinen 2009)

Presently, it is estimated that pipes installed in the 1970s have the technical service age of 40-50 years. This combined with renovation dept from previous decades indicates that annual renovation need in the next decades is as high as 2 000 km per year, which is fivefold compared to realization in 2009. Thus, the rate of renovation of water networks should be significantly increased in order to prevent further demolition of the pipe network. (Heikkinen 2009)

Kangasala Water has bundled up a general Municipal Water Supply and Sewerage Development plan 2004-2030, which is an analysis of the current situation supplemented by future developments. The plan was extended to cover the renovation of old parts of the network in 2011-2060. Fifty years is regarded as the service age of water pipes, which means an average annual renovation rate of 2 % (6 400 m/a) of the total length of mains. Because of some renovation depth from the past, the renovation volume will be increased gradually to 7 500 m/a within first five years which is kept up until 2032 when the depth is fully covered. After that, the annual renovation volume is decreased to the average level (2 %).

Lempäälä waterworks has also brought up a Water Service Development Plan 2010-2017. One of the main objectives of the plan is to add more financial resources to renovate the water network in order to reduce non-revenue water. The renovation programme is set to a period of five years and the areas to be renovated in 2011-2016 are determined within 2011. Burst history is the main indicator when decisions are made to allocate renovation to certain divisions of the network.

For both municipalities one of the spearhead challenges for the future is to ensure sufficient capacity for growing water consumption and providing services for new development areas. After all, NRW is not such a remarkable issue in these two Finnish municipalities as it is in Keetmanshoop, even though the reduction of it is considered as one the main targets in the future.

5.4.4. Financial aspects

The capital costs and the operating expenditures are covered by direct customer charges in Finland. Usually, water charges are based on water consumption and in addition, most water undertakings also have connection charges. However, the use of a fixed fee, which is independent of consumption, is the most recent trend. In principle, the municipal water undertakings aim at the full financial cost recovery, but charges may include a reasonable rate of return on capital investments. (Hukka & Seppälä 2004) Magnitude of connection fees in Kangasala and Lempäälä depend on gross floor area according to the building permit in case of residential buildings. Table 5.3. represents water tariffs in reviewed Finnish municipalities and Keetmanshoop.

Table 5.3. *Water tariffs in Kangasala, Lempäälä and Keetmanshoop in 2010 (VAT's exluded).*

	Kangasala		**Lempäälä**		**Keetmanshoop**	
Water tariff [N$/$m^3$]	11,3 (1,17)		12,5 (1,29)		10,22 (1,05)	
New connection [N$/$m^2$][1]	10 515-17 266 (1 084-1 780)		≥ 9 816 (1 012)		160 (16,5)	
Basic charge [N$/year]	Consumption		Meter size		Type	
	< 50 m^3	209,52 (21,60)	15-20 mm	413,22 (42,66)	Residential	36,30 (3,74)
	50-300 m^3	378,30 (39,00)	21-40 mm	1 571,40 (162,00)	Senior	No charge
	301-1 000 m^3	747,29 (77,04)	> 40 mm	4 398,76 (453,48)	Non-residential	155,85 (16,07)
	1 001-2 000 m^3	1451,51 (149,64)				
	2 001-5 000 m^3	2832,01 (359,11)				
	> 50 001	5520,85 (569,16)				

Notes: 1) For single-family houses
Values in brackets are in euros

Sources: Kangasala Water
Lempäälä waterworks
Municipality of Keetmanshoop

The YVES-research 2008 concludes that overall in Finland money spent on the renovation of existing water network infrastructure has been 61 million euro per year during the third millennium. This is about half of the money invested in building new water networks. The unit price for renovating water pipelines was in the range of 140-190 €/m. Due to large renovation debt from the past decades, the investments on renovating water networks should be increased to about 160 million, which will increase the annual expenses of water utilities by some 15-20 % on average. This will, of course, have an effect on consumer's water tariffs as well.

In Kangasala, the renovation debt is regarded to be fairly small so there is no need to make huge investments in order to catch up that gap. As discussed earlier, Kangasala Water will increase its renovation allowance step by step in 2011-2060 according to the plan and it is estimated that the cost for renovating the whole existing network is about

38,6 million euro with the current value of euro. Unit price for water network renovation is estimated to be 120 €/m.

Lempäälä waterworks, on the other hand, estimates their debt to be some 1-2 million euro. Lempäälä waterworks has not determined any exact unit price for renovation since the costs depend so highly on the surrounding conditions and pipe sizes etc. Lempäälä waterworks has also decided to allocate more and more money on renovating the water network in the future. The plan takes place from 2011 till 2017 while the investment sum will be raised from 400 000 € to 900 000 €. Table 5.4. combines some key figures in three reviewed waterworks.

Table 5.4. *Key figures of waterwork's economy in Kangasala, Lempäälä and Keetmanshoop*

	Kangasala Actual 2009	**Lempäälä Actual 2010**	**Keetmanshoop Budget 2010/2011**
Volume of business [N$][1]	47 670 272 (4 914 461)	35 585 856 (3 668 645)	12 020 000 (1 239 175
Investment on renovating water network [N$]	1 358 000[2] (140 000)	2 910 000[2] (300 000)	314 541[3] (32 427)
Business surplus [N$]	-616 192 (-63 525)	906 028 (93 405)	707 682 (72 957)

Notes: 1) Volume of business and business surplus are for both water and wastewater in Kangasala and Lempäälä, but only for water vote in Keetmanshoop
2) Budgeted for 2011 in Kangasala and Lempäälä
3) Author's suggested investment for 2013 according to the water loss reduction programme in Chapter 6.

It seems that volume of business in Keetmanshoop is considerably smaller than in the Finnish municipalities. However, when the investment on renovation is compared with the volume of business, the suggested value in Keetmanshoop looks fairly reasonable compared with Kangasala and Lempäälä.

6. WATER LOSS REDUCTION STRATEGY

Since the water losses in Keetmanshoop are on the increase and thus monetary losses are alarming, a development plan for the network ought to be carried out. This research has given evidence that the biggest part of the real losses, which comprise about 33 % of the total input water, is due to the leaking pipe network which is driven by excessive pressure. Even though the detailed data of condition of the water distribution system is still not adequate, it cannot be a reason for not developing a non-revenue water reduction strategy already with the level of data already available. It is obvious that the problem with non-revenue water is getting worse all the time.

The development plan is divided into two: short-term plan and long-term plan (Chapter 6.2. and Chapter 6.3.). Since it is impossible to eliminate non-revenue water totally, a target must be set. The short-term plan takes two and the long-term plan ten years to be completed. With this amount of time and usable resources, it will be feasible to set the target to reduce water losses to around 23 % of the annual system input. This would be in line with many Namibian water utilities' water loss levels. Nevertheless, if seems meaningful later on, the target can be re-evaluated.

The quantities of pipes, shut valves etc. suggested in this chapter do not include those replaced with normal ad-hoc maintenance activities. Before the short-term and the long-term plans are presented, it is estimated how the situation of water and financial losses would develop if the water loss reduction programme is not taken into use and ad-hoc maintenance is kept as the only water network management strategy. This non-ideal strategy is considered for a period of ten years and will be discussed in Chapter 6.1.

6.1. Option zero – no strategy

Option 0 represents estimates on monetary losses if no planned renovation is done. There is some natural rate of rise in leakages that occurs which increases demand for water purchase more and more in the future. The rise will occur especially due to the increased number of unreported bursts and increasing background leakage. During the period of 2005-2010 water purchase from NamWater has ranged from 1 564 000 m^3 to current value of 1 637 279 m^3 (2009/2010). The volume from 2009, which is 1 593 000 m^3, is used as an initial value in these calculations and the rate of rise in water losses is estimated to be 0,5 % per year from the current 33,5 %. See Table 6.1. for the calculations of water and monetary losses during this period of ten years. The change in

NamWater's tariffs (6,45 N$ in 2010) is not taken into consideration because the calculation corresponds to a current value of the Namibian dollar.

Table 6.1. *Estimation on the development of water and financial losses in 2011-2020. Volume of water purchase in the third column rises due to increasing real losses.*

Year	Water losses [%]	Water purchase [m^3]	Lost water [m^3]	Monetary losses [N$]
2011	33,5	1 593 000	533 655	3 442 075
2012	34,0	1 600 965	544 328	3 510 916
2013	34,5	1 608 970	555 095	3 580 360
2014	35,0	1 617 015	565 955	3 650 411
2015	35,5	1 625 100	576 910	3 721 072
2016	36,0	1 633 225	587 961	3 792 349
2017	36,5	1 641 391	599 108	3 864 246
2018	37,0	1 649 598	610 351	3 936 766
2019	37,5	1 657 846	621 692	4 009 916
2020	38,0	1 666 136	633 132	4 083 698
2021	38,5	1 674 466	644 669	4 158 118
2022	39,0	1 682 839	656 307	4 233 180
			Total	**45 983 108**

This scenario is scary in terms of total monetary losses as municipality would lose more almost 50 million Namibian dollars due to the real losses. The increase in the water losses percentage from 33,5 to 39 in eleven years is realistic since as Figure 4.4. indicates, NRW has been on a steady incline for previous years. Option zero is thus not recommended in order to avoid massive financial losses in the future.

6.2. Short-term water loss reduction programme

The short-term strategy will concentrate on every-day operational problems that the water maintenance teams are facing. It also aims to provide suitable information to be used in the long-term programme. The first phase of the plan concentrates on enhancing the functionality of the network by going through (once again) the valves in critical locations of the network and repairing or replacing those that do not operate. As the previous check-ups (2009-2010) on valves have indicated, around half of them are in poor condition, thus do not either close all the way or leak heavily. The second part of the plan, which aims to provide sufficient data for further developments, consists of a record-keeping practice of maintenance work and data collection with new district water meters. It also includes systematic and extensive water meter testing. With the help of this testing procedure, the municipality will gain knowledge on how big portion of the NRW is apparent losses due to under-registration of water meters and will be able to replace those that have too much error. The components included in this short-term plan are discussed below in this chapter. Prices used in financial calculations were received from suppliers (Valco Pipes, Sinclair Service) in the mid 2010, so they may need to be updated to correspond to present values when the municipality starts the development programme.

6.2.1. Shut valve check and renovation programme

Repairing or replacing non-functional shut valves will give benefits such as enhance the service level to consumers, since water maintenance teams can isolate a smaller subdivision of water distribution system, thus water is cut-off from smaller number of residents. Also, some water losses can be reduced by being capable of cutting off water from a heavily leaking pipe immediately without the need to search for a functional valve in the field. According to the author’s observations, the present maintenance teams in Keetmanshoop would have time to complete both, the testing procedure and the renovation. Thus, no money needs to be allocated to the work part. However, those shut valves that need to be replaced, cause expenses to the municipality. A total number of thirty shut valves should be picked for replacement in the period of two years. Since there is no initial information on which size valves are to be replaced, it is estimated that the proportion of shut valve sizes for replacement follows the proportion of sizes of existing shut valves in the network.

6.2.2. Water meter testing and replacing

As discussed earlier, water meters tend to deteriorate with age, resulting in inaccurate readings. Since the water sales are a major income for Keetmanshoop municipality, accounting for all water should be a top priority. Implementing a water meter replacement programme will not only decrease apparent losses, but will also increase revenue. Water meter testing and replacement programme should be adapted for both, consumer and public meters. Making sure that the meters at the municipality’s own premises record accurately enables the calculation of authorized unbilled consumption and helps to reduce water consumption where it is excessive. An ultimate goal of the metering practice is that 100 % of all water that is consumed is also metered. However, this is almost impossible to achieve since it may not be cost-efficient to record, for example, usage for network flushing or fire fighting, but this consumption is fairly small portion of total apparent losses. Water meter testing and replacement programme consists of the following:

1) Go through public premises and check whether a water meter exists and install one if needed.
2) Pick water meters to be tested so that all types and sizes are represented. Most focus must be on the biggest consumers such as hotels, youth hostels and schools because an error in their registration has a greater effect on revenue

issues. Before the meter's accuracy is tested it needs to be made sure that there is no other water consumption at the same time. The procedure must include little and big test flows.

3) Calculate the accuracies of water meters tested and evaluate which of them need to be replaced by a new meter. The threshold limit could be five percent under-recording.
4) Install a new water meter in the spots evaluated on point 3.

It is simple to calculate direct savings achieved by the meter replacement programme. First, clarify the total annual consumption by the particular customer whose meter is under-recording and calibrate that volume to correspond with the actual consumption when the error has been taken into consideration. As an example, the annual consumption according to billing in 2008 at Suiderlig High School was approximately 30 000 m^3. If their water meter is under-recording by five percent, the actual annual consumption is about 31 600 m^3. Thus, the annual volume of non-revenue water would be 1 600 m^3 with respective dollar amount of more than 16 000 N$. The annual saving is more than five-fold compared with the price of size 50 mm water meter used in that premise (2 833 N$) and additional savings will be gained year after year as long as the new meter records accurately. Because it is impossible to predict the impact of the water meter testing and replacement programme on water losses, it will be left out from financial calculations.

6.2.3. Data collection for long-term water loss reduction programme

The data for the long-term pipe rehabilitation and replacement programme should comprise at least of the following:

- consumer usages in different parts of the water network
- flow profiles for different parts of the water network
- based on first two points above, the calculation of NRW in smaller subdivisions to reveal the most problematic areas
- failure information (type of pipe failure, the probable cause of the failure)
- work management records on repairs (type, location, date etc.)
- pressure data
- meter testing results
- details of water meter and shut valve replacements (type, date etc.).

Data must be recorded effectively in order to get the maximum benefit for further development work. All personnel must be educated so that they understand these practices and realize their importance. The data can first be collected into a simple paper form and later transferred into a computer data base for broader approach and analysis. Again, the data must be used to update the water distribution AutoCAD-layout. The more data the municipality will collect, the easier and more reliable it will be to support decisions on which parts of the network need most resources to be allocated. Thus, an appropriate level of data will enhance the management of water infrastructure and enables investing in right areas.

Some of the data stated above is already available, such as pressure readings from 2010 and the water meters testing data from 2008, but these practices also ought to be done more comprehensively. As discussed previously, the meter testing programme should comprise a bigger number of water meters and especially include bigger meters (>20 mm).

The implementation of DMAs is the only part of this data collection strategy which demands significant investments. An appropriate size of a DMA would be between 300-400 service connections. That way there will be total of 10 DMAs in the network. Even though electronic water meters are more expensive than regular mechanic meters, it is essential to receive demand profiles out of the zonal metering practice. Especially the records of night flows will indicate areas where the night time consumption is large. Thus, those areas are suspects of high NRW. The meter testing and replacement programme in Chapter 6.2.2. plays a significant role in the implementation of DMAs to ensure that the NRW in different areas is measured effectively and accurately.

6.3. Long-term water loss reduction programme

The data needs for the long-term programme should have been achieved from the implementation of the short-term programme described in Chapter 6.2. Also, the operative level of water network will improve due to the repair of shut valves and installation of new ones. The long-term programme consists of implementation of pressure zones with installation of PRVs and systematic replacement of the mains. The data collection programme provides information that support decisions on which areas are the worst in terms of water losses, in order to start the replacement programme from those zones. When the pipes are replaced systematically, consumers can be informed beforehand to allow awareness of a supply shortage. That way the programme will affect service levels as little as possible.

The programme is carried out so that the total length of mains replaced yearly increases with time. First three years the length is 1 000 m and increases step by step to 3 000 m for the last three years. That way the replacement for the follow-up years can be funded by savings from previous years. Finally, in ten years a total length of 23 000 m mains will be renewed which is about 15 % of total length of the mains. If this is kept as an average replacement rate, all mains would be renewed in 65 years.

Pressure management is implemented in the long-term programme and while four PRVs will be installed within the first two years. The network simulations explained in Chapter 5.8. provided suggestions on what could be effective areas to adapt pressure reduction activities, but these ideas must still be supported by new and more sufficient pressure measurements through the network. Even though the total number of 30 shut valves will already be replaced in the short-term programme, two valves per year will be replaced in the long-term programme.

6.4. Financial aspects

The costs for the main and shut valve replacements are calculated using a unit price N$/m (Namibian dollars per meter of pipe). The following information and estimates are used in the calculation of the unit price for mains:

- Cost of man-hour is 22 N$ (plumber's average salary in Keetmanshoop).
- A group of four men is doing the installation work and they complete the replacement of one pipe in two hours (based on observations and discussions with the employees of ITS).
- The pipe costs are from July 2010 (Appendix 5).
- The reconstruction of surface material where pipes are under tarred road is not taken into account.

Because it is not wise to calculate the cost of every pipe size separately, only one price is determined. The following equation explains better how this is done:

$$N\$/m_{pipe} = \frac{N\$/pipe_{50mm} \cdot l_{total,50mm} + N\$/pipe_{63mm} \cdot l_{total,63mm} + \ldots + N\$/pipe_{200mm} \cdot l_{total,200mm}}{L}$$

with	$N\$/m_{pipe}$	the price of pipe per meter (uPVC)
	N$/pipe	the price of a particular pipe size (6 m uPVC)
	l_{total}	the total length of mains of a particular pipe size
	L	the total length of mains

Then the cost of work is added to the value extracted from equation above by using the following equation to get the final unit price:

$$N\$/m = {}^{N\$}\!/_{m_{pipe}} + {}^{MH \cdot h}\!/_{m_{pipe}}$$

with N$/m the unit price for pipe replacement
MH the cost of a man-hour
h the time needed for replacement by maintenance team

The same procedure is used to calculate the unit price for shut valves since sizes also range between 50 mm and 200 mm. The unit price used in following cost calculations is thus 225 N$/m for the mains and 1 504 N$/piece for the shut valves. See Table 6.2. for the total costs of the water loss reduction programmes.

Table 6.2. Costs for the water loss reduction programmes.

Year	Pipes [m]	Shut valves [pcs]	Electronic water meters [pcs]	Pressure reducing valves [pcs]	Total cost [N$]
2011		15	5		89 564
2012		15	5		89 564
2013	1 000	2		2	271 788
2014	1 000	2		2	271 788
2015	2 000	2			452 963
2016	2 000	2			452 963
2017	2 000	2			452 963
2018	2 000	2			452 963
2019	2 000	2			452 963
2020	3 000	2			677 939
2021	3 000	2			677 939
2022	3 000	2			677 939
Total	**21 000**	**50**	**10**	**4**	**5 021 334**

As can be seen, the replacement of the pipes comprises the biggest portion of the costs. The total cost for this twelve-year programme is about five million N$ (excluding water meter replacements). The monetary losses without a strategy, explained in Chapter 6.1., would be more than four million dollars only in a single year of 2022. In this light, the costs of the programme seem to be reasonable. As is the purpose of this water loss reduction programme, the percentage of the losses should be cut down. The goal is to reduce the water losses from 33,5 % to around 23 % of the total system input volume. Table 6.3. summarizes an estimate on how the water loss percentage develops during the programme and represents the achievable savings.

Table 6.3. *Savings in water losses and money due to the long-term programme in 2013-2022. The fourth column includes the estimate of increase in water losses if no water loss reduction programme was implemented as is demonstrated in Table 6.1.*

Year	**RIL from previous year [%]**	**New water loss percentage [%]**	**Saved water [m3]**	**Saved money [N$]**
2013	3	32,5	16 010	103 262
2014	3	31,5	39 504	254 801
2015	4,5	30,6	62 532	403 335
2016	4,5	29,2	92 415	596 076
2017	4,5	27,9	121 311	782 456
2018	4	26,6	149 265	962 760
2019	4	25,6	174 199	1 123 582
2020	3,5	24,5	198 454	1 280 025
2021	3,5	23,7	220 102	1 419 658
2022	3	22,9	241 272	1 556 202
Total			**1 315 063**	**8 482 156**

Note: RIL= reduction in water losses

While implementing the short-term programme, mostly the apparent losses will be reduced due to improved water metering accuracy. Then the implementation of pressure management and systematic pipe replacement programme after the first two years will start reducing the proportion of the real losses and gaining more significant savings. As the programme continues till 2022, the percentage of water losses will keep decreasing, but the rate of decrease is slowly going down since it is easier to cut down the losses when the original level is high. The total savings and costs are summed up in the graph in Figure 6.1. The curve intersects the X-axis in 2017 which means that the total savings reaches the total costs since the beginning of the programme then. Thus, it takes six years from the beginning to start gaining profit but the curve at this point is rigid, hence promising outstanding financial savings later on.

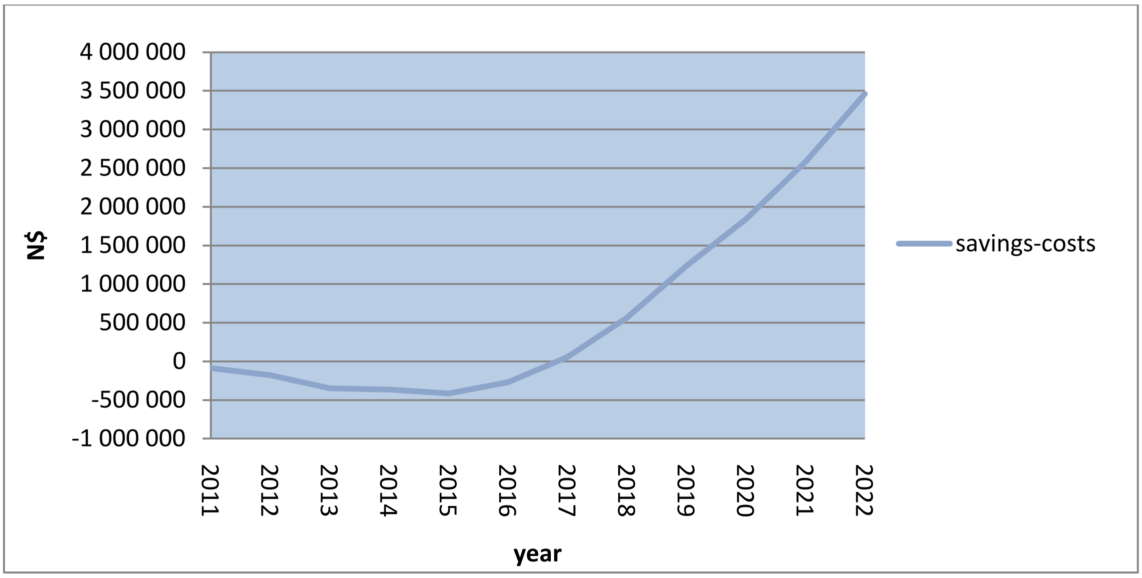

Figure 6.1. *The sum up of the total savings and costs caused by the water loss reduction programme in 2011-2022. Total savings reaches total costs in 2017, six years after the beginning of the programme.*

The schedule for the whole programme is illustrated in Figure 6.2.

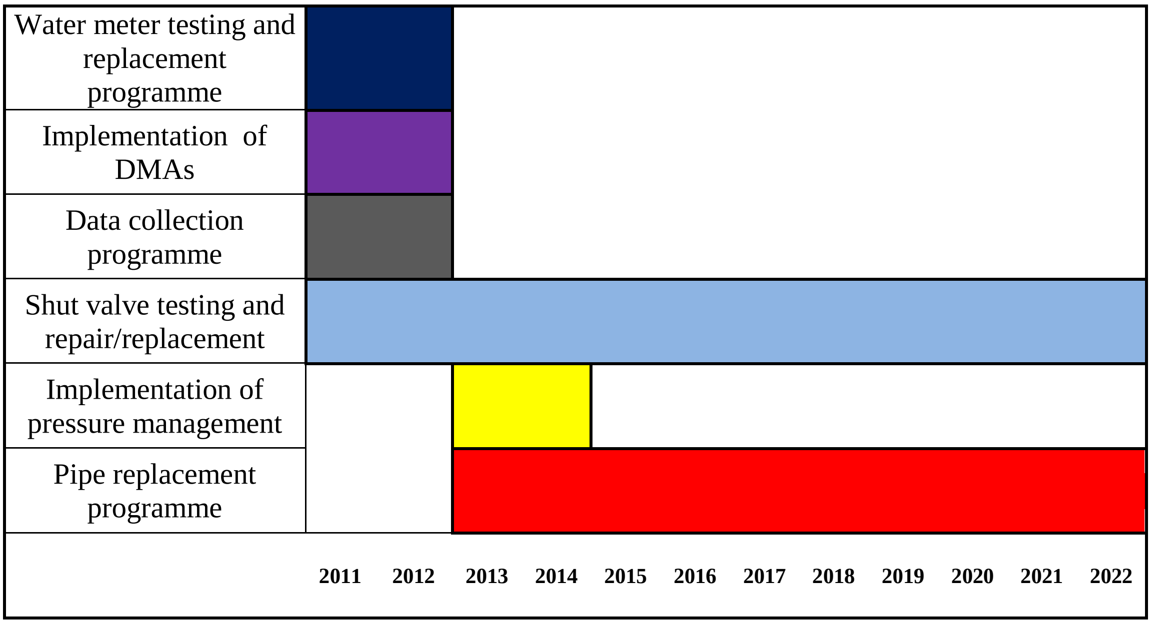

Figure 6.2. *Time schedule of the water loss reduction programme.*

As already discussed, the short-term plan will take place during the first two years and the long-term plan in the ten following years. However, the elements of the short-term plan should be maintained later on as well, even though most of the work is done during the first years. Such items as the NRW development in the DMAs will give beneficial feedback for the municipality on how things are progressing.

7. DISCUSSION AND CONCLUSIONS

7.1. Discussion

This research was a direct follow-up work for Seppänen's research in 2008. Seppänen pointed out several important topics which should be improved in water service delivery in Keetmanshoop. Unfortunately, the same problems still existed two years later. By far the most problematic issue in 2008 and still today, is the high volume of non-revenue water. In current research field observations and interviews were mad in Keetmanshoop to get an understanding of the current situation and a concrete strategy was compiled to cut down the massive water losses which cause financial burden to the municipality. It was found that the level of non-revenue water has been on a rigid increase because the management of the water sector has not been able to tackle the problems.

Keetmanshoop was compared with a few Namibian municipalities and with Finnish counterparts to see how management of water issues differs. It seems that the magnitude of the problems is a lot worse in Keetmanshoop than in any other municipality reviewed. It is clear that since Finland has abundant water sources, there can be a better focus on the water quality and delivery issues than in Namibia, which is one the most arid countries in the world. However, Finnish water utilities are likely to face increasing level of non-revenue water in the future because of deteriorating infrastructure unless this problem is tackled seriously. Waterworks of Kangasala and Lempäälä also have acknowledged this and have started a long-term renovation programme. Although the level of the water network management differs a lot between the Namibian municipalities reviewed, the non-revenue water level seems to be fairly well in control compared with Keetmanshoop.

Interviews, field observations, literature surveys, field measurements and computer simulations were the methods used in this research. A number of interviews were conducted in Keetmanshoop along with single interviews in other reviewed municipalities. Interviews in Keetmanshoop included discussions with managers of technical and finance departments. As the main focus was on Keetmanshoop, other municipalities were explored very briefly and the study did not go into too many details. The literature survey concentrated mostly on seeking the main causes of non-revenue water and ways to tackle them in general. It was found that a lot of studies on water loss management have been done throughout the world and the implementation of water loss reduction programmes have resulted in magnificent savings despite of size of the water supply systems. The literature survey also gave a good idea of general condition of the water networks in Finland and took a look in the future. Field observations were done to get a picture on how everyday operations of water network are performed. Only a few field measurements were done and they consisted of night flow analysis during one night in July and pressure measurements throughout the water network. The main focus with the computer simulations was to run the built model of Keetmanshoop water distribution network with reduced pressure.

The chosen research methods gave a lot of vital information to form a basis for the main target of this research; implementing a non-revenue water reduction strategy. However, it was noted that some information was not easily extractable from Keetmanshoop's data bases at the municipality office. For example, meter reading books could not be found to cover the whole year 2009, since December 2009 data was missing. Thus in order to get figures representing full year 2009 the data from January to November was multiplied by 12/11. Also, financial figures were inadequate since the up-to-date-budgets did not include salaries at all.

The main outcome of field measurements was surprisingly high pressure levels. This was an important result since, as discussed in the theory part of this research, pressure has proven to boost the leakage rates and the increment of new pipe bursts with great deal. The created model for the computer simulations proved to correspond with the actual measured pressures at average consumption levels. However, too few field measurements were done and the model should be calibrated with measured pressures and flows at certain pipelines and junctions to be accurate and reliable.

7.2. Conclusions

The problem of high proportion of non-revenue water concerns water utilities worldwide. Usually in developing countries water utilities do not have enough human and financial resources to tackle the problem efficiently. According to observations during the research period, the high percentage of non-revenue water is also the main issue that Keetmanshoop is presently struggling with. The problem is well acknowledged, but because of insufficient management and financial resources, the municipality has not been able to address it effectively. Overall, management of Keetmanshoop water distribution system needs considerable improvement. Since more than one third of all water supplied to Keetmanshoop water network is counted as non-revenue water, the situation is alarming. Given the fact that non-revenue water has also been on the increase at least for the last few years, it goes without saying that financial losses will be out of control in the future without effective actions.

Because of improper monitoring of the system, it can only be estimated how non-revenue water is divided into components, but leaks and metering inaccuracies are likely to be the main causes. Presently the water network is managed with ad-hoc maintenance and the problems are tackled only when there is clear evidence of failure. In addition to deteriorating water infrastructure, the water pressures are proven to boost leakages in the network. At the moment, the whole water network in Keetmanshoop is under a single pressure zone and vast parts of the town have excessive pressure. As the literature review indicates, pressure has a great effect on leakage rates and occurrence of new pipe bursts.

A strategy for reducing non-revenue water systematically is introduced in this thesis. The areas which are given most focus in the strategy are data collection, record keeping, meters accuracy and pipe and shut valve replacements. The non-revenue water reduction programme is divided into two phases. The first phase is a short-term plan which concentrates on collecting accurate data for future needs and improving the efficiency of the water network by renovating shut valves. With the help of actions completed during the first phase, a long-term plan should be started as a second phase. The long-term plan aims to control pressure to agreed levels and replace pipes systematically. The monitoring of the system which is started in the first phase should be maintained during the second phase as well, especially to give beneficial feedback to the managers of the water sector.

The monetary issues are of a great importance and this thesis can only make estimates on costs and savings. However, the suggested costs for the programme as might seem fairly high at during the first years, but it is clear that the programme will provide revenue soon and prove to be highly profitable in the future.

It is suggested that the staff of Keetmanshoop municipality will start carrying out the programmes. The biggest part of the further research should consist of collecting additional data. The data will not only be beneficial for the water loss reduction programmes introduced in previous chapter, but also for further network simulations. Simulations completed and represented in this study are only rough and should be used with care. However, with larger amount of measured field data, the simulation will give more reliable results, and thus provide a lot of help in decision making. Simulation results will help in designing especially the network division into pressure management areas and district metering areas.

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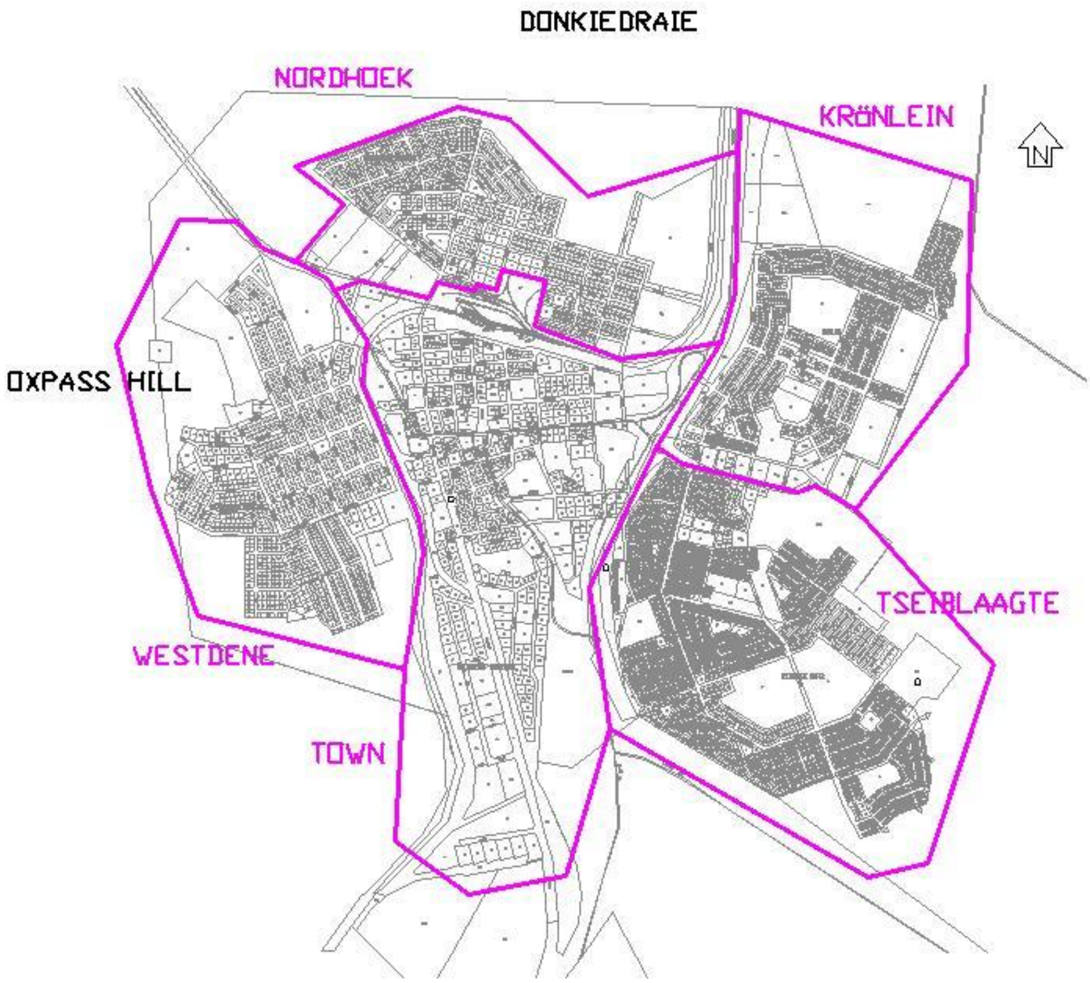
APPENDIX 1: KEETMANSHOOP TOWN LAYOUT



APPENDIX 2: SIMULATION INPUT DATA

PIPES DATA

Pipe No.	Lenght (m)	Diameter (mm)	Material	Roughness coefficient[1]
1	168	200	AC	140
2	43	200	AC	140
3	342	150	AC	140
4	450	150	AC	140
5	1325	100	PVC	130
6	470	50	AC	140
7	436	150	AC	140
8	470	150	AC	140
9	284	150	AC	140
10	249	150	AC	140
11	577	150	AC	140
12	248	150	AC	140
13	907	150	AC	140
14	865	150	AC	140
15	1099	150	AC	140
16	2193	150	AC	140
17	3040	200	AC	140
18	392	150	AC	140
19	225	200	AC	140
20	241	200	AC	140
21	164	150	AC	140
22	232	150	AC	140
23	414	150	AC	140
24	627	150	AC	140
25	292	100	AC	140
26	654	75	AC	140
27	3275	150	AC	140
28	471	150	AC	140
29	779	100	AC	140
30	1340	150	AC	140
31	2706	125	AC	140
32	1240	200	AC	140
33	290	150	PVC	130
34	984	150	PVC	130

35	631	150	AC	140
36	823	150	AC	140
37	343	150	AC	140
38	343	100	AC	140
39	76	150	AC	140
40	643	75	AC	140
41	580	150	AC	140
42	1240	200	AC	140
43	1430	200	AC	140
44	1448	150	AC	140
45	500	150	AC	140
46	438	150	AC	140
47	674	100	AC	140
48	572	150	AC	140
49	254	150	AC	140
50	962	75	AC	140
51	757	150	PVC	130

Source: 1) The Engineering Toolbox 2010

JUNCTIONS DATA

Junction	Elevation [m]	Location	Number of erven	Average demand [l/s]	Peak Demand [l/s]	Minimum demand [l/s]
1	1038	Westdene	0	0,0	0	0,0
2	1036	Westdene	0	0,0	0	0,0
3	1019	Westdene	120	3,3	6,6	2,0
4	999	Westdene	157	4,3	8,6	2,6
5	1009	Westdene	48	1,3	2,6	0,8
6	1019	Westdene	40	1,1	2,2	0,7
7	1020	Westdene	21	0,6	1,1	0,3
8	1012	Westdene	27	0,7	1,5	0,4
9	1011	Westdene	11	0,3	0,6	0,2
10	1014	Noordhoek	28	0,4	0,8	0,3
11	1011	Noordhoek	45	0,7	1,3	0,4
12	1017	Noordhoek	60	0,9	1,8	0,5
13	1012	Noordhoek	63	0,9	1,9	0,6
14	1007	Noordhoek	36	0,5	1,1	0,3
15	1004	Noordhoek	20	0,3	0,6	0,2
16	1002	Town Center	97	2,8	5,6	1,7
17	990	Town Center	77	2,2	4,4	1,3
18	1003	Town Center	241	6,9	13,9	4,2
19	1003	Town Center	38	1,1	2,2	0,7
20	1012	Noordhoek	152	2,3	4,5	1,4
21	948	Industrial Area	37	1,1	2,1	0,6
22	1022	Krönlein	0	0,0	0,0	0,0
23	1019	Krönlein	64	0,9	1,8	0,6

24	1007	Krönlein	115	1,7	3,3	1,0
25	1016	Krönlein	90	1,3	2,6	0,8
26	1006	Krönlein	176	2,5	5,1	1,5
27	1012	Krönlein	123	1,8	3,5	1,1
28	1005	Krönlein	28	0,4	0,8	0,2
29	1003	Krönlein	91	1,3	2,6	0,8
30	999	Krönlein	102	1,5	2,9	0,9
31	997	Tseiblaagte	17	0,1	0,2	0,1
32	987	Tseiblaagte	304	1,6	3,3	1,0
33	976	Tseiblaagte	70	0,4	0,8	0,2
34	970	Tseiblaagte	362	2,0	3,9	1,2
35	964	Tseiblaagte	530	2,9	5,7	1,7
36	975	Tseiblaagte	70	0,4	0,8	0,2
37	960	Tseiblaagte	177	1,0	1,9	0,6
38	957	Tseiblaagte	326	1,8	3,5	1,1

APPENDIX 3: SIMULATION RESULTS

A) Current situation

Simulation type:				Flow analysis		
Conditions:				Ave, min and max		

Label	From	To	Average flow [l/s]	Min flow [l/s]	Peak flow [l/s]	Peak velocity [m/s]
1	R-1	J-1	85,6	83,1	91,6	2,64
2	J-1	J-2	61,3	58,4	68,4	1,86
3	J-2	R-2	33,1	33,9	30,9	1,92
4	R-2	J-3	6,6	3,6	10,4	0,2
5	J-3	J-4	3,2	1,6	7,1	0,2
6	J-4	J-5	-1,1	-1,0	-1,5	0,52
7	J-5	J-6	-8,5	-7,7	-11,1	0,43
8	J-6	J-7	-10,4	-9,1	-13,7	0,51
9	J-2	J-7	28,2	24,5	37,5	1,39
10	J-7	J-8	11,7	10,2	15,5	0,58
11	J-8	J-9	5,2	4,6	6,9	0,26
12	J-6	J-9	0,8	0,7	0,5	0,04
13	J-9	J-15	5,7	5,1	6,7	0,29
14	J-5	J-17	6,1	5,9	7	0,33
15	J-8	J-10	5,8	5,1	7,1	0,29
16	J-7	J-12	5,6	5,0	7,1	0,28
17	J-1	R-3	24,3	24,7	23,2	0,79
18	J-12	J-10	-2,2	-2,1	-2,4	0,12
19	J-10	J-11	3,1	2,8	4	0,16
20	J-11	J-14	2,5	2,4	2,7	0,13
21	J-13	J-12	-7	-6,6	-7,7	0,21
22	J-14	J-13	-2,5	-1,9	-4,4	0,06
23	J-15	J-14	4,4	3,9	6	0,22
24	J-15	J-16	9,7	8,9	12,1	0,5
25	J-16	J-17	5,4	5,4	6,7	0,31
26	J-17	J-18	8,3	9,3	7,2	0,53
27	J-18	J-19	-0,6	2,1	-4,8	0,26
28	J-16	J-19	1,5	1,8	-0,2	0,41
29	J-17	J-21	1,1	0,6	2,1	0,04
30	J-19	J-20	-0,2	3,2	-7,2	0,18
31	J-20	J-13	-3,5	-4,1	-1,4	0,52
32	J-20	R-3	1,1	6,0	-10,4	0,34

33	J-36	J-18	-1,9	-3,1	1,9	0,25
34	R-3	J-22	8,1	3,9	19	0,12
35	J-22	J-23	11,3	6,8	22,6	0,38
36	J-23	J-24	1,7	1,0	3,3	0,06
37	J-23	J-25	8,8	5,3	17,5	0,3
38	J-25	J-26	3,4	2,1	6,9	0,12
39	J-25	J-27	4	2,4	8	0,14
40	J-27	J-28	0,8	0,5	1,6	0,06
41	J-26	J-28	0,9	0,5	1,8	0,03
42	J-27	J-30	1,5	0,9	2,9	0,2
43	J-28	J-29	1,3	0,8	2,6	0,04
44	R-3	J-22	8,1	3,9	19	0,12
45	J-22	J-31	4,9	1,0	15,5	0,03
46	J-31	J-32	3,9	2,3	8	0,13
47	J-32	J-33	0,4	0,2	0,8	0,01
48	J-32	J-34	1,8	1,1	3,9	0,06
49	J-34	J-35	-1,9	-1,1	-3,5	0,15
50	J-35	J-36	-2,8	-1,7	-5,4	0,1
51	J-31	J-36	0,9	-1,4	7,3	0,08
52	J-35	J-37	1	0,6	1,9	0,13
53	J-34	J-38	1,8	1,1	3,5	0,06

Note: The sign of the flow indicates the direction. Positive sign means that the direction is from the junction in the second column to the junction in the third column and negative means the opposite direction.

B) Pressure reduction applied

PEAK DEMAND

Simulation type:	Pressure control
Conditions:	Peak demand
Pressure control applied to:	Pipe-32 & Pipe-45

Junction	Elevation [m]	Demand [L/s]	Initial Pressure [bars]	Reduced Pressure [bars]	Pressure drop [bars]
1	1 038	0	0,6	0,6	0
2	1 036	0	0,7	0,7	0
3	1 019	6,6	1,7	1,7	0
4	999	8,6	2,6	2,6	0
5	1 009	2,6	2,3	2,3	0
6	1 019	2,2	1,5	1,4	0,1
7	1 020	1,1	1,5	1,5	0
8	1 012	1,5	2,2	2,2	0
9	1 011	0,6	2,2	2,2	0
10	1 014	0,8	1,9	1,8	0,1

11	1 011	1,3	2,2	2,1	0,1
12	1 017	1,8	1,6	1,5	0,1
13	1 012	1,9	2,1	2	0,1
14	1 007	1,1	2,5	2,5	0
15	1 004	0,6	2,8	2,8	0
16	1 002	5,6	2,9	2,9	0
17	990	4,4	4,1	4	0,1
18	1 003	13,9	2,7	2,6	0,1
19	1 003	2,2	2,8	2,8	0
20	1 012	4,5	2	2	0
21	948	2,1	8,1	5,3	2,8
22	1 022	0	1,1	1,2	-0,1
23	1 019	1,8	1,2	1,2	0
24	1 007	3,3	2,3	2,3	0
25	1 016	2,6	1,1	1,1	0
26	1 006	5,1	2	2	0
27	1 012	3,5	1,4	1,4	0
28	1 005	0,8	2,1	2,1	0
29	1 003	2,6	2,2	2,3	-0,1
30	999	2,9	2,3	2,3	0
31	997	0,2	3,4	2,2	1,2
32	987	3,3	4,2	3	1,2
33	976	0,8	5,3	4,1	1,2
34	970	3,9	5,8	4,6	1,2
35	964	0	6,6	5,4	1,2
36	975	0	5,5	4,4	1,1
37	960	1,9	6,7	5,5	1,2
38	957	3,5	7,1	5,9	1,2

MINIMUM DEMAND

Simulation type:	Pressure control
Conditions:	Min demand
Pressure control applied to:	Pipe-32 & Pipe-45

Label	Elevation [m]	Demand [L/s]	Initial Pressure [bars]	Reduced Pressure [bars]	Pressure Drop [bars]
1	1 038	0	0,7	0,7	0
2	1 036	0	0,8	0,8	0
3	1 019	2	1,7	1,8	-0,1
4	999	2,6	3,6	3,7	-0,1
5	1 009	0,8	3	3,1	-0,1
6	1 019	0,7	2,1	2,1	0
7	1 020	0,3	2,1	2,1	0
8	1 012	0,5	2,8	2,8	0
9	1 011	0,2	2,9	2,9	0
10	1 014	0,2	2,5	2,6	-0,1
11	1 011	0,4	2,8	2,9	-0,1
12	1 017	0,5	2,2	2,3	-0,1
13	1 012	0,6	2,7	2,8	-0,1
14	1 007	0,3	3,2	3,3	-0,1
15	1 004	0,2	3,5	3,5	0
16	1 002	1,7	3,6	3,7	-0,1
17	990	1,3	4,8	4,9	-0,1
18	1 003	4,2	3,4	3,5	-0,1
19	1 003	0,7	3,4	3,4	0
20	1 012	1,4	2,5	2,5	0
21	948	0,6	8,9	5,4	3,5
22	1 022	0	1,4	1,3	0,1
23	1 019	0,5	1,6	1,6	0
24	1 007	1	2,8	2,8	0
25	1 016	0,8	1,9	1,9	0
26	1 006	1,5	2,8	2,8	0
27	1 012	1,1	2,3	2,2	0,1
28	1 005	0,2	2,9	2,9	0
29	1 003	0,8	3,1	3,1	0
30	999	0,9	3,5	3,5	0
31	997	0,1	3,8	2,2	1,6
32	987	1	4,8	3,2	1,6
33	976	0,2	5,8	4,3	1,5
34	970	1,2	6,4	4,9	1,5
35	964	0	7	5,5	1,5
36	975	0	6	4,4	1,6
37	960	0,6	7,4	5,8	1,6
38	957	1,1	7,7	6,1	1,6

APPENDIX 4: KEETMANSHOOP MUNICIPALITY FINANCIAL YEAR 2010/2011

Water vote: 032

	Budget 2010/2011	Budget 2009/2010	To date 2009/2010
Salaries, wages and allowances			
Salaries and allowances	1 164 984	787 211	644
Leave bonus	97 082	65 601	0
Fuel & vehicle allowance	104 400	72 000	0
Social security	8 216	6 851	0
Medical contributions	134 172	113 158	0
Pension and fund contribution	252 802	170 825	0
Overtime	62 278	57 240	0
Housing contribution	174 748	98 402	0
Standby allowance	0	4 228	0
Sub Total	1 998 682	1 375 516	644
General expenses			
Administrative levy	0	0	0
Advertising	0	0	0
Fuel	60 000	80 000	60 293
Printing and stationary	1 000	1 000	172
Electiricty consumption	0	0	0
Publicity and subscriptions	0	0	0
Insurance	0	0	0
Cleaning materials	5 000	2 000	6 364
Water purchace	10 000 000	9 800 000	11 740 777
Treatment water	15 000	15 000	5 810
Water consumption	0	0	0
Cellphone subsidies	0	0	0
Vehicle registration	2 000	2 000	1 368
Consulting fees	0	0	0
Protective clothing	10 000	8 000	6 355
Contracts	0	0	0
Installment credit	0	0	0

Termination leave	0	0	0
Severance pay	0	0	0
Acting allowance	0	0	0
Long service allowance	0	0	0
Sundry payment	0	0	0
Unpaid leave	0	0	0
Sub total	10 093 000	9 908 000	11 821 140
Repair and maintenance work			
Tools & equipment	20 000	20 000	17 984
Buildings	0	0	0
Machinery & Equipment	3 000	5 000	2 398
Network	300 000	300 000	351 934
Vehicles	20 000	12 000	21 662
Contribution funds	0	0	0
Sub total	343 000	337 000	393 979
Capital expenses			
External interest	25 000	0	40 179
External redemption	20 000	0	21 985
Interest	0	0	0
Redemption	0	0	0
Sub total	45 000	0	62 165
Contribution to capital spending			
Vehicles	18 000	0	0
Fencing	20 000	20 000	0
Pre-paid water machines	0	0	0
New tools	10 000	18 000	2 037
Water pump	0	0	0
Chlorine plant	0	0	0
Auxillary pipe	0	0	0
Capital	0	0	0
Water meter NAMW/DAM	50 000	50 000	0
Licence fee prepaid	0	50 000	0
Disinfection system	150 000	150 000	0
Sub total	248 000	288 000	2 037
Total	12 727 682	11 908 516	12 279 987

Income

Departmental sales	0	0	1 483 524
Sundries	20 000	10 000	19 743
Public sales	12 000 000	11 500 000	11 141 377
Contribution (from vote 60)	0	0	0
Capital development fund	0	0	0
Total	12 020 000	11 510 000	12 644 646
NETT	707 682	-398 516	364 658

APPENDIX 5: COSTS FOR WATER NETWORK INFRASTUCTURE

Table below represents the costs for water network infrastructure. Prices were extracted from the price catalogues of two companies situated in Windhoek: Valco Pipes and Sinclair Services. Prices are from July 2010 with VAT (15 %) included.

Shut valves

Size (mm)	Price (N$)
50	754
63	672
75	900
90	1 226
110	1 528
160	2 521
200	4 436

Water meters (Kent, brass)

Size (mm)	Price (N$
15	326
20	408
25	701
40	2 331
50	2 809
75	-
100	2 841
150	3 457

Pressure reducing valves (PRV)

Size (mm)	Price (N$)
150	21901

Water meters (Valco Pipes, plastic)

Size (mm)	Price (N$)
15	358

Pipes (uPVC, 6m)

Diameter (mm)	Price (N$)
50	69
63	118
75	139
90	195
110	247
125	363
160	580

Electronic water meters

Size (mm)	Price (N$)
40	9 082
50	9 371
65	9 497
80	9 600
125	11 794
150	13 399