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TAMPERE UNIVERSITY OF TECHNOLOGY

MATTI AALTO

WATER NETWORK MANAGEMENT PLAN FOR KEETMANSHOOP, NAMIBIA

Master of Science thesis

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Abstract

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Namibia is one of the driest countries in the world, but water distribution is not technically difficult to implement for population of 2.3 million. Rainy season gives enough water to reservoir lakes for whole year, land is sandy and easy to dig and pipes do not need to be installed deep because air temperature is always on plus degrees. Still weakly organized water distribution causes big losses and extra work in municipality of Keetmanshoop.

The municipality buys 1.7 million cubic meters water per year from a bulk water supplier, NamWater. Only 65% of water bought from Namwater is billed from customers. The rest 35% consists mainly of metering errors, leaks and municipality's own use. Unbilled water causes 4 000 650 N$/y (537 000 m^3) losses for municipality. Average annual increase of unpaid bills is 26 % of total sales, which increases economic difficulties. Totally about half of water bought from NamWater is lost through leaks in network or leaks in customers' water fixtures. Minimum night flow to network is normally 100-110m^3/h year round, which is about 50-55% of average daily flow.

Tens of valves are leaking, but smaller leaks are seldom fixed as plumbers concentrate on fixing big pipe bursts. In 2012 the main valves were checked with plumbers, water distribution map was updated and the network was planned to be divided in 45 sectors by 104 valves. Already 55 of them are usable, 28 should be added, 13 should be replaced and the condition of 8 should be checked. Because of inactive water meters 8-18% of business-consumers' consumption is not measured. Money loss of 300 000 – 700 000 N$/y can be reduced to under 50 000 N$/y by simply replacing inactive meters. Many meters of big users were also inaccurate. Tested meters ran on average 30.3 % less than the real flow.

Investments in planning would be profitable. With such big water- and economical losses like in Keetmanshoop, a water engineer could find more savings for municipality than his/her salary costs are. After hiring a water engineer and replacing inactive water meters, next steps are replacing the most important valves and taking the water distribution map in use. After suburb water meters and pressure reducing valves are installed, it is time to start systematically rebuild the network road by road.

Simple calculations of money savings are almost always the easiest way to rationalize the importance of investments. Methods of calculating water balance in Keetmanshoop are also suitable for other cases. Even rough calculations show the magnitude of water- and economical losses, which often are sufficient arguments to start developing the water distribution system.

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO
Rakennustekniikan koulutusohjelma
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Kuivuudesta huolimatta vesihuollon toteuttaminen Namibiassa ei ole teknisesti kovin monimutkaista. Sadekaudella vettä saadaan kerättyä koko vuodeksi riittävä määrä tekojärviin. Hiekkainen maaperä on helppoa kaivaa ja putket voivat olla lähellä maan pintaa, sillä jäätymisvaaraa ei ole. Kuitenkin heikosti järjestetty vedenjakelu aiheuttaa vesihävikkiä, taloudellista tappiota ja ylimääräistä työtä.

Keetmanshoopin kunta ostaa vuosittain 1,7 miljoonaa kuutiometriä vettä tukkuyhtiö NamWaterilta, mutta vain 65 % siitä laskutetaan asiakkailta. Laskuttamatta jäämisen pääsyyt ovat mittarien toimimattomuus, vuodot ja kunnan oma käyttö. Kunnalle laskuttamattomasta vedestä aiheutuva tappio on noin 400 000 euroa (537 000 m^3) vuodessa. Asiakkaiden vesilaskuista 26 % jää maksamatta vuosittain, mikä lisää kunnan taloudellisia ongelmia. Noin puolet NamWaterilta ostetusta vedestä häviää vuotoina verkostossa tai asiakkaiden vesikalusteissa. Pienin yövirtaama verkostoon on ympäri vuoden 100-110m^3 tunnissa, mikä on 50–55 % keskimääräisestä päivävirtaamasta.

Verkostossa on kymmeniä vuotavia venttiileitä, mutta pieniä vuotoja korjataan harvoin, sillä verkostomiehet keskittyvät suurien putkirikkojen korjaamiseen. Vuonna 2012 arvioitiin verkostoasentajien kanssa pääventtiilien kuntoa, päivitettiin verkostokarttaa ja tehtiin suunnitelma jakaa verkosto 45 sektoriin 104 venttiilillä. Arvion mukaan tällä hetkellä kyseisistä venttiileistä 55 toimii, 28 puuttuu, 13 pitäisi vaihtaa ja 8 kunto pitäisi testata. Jumittuneiden vesimittareiden takia 8-18 % suurkuluttajien vedenkulutuksesta jää mittaamatta. Tämän 30 000 – 70 000 euron vuosittaisen menetyksen voi pudottaa alle 5 000 euroon vaihtamalla mittarit toimiviin. Lisäksi mittaritestit osoittivat suurten kuluttajien mittarien mittaavan keskimäärin 30 % todellista virtaamaa vähemmän.

Suunnitteluun kannattaisi Keetmanshoopissa investoida paljon nykyistä enemmän. Suhteellisen yksinkertaisesti ratkaistavissa olevia suuria ongelmia on niin paljon, että palkattu vesihuoltoinsinööri tuottaisi kunnalle moninkertaisesti oman palkkansa verran säästöjä. Toimimattomien vesimittarien vaihdon ja suunnittelupuolen henkilön palkkaamisen jälkeen seuraavaksi tärkeintä on keskittyä verkostokartan käyttöönottoon jokapäiväisessä työssä sekä tärkeimpien venttiilien uusimiseen. Sitten kannattaisi jatkaa kaupunginosittaisten vesimittarien ja paineenalennusventtiileiden asentamisella, joiden jälkeen putkia voidaan alkaa uusimaan systemaattisesti tie kerrallaan.

Yksinkertaiset laskelmat investointien tuottamista säästöistä ovat helpoin tapa osoittaa investointien tärkeys. Myös suurpiirteisillä laskelmilla voidaan löytää vesijohtoverkoston merkittävimmät kehittämistarpeet. Keetmanshoopin vesitaseen laskemiseen käytettyjä menetelmiä voidaan hyödyntää muissakin vastaavissa kunnissa.

PREFACE AND ACKNOWLEDGEMENTS

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Tampere 13th of August 2014

Matti Aalto

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Abbreviations and notations

AC	asbestos cement
CAD	computer aided design system
IWA	International Water Association
NamWater	Namibia Water Corporation Ltd
NRW	non-revenue water
PE	polyethylene
PVC	polyvinyl chloride

1 Introduction

1.1 Water as a basic need

Everyone needs water every day at least for drinking and cooking. Water is also used in various other important purposes like washing, cleaning, irrigation, livestock needs and industry. Getting enough water, or at least getting enough clean water, is workable in many parts of the world (water.org 2014). Especially poor people in dry areas suffer the lack of water (Prüss-üstün et. al. 2008). Despite of comparatively small volumes of water available, water use is often inefficient (Prüss-üstün et. al. 2008, SIWI & WHO 2005). Weakly organized water distribution causes water losses, economic losses and unnecessary extra work. It also inequalizes poor and rich. The economic benefits of improved water supply usually outweigh the investment costs (SIWI & WHO 2005).

1.2 Keetmanshoop

Namibia is one of the driest countries in Africa. Keetmanshoop lies in Karas' region in Southern Namibia between Kalahari and Namib deserts. Summer from November to March is hot and sometimes rainy (*Figure 1*). Winter from June to August is dry with cold nights. Annual rainfall in Karas is on average 138 mm (climatemps.com 2013).

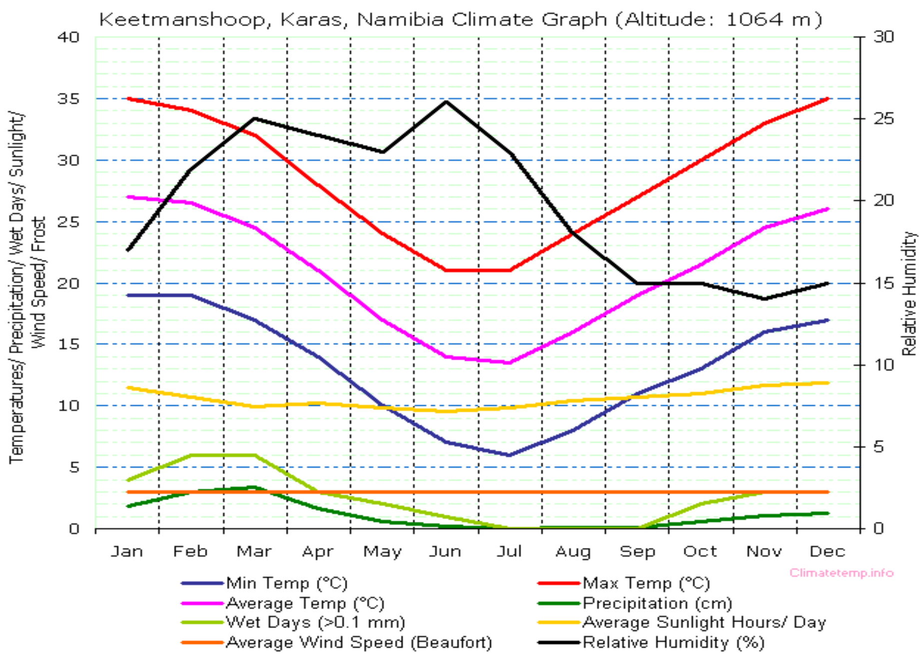


***Figure 1**. Climate Graph of Keetmanshoop (climatemps.com 2013).*

Namibia is one of the most sparsely populated countries in the world with area of 824 290 km^2 and population of 2.3 million (countryeconomy.com 2014). Population of Keetmanshoop is about 17 000. The town is divided in five suburbs (*Appendix 1*) and differences in standard of living are still high. Westdene is the richest suburb and Tseiblaagte is the poorest. Krönlein and Nordhoek are between them. Town center is mainly area of business buildings but also some wealthy people live there.

Water used in Keetmanshoop is ephemeral surface water that is collected in Naute dam during rainy season. The Naute reservoir lake lies 40km south from the town. Evaporation is high, over three metres per year (Digital Atlas of Namibia 2002), but a large drainage basin still gathers sufficient volume of water for Keetmanshoop's use.

A state owned company, NamWater, is responsible for collecting water and pumping it to reservoirs near the town. Municipality buys water from NamWater and is responsible of water after it has left the NamWater reservoirs. Water flows from reservoirs to the network only by gravity. Pumping stations or pressure reducing valves do not exist.

Groundwater exists in Keetmanshoop year round, but not enough for the town's use. Groundwater flows on ground through three boreholes continuously by its own pressure and some poor people use it for daily purposes. Only in very dry years the boreholes may be dry. Also municipality uses some groundwater for irrigation.

1.3 Objectives

The main aim of this study was to find solutions to reduce the volume of non-revenue-water (NRW) in municipality of Keetmanshoop. This is a first part of a three years project and the target of the whole project is to reduce the NRW to lower than 20% in Keetmanshoop.

Seppänen (2008) and Löppönen (2011) have done preliminary studies in Keetmanshoop. The aim of this study was also to update the most important data of the earlier studies and calculate as reliable water balance for Keetmanshoop as possible. Based on these supplements and new studies, a plan to improve water distribution system and water billing was done. The plan concentrates on the most obvious improvements and planning future studies, because concentrating on uncertain results may lead to several failures in implementing the plan (Vermersch & Rizzo 2008). Solutions of this work may be possible to use also in other towns with similar challenges in water distribution.

2 Background, Materials and Methods

2.1 Water distribution map

Building of water network in Keetmanshoop has started in early 1940s from the Town Center and Westdene. Network was expanded to Tseiblaagte and Krönlein in 1960s. (Seppänen 2008) Some old maps from the building time still exist, but the network has changed a lot after those days. Fixing and extending of network has been done but not documented. Namhindo (1992) draw a map of main pipes in 1992. Nowadays the length of mains is approximately 150 km.

AutoCAD based water distribution map was drawn in 2007 by Paula Peltola and Maria Lukkala from Tampere University of Technology assisted by two students, Festus Nebayi and Dawid Eisub, from the Polytechnic of Namibia. Location of valves and fire hydrants and routes of pipelines were checked with experienced local plumbers. Only valves that were located were drawn on the map (Peltola 2012). Possible errors of plumbers' knowledge could not be properly evaluated.

In 2012 the routes of the main pipes (bigger than 5 inches) were walked through with an experienced plumber, Ambrosius "Jackals" Kaffer. Every valve on those pipes was looked for. Mr Kaffer's knowledge of functioning of the valves was written down and updated on AutoCAD map. Other valves and fire hydrants nearby these mains were checked on the same trip. The work took about six days.

In many places Mr Kaffer's ideas differed from the existing map. Corrections on the map were done, if it seemed clear that there was a mistake. All places with significant differences were checked at least two times with Mr Kaffer from different directions and also other plumbers were interviewed. In some places nobody remembered connections of pipes and in many places the situation remained unclear. In those places the uncertainty was written on the map. Especially pipe connections in Town Center remained unclear after the field work with Mr Kaffer.

2.2 Dividing the network in zones

The main valves were searched in the field with Mr Kaffer. His assumptions about functioning of the valves were written down but the operation of only few valves were tested. The results of the experiment were written down on a new layer of AutoCAD water distribution map. Some valves were tested already in 2010 (Löppönen 2011).

Local plumbers and their foremen said they mainly know the condition of valves. They thought that the testing of valves should be done when they have new valves and are ready to replace those that are out of order.

After collecting the information about valves the network was planned to be divided in zones for simplifying maintenance and reducing water losses and improving reliability of water supply. The valves needed for the dividing were marked and the zones were drawn on the AutoCad map. The important valves were also classified in 3 categories: already usable, should be replaced and should be added.

2.3 Water use

Water use is not efficient in Namibia. Reducing water losses is poorly organized in water distribution and among water users. With good water demand management water use is possible to reduce 4-80% in urban centres of Namibia (Government of the Republic of Namibia 2010). The water demand management includes policy issues, legislation, technical issues, public education and awareness (Government of the Republic of Namibia 2010, van der Merwe 1998).

2.3.1 Metering of input in Keetmanshoop

NamWater has a continuous metering of water flow from their reservoirs to municipal water network. NamWater billing is based on this meter. In addition, NamWater has two other working meters. One is in a line between the Naute Reservoir Lake and Oxpass Hill reservoirs. Other is just before the reservoirs in Oxpass Hill.

In this study the system input volumes are based on NamWater's accounting. Billed consumptions of municipality's customers are based on municipality's accounting.

2.3.2 Non-revenue water

Non-revenue water (NRW) is the difference between water network input and billed authorized consumption. NRW includes unbilled authorized consumption, apparent losses and real losses. Unbilled authorized consumption includes water of fire hydrants, pipe scouring and other municipal unbilled use. Unauthorized consumption and meter inaccuracies are apparent losses. Real losses include leakage of mains, reservoir overflows and service connection leakages. (Lambert & Hirner 2000)

World Bank estimated the global annual volume of NRW as 48.6 billion cubic meters. In the developing countries the average of NRW is evaluated as 40-50% of the total water produced. (Kingdom et al. 2006) Examples of high NRW:s are several. In KwaZulu Natal's province in Eastern South Africa NRW is almost 40% (infrastructurene.ws 2012). In urban areas of Namibia the range of NRW is 6-50%, but it should not be more than 10% (Klintenberg 2009). In Arandis in western Namibia NRW was 52.2% in 2006 (Africon Namibia 2008).

NRW is probably the best indicator for utility to monitor its efficiency in water distribution. Target for NRW reduction can be set to ensure efficient operations and to show utility's planning abilities to customers and policy makers (Trow & Pearson 2010). Reducing NRW increases financial resources of utilities and improves service for customers (Farley et. al. 2008).

2.4 Water Meters

According to municipality's accounting Keetmanshoop's water network includes 3791 customers' water meters. Functioning of the meters was analysed by doing measurements on field and by using existing data. Seppänen (2008) tested 57 household meters (15-20mm) in 2008. The test was done by filling a 5 litre container from a tap and checking the reading of the meter. The mean error of the meters was -1.8 % (over recording).

In 2012, meter testing was done in a same way as in 2008: by taking a certain volume of water from a tap and checking the readings of the meter. It was ensured that the property had no other consumption. The condition of 28 business meters (20-80mm) was checked (*Appendix 7*). Only four of them were tested because most of the properties had some consumption all the time. Also 15 household meters were tested in 2012. A 27.4 litre container was used in big properties and 10 litre container in households. Tests of big consumers' meters were repeated 2-3 times. During the tests all big properties had a small constant flow (leak) that was subtracted from meter readings. For calculating the metering error (%) was developed a formula,

$$E = \frac{\sum_{i=1}^{n}\left(V_M - V_C - \frac{V_L * t_C}{t_L}\right) * 100\%}{n * V_C}, \qquad (1)$$

where V_M = volume according to meter, V_C = volume of the container, V_L = volume in leak flow test (Chapter 2.5.2), t_L = time of leak flow test, t_C = time of container test and n = number of repeats.

Meters' functioning at small flow rates was also tried to measure by the container test. The idea was to open a tap slowly and check the flow as meter started to run. Because of continuous water use and constant leaks in most of the buildings the test succeeded only in one place.

For water balance municipality's water loss through inactive meters was calculated from monthly readings of 34 big meters (total consumption of 180 000 m^3/year). Financial years 2010-2011 and 2011-2012 were checked, and loss of cubic meters was counted by comparing "meter inactive"-months with normal months. Hospital was left out of comparison, because it uses about 11 % of water demand of business consumers and its meter was inactive almost whole comparison period. Hospital's water demand would have had too big effect on results.

2.5 Leaks

Volume of water lost through continuous leaks is possible to evaluate by measuring night flow. It is possible to check the input to Keetmanshoop's water network from NamWater's continuously recording meter readings. Municipal reservoirs on Donkie draai and Oxpass hill may fill up or empty during night, which has to be taken into account in night flow measuring. Water levels of the reservoirs were measured at one night at 11-12 pm and at 3-4 am to calculate the real night flow to network. Filling pipe of Donkie draai was closed to calm water surface and ease the measuring of water levels. Night flow is considered to consist mainly of leaks, but include also some real night use and possible thefts. Normally night flow should not be more than 10-15% of the average daily flow (Desert Research Foundation of Namibia 2010).

In this work term "continuous flow" is often used instead of nigh flow. Normally night flow consists mainly of leaks, which means that the same leaks exist also during daytime. The minimum night flow is roughly as big as the continuous loss flow. The continuous flow is one way to evaluate the total volume of water loss.

2.5.1 Leaks in municipality's network

According to water distribution map about 90 % of pipes are asbestos cement (AC) in Keetmanshoop. It has been the material of mains for decades, but after 2004 only polyvinyl chloride (PVC) pipes have been used (Löppönen 2011). In the beginning of 1990s polyethylene (PE) replaced galvanized steel in house connections (Seppänen 2008).

Pipe bursts are common in Keetmanshoop and fixing of them is almost daily work of plumbers. The bursts and fixing of them cause transient pressure fluctuations which damage the network in many ways leading to new bursts (Charalambous 2010). Also too high pressure, even 9 bars in some areas (Löppönen 2011), causes pipe bursts in Keetmanshoop (Bonthuys 2012), because the whole network works by gravity without pressure reducing valves.

Nowadays in Keetmanshoop normal burst or leak in AC pipe is fixed by replacing three four metres long AC pipes by two six metres long PVC pipes. Systematic replacing of old pipes has not been done and the network is a mixture of AC and PVC pipes. The vast majority of network is still AC.

Volume of water lost through leaks was evaluated in order to be able to calculate water balance. Leaks were divided into big and small ones. A big leak means a burst that surfaces and is repaired by plumber team and small leak is a leak that remains unnoticed and is thus not fixed in current practice. The volume of big leaks is calculated by using approximations of leaks between June 20th and August 7th 2012. Volumes are calculated by using NamWaters night flow data and by measuring the flow of a leaking valve with a cup and stopwatch. Also many smaller leaks were fixed during that time.

In addition of fixing leaks the amount of leaks and the volume of water lost could be reduced by reducing pressure in the network (Lambert & Thornton 2011). The pressure reduction has turned out to be one of the most cost effective ways to reduce leaks (Mckenzie & Wegelin 2011). It reduces leak flow rates and burst frequency and extends residual asset life (Lambert 2013).

2.5.2 Leaks in customers' water fixtures

Leaking toilets, showers and taps are problems of water users as the flows through these leaks are metered and users need to pay the water lost. This billed water does not lead to direct financial losses for municipality, but it causes indirect problems like difficulties to customers in paying their bills.

Some customers' leaks may be so small that water meter does not meter the flow at all. The municipality loses in these kinds of situations, but the amount or volume of these leaks is difficult to estimate.

Leaks in big water users' own network (water fixtures and pipes) were checked by monitoring the property's meter when there was no other water use in the property, for example at night or on weekend. The meters were monitored 5-12 minutes with stopwatch and the time was recorded after every ten liters or some other certain volume to ensure that the flow is constant. Leak flow was counted from total time and total flow during the test. After the monitoring, meters were tested by 27.4 liter container test that is explained in paragraph 2.4. The metered value of leak flow was corrected by adding or subtracting the meter's error. Tests were repeated once or twice in every place. For calculation of leak flow was developed a formula,

$$Flow = \sum \left(\frac{V_L}{t_L} * \frac{100 - E}{100} \right), \tag{2}$$

where V_L= volume of flow during test, t_L = test time and E = error (%) of meter.

Intensity of the flow may affect the metering error. During the container tests the flow was higher than during leaks. The values from container tests are still used to correct leak calculations because they are the best available approximations of the metering error.

Some water fixtures of big users were checked by visiting in toilets and bathrooms. The volume of leaks was either metered by a 0.5 liters bottle and stopwatch or evaluated. Water losses of leaking toilets were counted from volume and filling interval of toilet's container. If the leak was as big as filling flow, the flow was calculated by filling time of a toilet nearby.

2.6 Water balance

The first objective in studying NRW was to determine the water balance of Keetmanshoop as well as possible. Determining the water balance means exploring volumes of water used in different purposes or lost in different parts of network. The balance was calculated according to International Water Association's (IWA) guidance (Lambert & Hirner 2000) (*Figure 2*) applying it to local circumstances. Studies were done by going through the existing data, by checking the municipality's accounting and NamWater's accounting, by doing measurements on field and by interviewing employees, customers and other water sector workers in the town. After collecting the data, tens of calculations and estimations were done.

Volumes of all components of water balance were calculated even if some parts had quite high range of possible errors. Range of error of all components is also important to evaluate (Fanner 2009). The ranges of error were often evaluated numerically but always at least by words.

Detailed explanations about contents of water balance are in their own chapters (2.3-2.5, 3.3-3.5). For example, NRW is explained in chapters 2.3.2 and 3.3.4.

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent* Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Metering Inaccuracies</td></tr>
<tr><td rowspan="3">Real* Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to the measurement point</td></tr>
</table>

***Figure 2**. IWA Standard Water Balance. (IWA 2013, Lambert & Hirner 2000)*

In addition to the water balance that IWA's recommends determine also some details about leaks and metering errors were included in determining the water balance of Keetmanshoop. The purpose of counting the details was to show the magnitude of water lost in different ways. Even rough calculations of these losses enable to focus improvements and future research on the most significant losses in the water system.

2.7 Reservoirs

The main purpose of reservoirs in water distribution system is to balance variations in water use. Functioning and necessity of reservoirs can be studied by measuring water levels in different times of day. If water level drops down during daytime, it indicates that the reservoir is necessary. Reservoir with constant water level may be useless if other reservoirs have enough capacity for possible disorders in water input. Small turnover in reservoir may weaken water quality. In addition to the water level measurements also interviews of municipality's staff were done for solving the functioning of reservoirs. NamWater have regularly done chlorine and bacteria measurements from water leaving their reservoirs and from some places of the network.

2.8 Finance

Financial data was collected from municipality's accounting. Also about 10 interviews were done with municipality's finance sector. Financial year of Keetmanshoop municipality is from July to June.

Monthly billing has been recorded in meter reading books, but they are not complete documents. About 25 % of pages are missing and some values are corrected afterwards.

Practices and challenges in billing in some other towns were solved out from literature and by about five interviews in Namibia. For example, in Arandis 5% of households has been out of billing register (Africon Namibia 2008). In Swakopmund systematic cutting of water of customers not paying their bills has led to regular paying in time (Demasius 2012).

In this work prices are shown in Namibian dollars (N$). In 2012 the exchange rate of Euro and N$ was 1 € = 9.42-11.55 N$.

2.8.1 Prepaid water meters

Installing of prepaid water meters has been considered as a solution to decrease remarkably the number unpaid bills. Still, prepaid meters are more expensive than normal meters and payback time should be calculated before investment. For calculating the shortest possible payback time of prepaid meters for a certain area was developed a formula,

$$t = \frac{(P_P - P_N) * n}{(T_S - T_B) * V}, \qquad (3)$$

where P_P = price of prepaid meter, P_N = price of normal meter, n = number of customers, T_S = tariff of water sold, T_B = tariff of water bought and V = volume of water sold. Maintenance costs of the network are not included in the formula meaning that the real payback time is longer.

2.8.2 Investing in maintenance of network

For example inactive and inaccurate meters, leaks and inactive valves cause financial losses for municipality. Currently there is no preventive maintenance to avoid these losses in Keetmanshoop. Problems are corrected only if they are noticed and someone starts to work to correct them. Water sector planning is needed to pay attention to losses and to reduce unnecessary costs.

Some costs of water losses are possible to calculate and compare for example with a water engineer’s salary. These calculations show the magnitude of savings the engineer should achieve to make municipality’s investment to hire him/her profitable.

3 Results

3.1 Water distribution map

AutoCAD based water distribution map was updated during field work in 2012. Locations of pipes, valves and firehydrants were quite well on the earlier map, but many connections of pipes and joints of valves were not reliable.

However, some significant updates for pipelines were made in 2012. For example, in two places 6 inches pipes were not connected the way they were on the map. From Northaug to Donkie Draai's reservoir is 260mm pipe that was not on the map. Some valves were added or removed from the map and in intersections some valves were moved to another pipe.

Checking the map's reliability during pipe bursts, when some valves were closed, showed that many places still remained unclear, especially in the Center. During these repair activities many firehydrants that should have had water according to map, did not have it. In general fewer connections exist in real life than on map. Pipes are not connected or valves may be closed. There are left and right handed valves in the network and it is unknown whether some valves are closed or open.

Even the flowing directions are not clear. For example according to Löppönen's (2011) model water flows from Tseiblaagte to Center, but field experience showed the opposite (fixing a leak on the Canon cop hill near the center). Still, the directions are mainly easily understandable straight away from the reservoirs as there are less circulation connections in real life than on map.

Conditions of 174 valves were asked from plumbers on field. According to these evaluations 93 valves were working and 81 (47%) were unusable. Total amount of valves on the map is 502.

3.2 Dividing the network in zones

Presently it is not possible to divide the network in zones, because many valves are not working and all connections are not known. The network includes also poorly planned pipe connections and useless valves. For example, pipes exist in both sides of many streets and some valves are near each other in same pipe. On the other hand tens of useful valves and some connections are missing.

Photo 1. *A Fire hydrant opened for reducing pressure to help fixing a leak nearby. The leaking pipe was not possible to close by valves. (Photo: Pekka Pietilä)*

The network was planned to be divided in 45 zones for simplifying maintenance and reducing water losses and improving reliability of water supply (*Appendix 2*). According to current knowledge 104 valves are needed to run the plan. Already 55 of these are usable, 28 new valves should be added, 13 should be replaced and condition of 8 should be checked. The first objective may be to divide the network in 5 zones according to suburbs.

***Photo 2**. A new valve clearly marked with a metal post. Pipes are not deep and the valve is almost on ground.*

Also plumbers (August 8th 2012) said that renewing gate valves is the most important matter to get better network. Plumbers are ready for installing if they get the valves. Amounts of meters and valves in municipality's stores in October 2012 are in *Appendix 6*.

3.3 Water use in Keetmanshoop

Municipality of Keetmanshoop bought 1 722 000 m^3 water from NamWater in financial year 2011-2012. The annual consumption has varied between 1 570 000-1 820 000 m^3 in 1999-2011 (*Figure 3*).

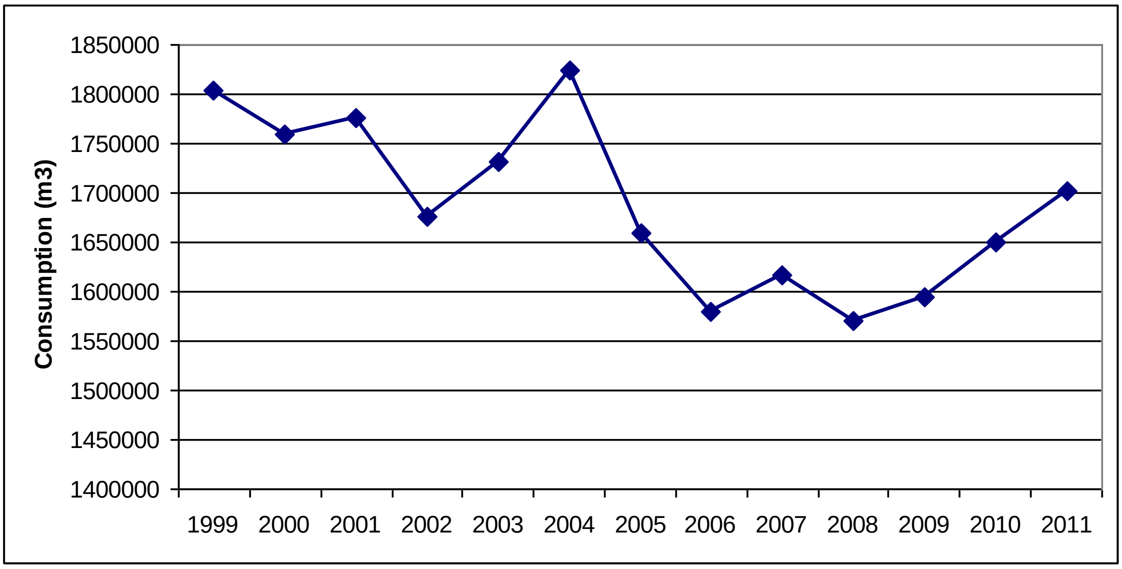


Figure 3*. Annul water consumption in Keetmanshoop in 1999-2011 according to NamWater's accounting.*

3.3.1 Periodical variation of water use

In Keetmanshoop more water is used during summer than during winter (*Figure 4*). Highest volumes are in February (mean 5590 m^3 / day) and lowest volumes are in July (mean 3760 m^3 / day). The main explanation of variation may be irrigation, because gardens need to be irrigated more in summer than in winter. Real evidence about the reasons of the variation does not exist. Volumes of water use for irrigation cannot be evaluated according to current knowledge.

Municipal swimming pool is used only in summer and it causes part of the variation. According to municipality's meter reading book the pool's consumption is 39 000 m^3/year. It is 160-180 m^3/day, if the pool is used 7-8 months per year. Because of leaks the pool needs to be filled up constantly and about 50mm pipe is flowing around 14 hours every day to fill the pool (Jansen 2012).

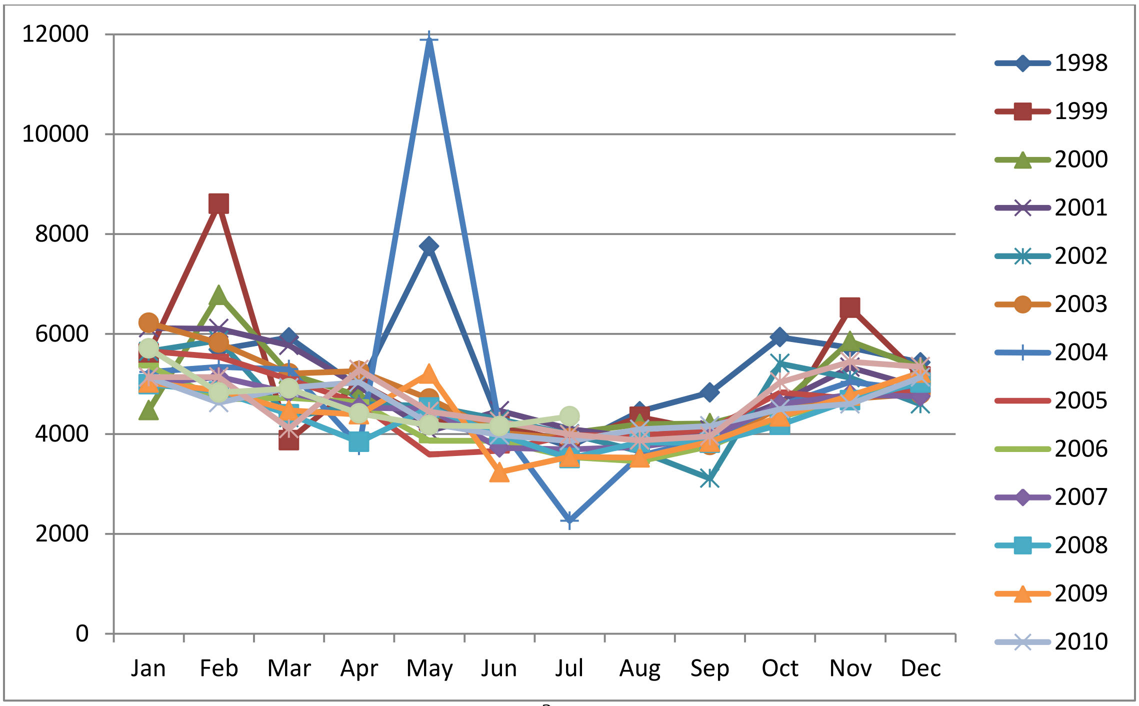


Figure 4. *Daily water consumption (m^3/day) in Keetmanshoop in years 1998-2012 based on NamWater's billing from municipality.*

The billing is done according to NamWater's meter once a month on average, but the billing period may vary from two to six weeks. The meter has been broken seven times (months) in 1998-2012 and consumptions of those months were estimated. (NamWater 2012a)

The highest billed consumption in May 2004 is based on the average of the earlier months because the meter stood. The billing time was only 14 days, which was not taken into account in billing. Because the time was less than half of normal, the consumption was evaluated more than twice as big as in earlier months. In addition, normal consumption in May is less than in earlier months.

Photo 3. *Irrigation may be the main reason of periodical variation of water use.*

Billing in February 1999 and in July 2004 are also calculated quantities and may have same kind of evaluation inaccuracies. NamWater installed new water meters in November 1999, which may somehow explain the extreme value of that month. Explanation for extreme value in May 1998 was not found.

3.3.2 Daily variation of water use

NamWater's continuous metering shows the water flow from its reservoirs to municipal water network (*Figure 5*). Readings of the meter and readings of NamWater's other meters before the reservoirs are quite similar (NamWater 2012a).

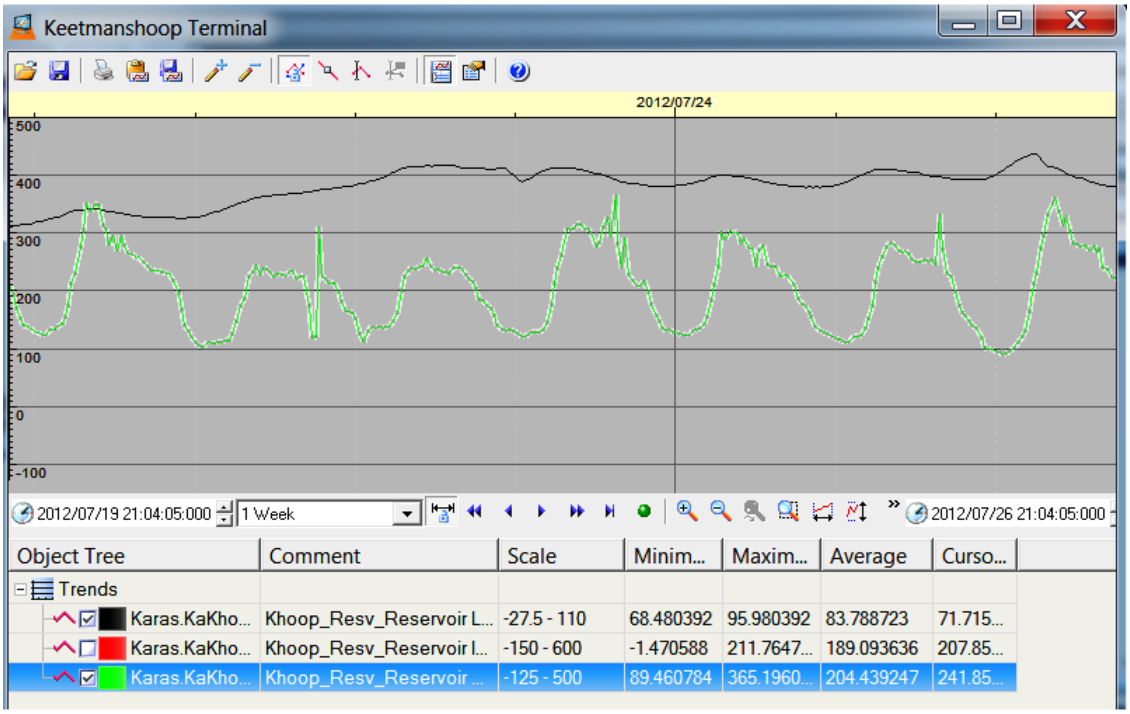


Figure 5. *Water input to Keetmanshoop network from evening of 19th July to evening of 26th July 2012. Screen print from NamWater's information system (NamWater 2012a). Numbers of y-axis are cubic meters per hour (m^3/h).*

Continuous metering provides with good possibilities to monitor night flow and leaks. During the week in *Figure 5* night flow varied between 90-110 m^3/h. Peaks in the curve are leaks. For example, short lived big leaks can be noticed on 23rd and on 25th of July. Reason of lower consumption in 21st of July is that supply to Tseiblaagte was shut off for two hours.

3.3.3 Water billed

Municipality of Keetmanshoop billed 1 115 000 m^3 water in financial year 2011/2012. Business users use about one third of billed water and households two thirds (*Figure 6*). Volumes are based on municipality's accounting summary. Billing is based on meter readers' monthly readings. Accounting is quite reliable, but some billing corrections that are made afterwards may be excluded from the summary. Still, error of billed volumes is less than 5%.

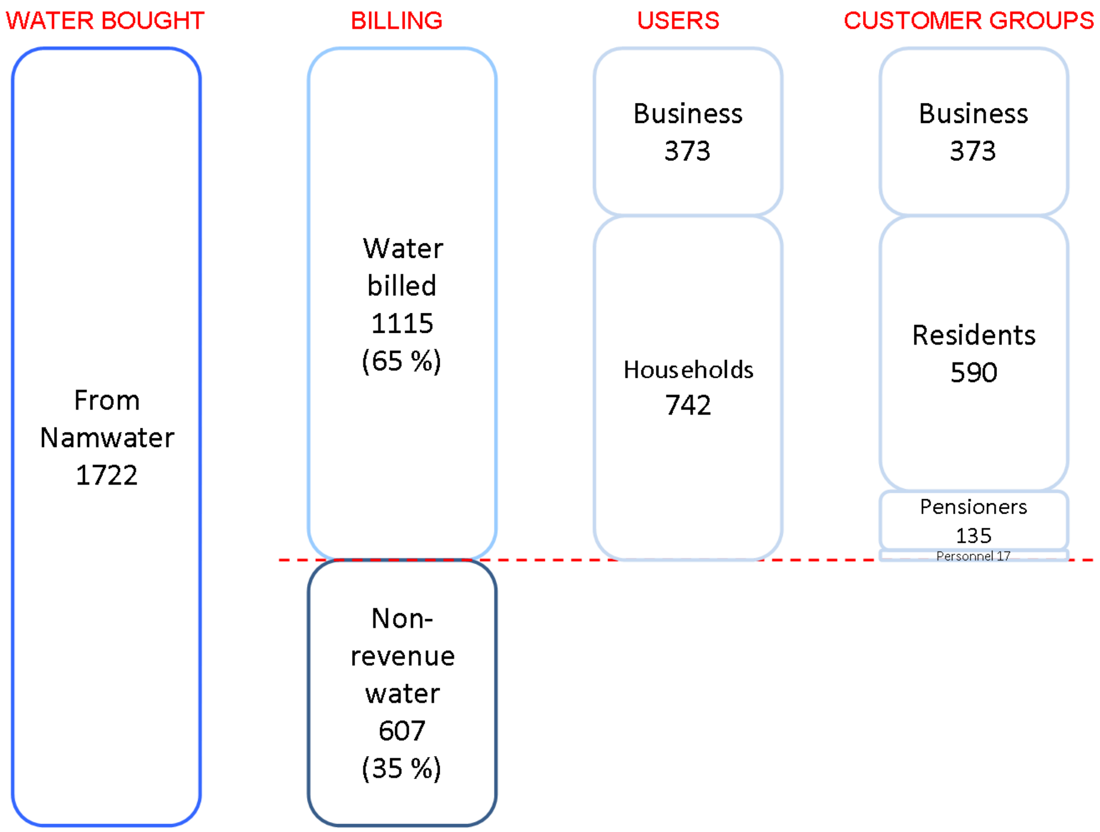


Figure 6. *Volumes of billed water in different customer groups in financial year 2011-2012. Numbers are *1000 m^3/year.*

The water distribution network is divided in 31 billing zones. Monthly water consumptions of those zones are available in municipality's accounting (*Appendix 8*). Still, consumptions of some months were missing and some meter reading mistakes were not corrected to this summary. The median consumptions per month are the most useful numbers of this data. Annual consumption calculated by the median consumptions is 1 026 000 m^3. Compared with total billed water it shows that maybe some zones are missing from the summary. Map of the zones were not available during the field work in 2012.

3.3.4 Non-revenue-water

The volume of NRW in Keetmanshoop was 607 000 m^3 in financial year 2011/2012. It is 35% of total consumption.

The easiest part of NRW to estimate is municipality's own consumption. Municipality's metered water consumption was 73 955 m^3/year in 2011/2012 (*Appendix 4*). According to meter readers all municipal consumption points have meters but in some places they are not working (Stoffel 2012). Meter reading book of municipal facilities shows that about one fourth of meters are inactive, which means that total municipal consumption is about 100 000 m^3/year. It is 6 % of total consumption. Some calculated meter inaccuracies are also included in these evaluations of unmetered use.

Magnitudes of metering errors and leaks are estimated as 315 000 m^3/year in total by generalizing measurements of certain meters or leaks. These calculations are presented later in chapters 3.4 and 3.5. Still the endpoint of 192 000 m^3/year of NRW, 11% of the total water input of network, is unknown. The volumes of metering errors and leaks may be underestimated or the unknown part may include for example thefts and accounting errors. No signs of thefts were found during studies in 2012, but local people told some stories about stealing water.

Also error in metering of water bought from NamWater may explain part of the unknown NRW. In some other towns inaccuracy of NamWater meter has been about 10%. Still, there is evidence that NamWater's meter is accurate in Keetmanshoop. Readings are comparable with NamWater's two meters on line before of reservoirs in Keetmanshoop (Calla Bonthuys 2012).

3.4 Customer water meters

According to municipality's accounting Keetmanshoop's water network includes 3791 water meters, 3518 of which are household meters and 273 business meters. Condition of 28 business meters was checked at least visually in July 2012 (*Appendix 7*).

3.4.1 Inactive meters

Because of inactive meters 8-18% of business-consumers' consumption is not measured. Highest peak of not measured water was 28% when Hospital's meter was inactive. Hospital's meter was inactive 2.5 years and the money loss of the meter's inactivity was about 1 000 000 N$ if nothing is received through negotiations afterwards. Total annual money loss caused by inactive meters varies between 300 000 – 700 000 N$ if the hospital is not taken into account. By installing new meters the loss can be reduced to under 50 000 N$ / year.

Other examples of municipality's money losses caused by inactive meters include Suiderlig school 21600 N$/month, J.A. Nel school 18000 N$/month and Canyon Hotel 5300 N$/month. Meter of Government Stores has not worked in more than two years.

Transnamib had two meters, but only one was running. In July 2012 was made a test by opening some taps in Transnamib, but both meters were at rest during that experiment. Maybe water went to the taps through the inactive meter, but third unknown joint is also possible.

Meters of J.A. Nel School, Canyon Hotel, TransNamib and Military base were replaced in October 13-14th 2012. In October 2012 new meters were ordered also to Kammalielie Primary school and Suiderlig High School. (Hamuteta 2012) Price of a good big meter

(40-100mm) is 2300-3000 N$ (Valco Pipes 2011). Compared with the money losses caused by inactive meters, the investment to new meter pays itself back in 2-15 days.

The biggest water consumers of Keetmanshoop and their billed consumptions are listed in *Appendix 3*. The list differs from Seppänen's (2008) list of 14 biggest consumers, because all of the biggest consumers were not found from municipality's logbooks in 2008. It is still possible that some big consumers are not in the list of *Appendix 3*. The appendix also includes information about inactive meters.

3.4.2 Metering errors

A container test of the water meters of four big users' showed that, at least back then, big meters in Keetmanshoop were inaccurate (*Table 1*). Meters are mainly running less than the real flow. Average error was 30.3 %. The metering errors were calculated by using the *formula 1* (page 5).

Table 1. *Metering errors of four big meters tested by 27.4l container in 2012. Leak flow is other constant flow during the test. Billed consumption is the average of financial years 2010/2011 and 2011/2012. Price of error is the financial value of extra billed or unbilled water counted by water price 10.32 $/m³.*

Place	**P.K. De Villiers High School**		**Primary School Keetmanshoop, meterS**		**Primary School Keetmanshoop, meterN**		**Kammalielie school**
Date	July 21	July 22	July 22	July 29	July 22	July 29	July 22
Flow (l)	36	36	14	15	20	23	26
Time (s)	53	32	103	100	23	26	62
Leak flow (l)	7.9	6.4	4.8	8.4	1.9	5.0	5.5
Metering error (l)	1.5		-19.5		-9.4		-6.9
Metering error (%)	**5.3**		**-71.2**		**-34.2**		**-25.0**
Billed consumption (m³/year)	3765		7077		15600		
Price of error (N$/year)	2059		-52001		-55059		

Small flow metering test succeeded only with one Suiderlig High Schools meter. The 27.4 litre container filled in 4 minutes and 2 seconds meanwhile the meter ran 1.8 litres. Corresponding metering error means 3336 m^3/year unmetered water, if the flow remained steady. This proves that metering of small flow by old big meter also underestimates water demand. However, the total volume of unbilled water caused by this underestimation is unknown in Keetmanshoop.

Only small part of meters were tested, but if revealed errors are generalized for all business-meters, errors cause 2 000 000 N$ money loss every year. Despite of uncertainty of this calculation, it’s sure that inaccuracies are a remarkable reason for unbilled water. Because of the metering errors, municipality loses for example 9000 N$/month in P.S.K. school alone. Compared with the price of a new meter, investment to new meters pays itself back in 15-20 days.

In 2012 the mean error of 15 tested household meters in Nordhoek and Westdene was 5.3% (under recording) (*Appendix 5*). The mean flow in 10 litres container test was 9.47 litres. In 20% of the properties continuous leaks were found. The mean leak was 311 m^3/year. The leaks were found in Westdene, where water consumption is the biggest, and thus the volume of leaks in households is not possible to generalize to the whole municipality. According to Seppänen (2008) the mean error of 57 tested household meters (15-20mm) was only -1.8 % (over recording).

Together inactive meters and metering inaccuracies of big consumers cause about 245 000m^3 unbilled consumption per year. It means that 40 % of big consumers water use is unbilled.

3.5 Leaks

3.5.1 Total night flow

According to NamWater’s meter minimum night flow to the network is normally 100-110m^3/h year round, which is about 50-55% of the average daily flow. This means 900 000 m^3/year continuous flow day and night. The rest 822 000 m^3/year is normal use during daytime. Lowest night flow values are 90 m^3/h (Bonthuys 2012). Filling or emptying of the reservoirs did not affect the night flow (*Table 2*).

Table 2. *Levels of municipality’s reservoirs and flow from NamWaters reservoirs to the network at night in July 25-26, 2012.*

Place	time1	time2	Level change (mm)	Flow (m^3/h)
Donkey draai reservoir (inflow valve closed)	23:12	3:36	-2	**-0.31**
Oxpass hill municipal reservoir	23:33	3:52	21	**0.94**
Namwater meter	23:30	3:30		**105**

Subtracting total NRW 607 000m^3/year from total continuous flow, 900 000m^3/year, gives a result that at least 293 000m^3/year (33%) of continuous flow is billed consumption. Because metering errors, municipal use and leaks happen mainly or partly in daytime, only 59% (356 000m^3/year) of NRW is evaluated to be continuous flow. According to this more accurate evaluation, 60% of the continuous flow is billed consumption, which means a lot of leaks in customers' water fixtures. The volume of leaks in customers' water fixtures could be calculated by subtracting two times real night use from continuous flow, but the volume of real night use is unknown.

3.5.2 Leaks in municipality's network

Tens of valves are leaking in Keetmanshoop's network. Water on ground surface and green bushes during dry season are signs of leaks (*Photo 4*). These signs exist mainly near valves, but in some places the situation looks more like pipe leaks. It seems that generally green bushes grow when the leak is small. After the leak grows also water penetrates on the surface. Despite of tens of leaks are known the municipality does not consider fixing of small or medium leaks as an important issue. Plumbers concentrate on fixing big pipe bursts and only few smaller leaks were fixed during the two-month field work of this study.

Photo 4. *Green bushes during dry season are clear signs of leaks.*

Sizes of leaks were evaluated if some kind of measurements were possible to carry out. In June 20-21st there was a pipe burst in Westdene. Two firehydrants were open the whole night to reduce pressure and help burst fixing because valves didn't work. Night flow to network was 170-180 m^3/h during the work, which means about $70m^3/h$ loss and total loss of about $800m^3$.

In June 22nd about $15m^3$/day leaking valve was found on Canon kop and it was fixed in July 23rd (*Photo 5*). In July 21-22nd the old reservoir of Canon kop filled up because of a mistake in fixing. Night flow during that night was $135m^3/h$, which means about $30m^3/h$ loss. The total volume of water lost during this leak was approximately $800m^3$.

***Photo 5**. A leaking valve on Canon Cop hill. It was possible to measure the water loss caused by this leak by a cup and a stopwatch.*

Fixing of pipe burst is daily work of plumbers. According to field experience in June-August 2012 total volume of leaks caused by bursts is approximately 3300m^3/month, about 40 000m^3/year. Water loss in pipe bursts is still possible to evaluate more accurately by going through the network input data of NamWater's continuously recording meter and analysing it during different bursts. Approximation 3300m^3/month is based on only few of this kind of comparisons.

Small leaks are mainly caused by leaking valve spindle seals. During the field work in July 2012 about 25 leaking valves were found. The approximated total number of leaking valves is about 50. A small leak is approximately 1 litre/minute on average and the total water loss of small visible leaks is 26 300 m^3 / year. In cases there were no visible water also green bushes growing near valves or pipeline were included in visible leaks. The amount and volume of invisible leaks are difficult to calculate, but an assumption is that all big leaks are visible and the volume of invisible leaks is small. All calculations of volumes of leaks include a wide margin of error, but magnitude seems smaller than it was thought earlier. However, leaks are increasing because of the aging network.

3.5.3 Night flow of big consumers

According to the night flow measurements (*Table 3*), big consumers' continuous flow is 42% of their total flow. In addition according to leak flow measurements (*Table 4*) even 55% of the big consumers' consumption is leaks. Both calculations are based on few measurements and the results are maybe higher than the existing volumes. Still, the results give a magnitude of wasted water.

The leaks are evaluated as 30% and continuous flow as 35% of the total consumption of big consumers. The continuous flow of big users is about 131 000 m^3/year metered water, increasing meter inaccuracies 86 000 m^3/year. Day use of big consumers (paid + metering errors) is (373 000m^3 – 131 000m^3) + (245 000m^3 – 86 000m^3) = 401 000 m^3.

Table 3. *Night flow of some big consumers. Löppönen (2011) measured the values in 2010.*

	July 25-26, 2012						
	evening		morning			2010 (Löppönen)	
Place	time	reading	time	reading	flow (m^3/h)	flow (m^3/h)	**Mean (m^3/h)**
Hospital	0:12	10.88	4:16	13.3	0.60	0.5	**0.55**
Police	0:26	81.09	4:23	84.75	0.93	1	**0.96**
Central Lodge						0.2	**0.20**
Transnamib, meterE	0:00	54.85	4:08	60.37	1.34	1.5	**1.42**
Dan Viljoen Clinic						0.2	**0.20**
Bird´s Mansion Hotel	0:33	57.214	4:26	58.169	0.25	0.3	**0.27**
P.S.K. Hostel	23:47	66.881	3:59	67.568	0.16		**0.16**
Total							**3.76**

Night flow of Transnamib seems to be real use because the meter stood sometimes during weekends. Also hospital's night flow may be mainly real use or filling the hospital's own reservoir, but the high night flow of police station is strange.

3.5.4 Leaks in big consumers' water fixtures

Possible leak sources of big consumers include toilets, showers, taps, irrigation systems and also pipes. Leak flow in customers' systems was measured in four schools during weekend (*Table 4*). The flow was constant in each of the cases. The leak flows were calculated by using the *formula 2* (page 7).

Table 4. *Leak flow of four big meters tested in 2012. Metering error is tested by container test (Table 1). Total leak is the leak counted with the metering error. Price of leak has been counted by water price 10.32 N$/m^3.*

Place	P.K. De Villiers High School			Primary School Keetmanshoop, meterS		Primary School Keetmanshoop, meterN		Kammalielie school	
Date	July 21	July 22	July 29	July 22	July 29	July 22	July 29	July 22	July 29
Volume (l)	100	100	50	15	25	10	30	50	30
Time (s)	669	503	712	321	298	120	156	568	419
Flow (l/min)	9.0	11.9	4.2	2.8	5.0	5.0	11.5	5.3	4.3
Flow (m^3/y)	4714	6270	2215	1474	2646	2628	6065	2776	2258
Metering error (%)		5.3		-71.2		-34.2		-25.0	
Leak with error (m^3/y)	**4463**	**5936**	**2097**	**2522**	**4529**	**3526**	**8136**	**3471**	**2823**
Price of leak (N$/y)	46058	61260	21641	26027	46739	36388	83964	35821	29133

Checking of water fixtures of the biggest consumers was done only in J. A. Nel Senior Secondary School where toilets and bathrooms were checked in Jul. 22, 2012. Girl's hostels bathrooms and toilets were in bad condition. Downstairs, two toilets were fully leaking. Upstairs big leaks in one shower and in two bathtubs were found. 5-10 of the taps were leaking a bit in both toilets and almost all taps were too difficult to turn completely off. Also some pipes outside of the building's northern end were leaking. Approximated total leak of the hostel was 12m^3/d. This may be one of the worst situations in Keetmanshoop's schools, but it is justified to assume that other schools have same kind of leaks.

3.5.5 Night flow of households

Continuous flow of households was calculated for determining water balance and evaluating the magnitude of leaks in households' water fixtures. The leaks in households' water fixtures were not measured by own studies but calculated by using the data of other studies.

The day use of households can be calculated by subtracting all other day use from the total day use. Other day “users” are big consumers, municipality and leaks. Big consumers’ day use is 401 000 m^3/year.

In water balance calculation leaks in municipality’s water fixtures are evaluated to be 30% of total water use, as the leaks of big consumers. Continuous flow of municipality’s own water use is evaluated to a little bit less, 28 %, because normally there is a little real water use at night and some leaks exist only in daytime when irrigation valves are open. Municipality’s own use at daytime is

(1-0.28) * 100 000 m^3/year = 72 000 m^3/year.

According to preliminary analysis of NamWater’s continuous recording of Keetmanshoop water network input pipe bursts are more common during daytime than at night. 75 % of big leaks are evaluated to be during daytime that means 20 000 m^3/year use flow and 20 000 m^3 continuous flow.

The day use of households is then

(822 000 – 401 000 – 72 000 – 20 000) m^3/year = 329 000 m^3/year.

This means (742 000 – 329 000) m^3/year = 413 000 m^3/year continuous flow for households. The calculation has a wide margin of error but shows the magnitude of leaks in households.

Still, irrigation is one part of the night flow and the real night use should be subtracted from continuous flow to get the volume of leaks in customers’ water fixtures. The irrigation is maybe the biggest part of real night use. The volume of leaks in customers’ water fixtures could be calculated as

continuous flow - real night use * 2 = leaks in customers’ water fixtures,

but the volume of real night use is unknown.

Irrigation is the biggest in Westdene, where 3 streets with about 100 households in total were walked through at one night in September 2012 and only four households had visible irrigation. Still, according to this study the volume of irrigation is impossible to evaluate. As the pool is filled and the main municipal irrigation is done in daytime, opening and closing of swimming pool doesn’t affect the volume of night flow (Jansen 2012).

The results of measuring leak flow and night flow and calculating customers' percentage of night flow show that about half of customers' water is wasted because of leaks. Despite wide margins of error, the magnitude of this result is reliable because of quite good reliability of night flow percentage calculations and similar results of all three studies.

3.6 Water balance of Keetmanshoop

Water balance of Keetmanshoop is shown in *Figure 7*. According to these calculations municipality loses 4 000 650 N$ from 537 000 m^3 of water per year counted by Nam-Water's tariff 2011-2012. In addition, the unpaid bills cause economic losses and extra work for municipality. When looking the situation from the perspective of all water users, it seems that about half of water is lost through leaks in one of the driest countries in the world.

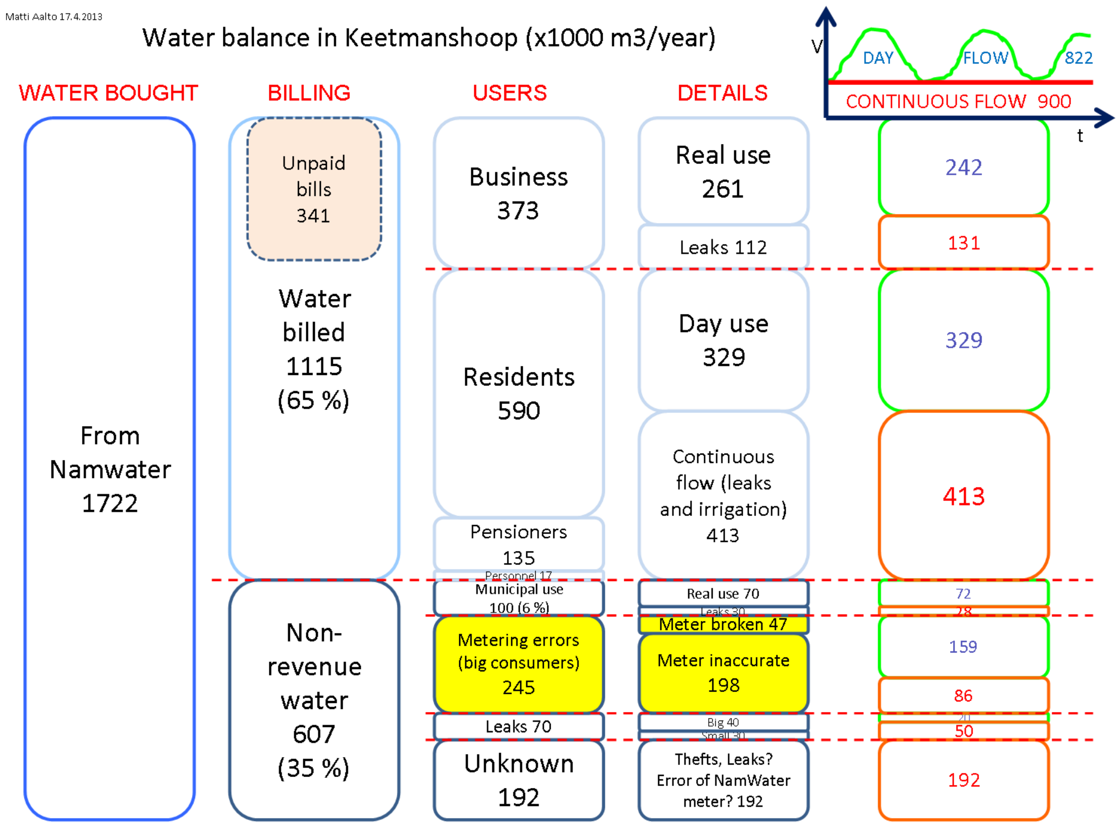


Figure 7. *Water balance in Keetmanshoop (x1000 m^3 / year). Numbers are based mainly on year 2011-2012 and partly year 2010-2011. "Unpaid bills" is an average of years 2008-2012. Detailed calculations are explained in their own chapters.*

Numbers in *Figure 7* are best approximations and margins of error are quite big in columns "Details" and "Continuous flow", and also in contents of NRW. Especially the continuous flow of households seems to be big, but direct evidence about it does not exist.

3.7 Reservoirs

Changes on water level of municipality's reservoir in Oxpass hill were measured on the weekend in 25th and 26th August 2012. Levels were measured at 4 am and at 1 pm. Water level dropped only by 2cm in both days, which means that the reservoir was not needed to store water during those days. The result can be generalized for whole year meaning that the reservoir may be useless.

The locations of some pipes and valves of Donkie draai reservoir are unknown, which make difficulties for the maintenance of the reservoir and the network, testing the network and cleaning the reservoir.

According to NamWater (Bonthuys 2012) municipality should have a chlorine meter, price of which is about 3500 N$. Chlorine may need to be added to water of Donkey draai, but then also knowledge about working with chlorine is needed (Bonthuys 2012).

3.8 Finance

Water sector has an own subsection in municipality's budget. The result of municipality's water sector's financial year 2011-2012 was negative (*Table 5*). 2010-2011 it was positive.

The budget consists mainly as water purchase and public sales. Water purchase has been 81-87 % of total outlay and public sales have been 94-95 % of total income in 2010-2012. Some income is also got from departmental sales and other smaller sources. For salaries, wages and allowances, 2 118 418 N$ (14 % of total outlay) in 2011-2012 was used. For fuel, 101 051 N$ (0.7 % of total outlay) was used. Other outgoings were smaller.

Table 5. *Summary about financial statements of water sector. Data collected from votes 2010-2011 and 2011-2012.*

	2010-2011	**2011-2012**
Water purchase	10879857	12301646
Public sales	12477197	12868475
Total outlay	12607467	15173120
Total income	13174139	13585837
Profit	566672	-1587283

Water billing in Keetmanshoop is based on basic charges and consumption charges (*Table 6*). Basic charge differs between consumer groups, but consumption charge is same in all groups. As a whole, basic charges are 14% of total sales. Values in *Tables 5* and *6* differ from each other as in *Table 5* the sums are received payments and in *Table 6* they are billed amounts.

Table 6. *Water sales in Keetmanshoop in 2011-2012. Sums are billed amounts.*

	Basic charges			Consumption			Sales
Group	**Consumers**	**Fee (N$)**	**Total (N$)**	**(m^3/y)**	**(N$/$m^3$)**	**Total (N$)**	**Total (N$)**
Business1	273	173.31	568443	372723	10.32	3846501	4414944
Business2	1	40.37	484	113	10.32	1166	1651
Residental	2667	40.37	1291945	589975	10.32	6088542	7380487
Pensioners	766	0	0	134780	10.32	1390930	1390930
Personnel	84	18.15	18313	17493	10.32	180528	198841
Total	**3791**		**1879186**	**1115084**		**11507667**	**13386852**

Water tariffs have increased steadily during the last ten years (*Figure 8*). Municipality's profit has also increased until 2011, but it is still seldom enough for maintenance costs. In 2011-2012 municipality bought water for 7.45 N$/$m^3$ and sold for 10.32 N$/$m^3$.

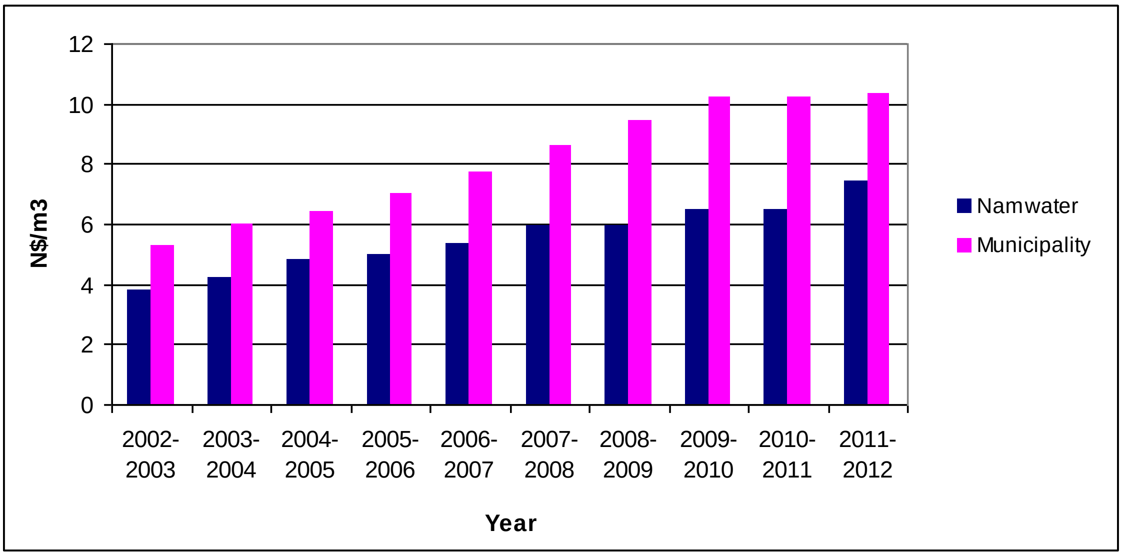


Figure 8. *Development of water tariffs in Keetmanshoop in 2002-2012.*

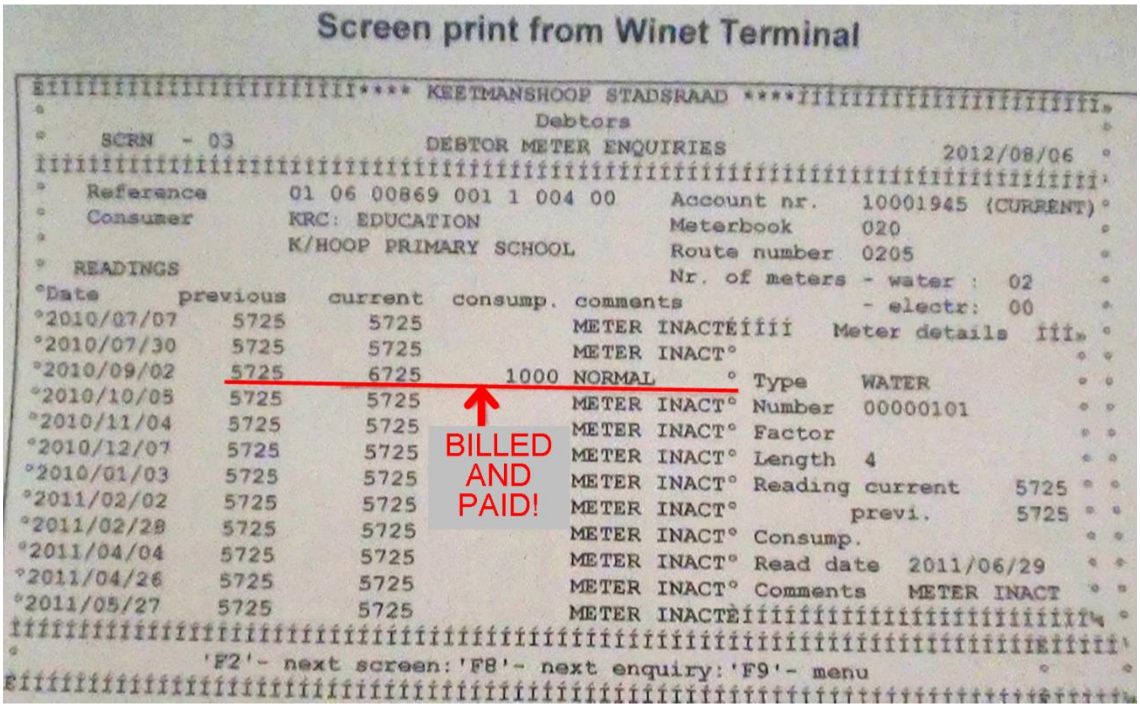
The sum of unpaid bills is increasing in Keetmanshoop (*Table 7*). At the end of June 2012, the sum of unpaid bills older than 120 days was 2 607 359 N$. The number of debtors was 4022 and the mean bill was 648 N$. Average annual increase of the unpaid bills is 26 % of total sales in 2011-2012. One reason for the increasing amount of unpaid bills is increasing unemployment (Visagie 2012).

Table 7. *Unpaid water bills in Keetmanshoop in years 2009-2012.*

	Unpaid bills (N$)
Current 30.6.2012	**33604547**
Current 30.6.2011	26869749
Current 30.6.2010	25581086
Current 30.6.2009	19633779
Average increase ($/year)	**3492692**
Average increase (m^3/year)	341751

According to municipality’s finance sector inactive meters cause economic losses and extra work for billing. Normally negotiations with customer afterwards do not lead to paying and all unmetered water is loss for municipality (Paulton 2012). Also Visagie (2012) told about the same problem. According to Visagie (2012) every household is in billing register in Keetmanshoop.

Billing is based on meter readers’ logbooks about readings. Billing is mechanical work for secretaries and they seldom check the reliability of readings (*Figure 9*). The *Figure 9* is a striking example of a mistake in meter reading. The meter has been inactive for a long time. The reader has made one number mistake in meter reading. The sum was billed and consumer paid the bill. Nobody noticed the mistake. If the bill is bigger than normally, almost always customers notice the mistake, leading to bill correction. In the situation of *Figure 9* no bill was sent for several months. Nobody had paid attention to the inactivity of the meter, which was really unfortunate.


Screen print from Winet Terminal

KEETMANSHOOP STADSRAAD
Debtors
SCRN - 03 DEBTOR METER ENQUIRIES 2012/08/06

Reference 01 06 00869 001 1 004 00 Account nr. 10001945 (CURRENT)
Consumer KRC: EDUCATION Meterbook 020
K/HOOP PRIMARY SCHOOL Route number 0205
READINGS Nr. of meters - water : 02
- electr: 00

Date	previous	current	consump.	comments
2010/07/07	5725	5725		METER INACT
2010/07/30	5725	5725		METER INACT
2010/09/02	5725	6725	1000	NORMAL
2010/10/05	5725	5725		METER INACT
2010/11/04	5725	5725		METER INACT
2010/12/07	5725	5725		METER INACT
2010/01/03	5725	5725		METER INACT
2011/02/02	5725	5725		METER INACT
2011/02/28	5725	5725		METER INACT
2011/04/04	5725	5725		METER INACT
2011/04/26	5725	5725		METER INACT
2011/05/27	5725	5725		METER INACT

Meter details
Type WATER
Number 00000101
Factor
Length 4
Reading current 5725
previ. 5725
Consump.
Read date 2011/06/29
Comments METER INACT

'F2'- next screen: 'F8'- next enquiry: 'F9'- menu

Figure 9. *Screen print of Keetmanshoop Primary School's consumption in 2010/2011 from municipality's accounting.*

3.8.1 Prepaid water meters

Prepaid water meters seem to be a poor solution for getting customers to pay their bills. Investing in prepaid water meters includes a high risk, because their price is high and quality is not always reliable. Most of consultants are absolutely against pre-paid water meters because there are so bad experiences about them in many places. At least pre-paid meters need more maintenance than normal meters.

It is important to count payback time carefully before investing in prepaid water meters. The price of a prepaid water meter for households is about 2400 N$ and the price of normal water meter is 400 N$. There are 3517 household meters in Keetmanshoop. Tariff of water bought is 10.32 N$/m^3 and tariff of water sold is 7.45 N$/m^3. Domestic consumption in Keetmanshoop is 742 428 m^3/year. According to *formula 3* (page 10) it takes 3.5 years only to get the investment back if prepaid water meters are bought for all domestic customers and all profit is used to payback.

But in practice all this profit is needed to cover salaries, spare parts and other operation and maintenance costs in water sector. During some years the income has not even covered all these necessary expenses and thus there has not been any money left for additional investments. If the same calculation is made per suburb, for example for Tseiblaagte, it is impossible to get the investment back before it is time to replace the meter. In Keetmanshoop water meters are replaced every 15th year on average (Seppänen 2008).

Payback time is possible to calculate also from the perspective of unpaid bills. The total amount of unpaid bills is increasing about 3 493 000 N$/year and the total amount of customers is 3791. If all unpaid customers are going to pay for prepaid meter installing, the payback time of 2400 N$ meter is about 2.5 years.

There are also big customers who are not paying their bills in Keetmanshoop causing the big difference between the two calculations. One possibility is to put new prepaid meters only for customers, who had not paid their bills.

3.8.2 Investing in the maintenance of network

In earlier chapters have been calculated money losses of different problems in maintenance of network. These expenses are comparable with water network manager‘s salary. For example, with 15 000 N$/month it is possible to hire a skilled manager. Yearly costs of the manager are 180 000 N$.

Compared with water prices, 180 000 N$ means 24 200 m^3 water bought from NamWater, which is 1.4% of total water demand. If the manager succeeds in reducing NRW 1.4 percentage points, he has earned his salary permanently. For example compared with 300 000 – 700 000 N$ yearly loss of inactive meters, the manager earns his/her salary back in short time only by ensuring that inactive meters are replaced. That kind of work takes only short part of working hours so he/she could mainly do other things to reduce municipality’s financial losses in water sector.

4 Management Plan

4.1 Water distribution map

The water distribution map is in most parts reliable enough for everyday use of plumbers. Updating the map is still important and it is most easily done in connection with maintenance work. The map's reliability increases steadily if corrections made always when plumbers notice any discrepancies. The map is never ready as the network is fixed all the time and the changes should be updated on the map continuously.

Educating plumber teams to use the map is the first step for its everyday use. Real work situations are the easiest way to carry out the educating. Trainer may be with a team for example one week. First it is the most effective to educate the plumbers who are interested in learning. The trainer may be an engineering student from Namibia or from Finland if none of the staff members is familiar enough with using the map. However, the student has to be familiar with using the map also.

Photo 6. *Water distribution map is an important tool in network management. A few persons are used to use it in Keetmanshoop at the moment.*

Water sector coordinator should have an AutoCAD on his/her computer and the coordinator should draw the updates on the map. Often it is easiest that the coordinator also sees the situation in the field, but it is also possible that plumbers draw the updates on paper and give the paper to coordinator.

Inspection of fire hydrants during pipe bursts, when some valves are closed, is one possibility to get information about connections. Opening a hydrant shows if there is water or not. If not, the hydrant is connected to water supply only through pipes that are closed. If water flows and pressure is normal, the hydrant is not connected to the closed pipes and water to it comes from another way. Same inspection is also possible to do fully or partly from taps.

Plotting on map the places where people call complaining low pressure or lack of water during pipe bursts is also a good way to get additional information on water flows in the network. The system is the same than in the hydrant inspections. In smaller areas it is also possible to close some valves for a while just for testing when there is not pipe burst.

New extensions should be updated on the map during installation or at least immediately after construction has been completed. Locations of pipes and valves should be checked in the field because they may differ from plans.

The map is not only showing the locations of pipes, valves and fire hydrants, but its function is also to store all other important information about the network, like the quality of valves, pipes and hydrants. The advanced map can be called water network management system. For certain type of new information, or for certain new project, it is possible to create new layers on AutoCAD map.

Modelling of the network was planned to be a part of this work, but it was left out because there were still several discrepancies in the map. Additionally there are good reasons to suspect that some valves are unintentionally closed and thus water does not flow as the map would suggest. In the future the modelling may be possible if the map becomes more reliable.

4.2 Dividing the network in zones

Network must be dividable into smaller sections to ensure effective maintenance work and to reduce wide interruptions in water distribution. Replacing the valves should be started zone by zone and the network should be tested when a zone is ready. Possibly fewer connections do exist than drawn on the map and in some zones fewer valves are needed than on the plan. Also some connections should be added to ensure better water distribution in exceptional situations. Plumbers are motivated to replace valves, which improves operating of the project. Municipality should always have a couple of different sized valves in stores. If the map receives important updates, the plan of dividing the network in sectors should also be updated.

Dividing the network in zones enables metering of water consumption per suburb or even smaller areas. In first case it is the most useful to measure consumption per suburb. The suburb water meters would help to locate areas with high night flow, which increases possibilities to localize leaks. The total suburb consumptions may also be possible to compare with billed consumption per suburb (*Appendix 8).* Still, the comparison requires more complete data of the billing zones.

Sometimes should be taken into account that water may flow either direction and the meter should record both flows. According to current knowledge 12 meters would be needed for measuring consumptions in all 5 suburbs. For example for Krönlein one meter may be enough in current situation. Connections between suburbs should be clarified and tested before installing suburb meters.

4.3 Water use in Keetmanshoop

4.3.1 Metering water input

To ensure the correctness of the flow measured by NamWater's meter, it is possible for the municipality to buy an own meter, which is installed in series with NamWater's meter. It has to be remembered that the meter also needs maintenance. Another possibility is to hire a company to test NamWater's meter accuracy every now and then.

If NamWater's meter gets broken and billing will be based on estimate, evaluating the consumption should be more exact. Big estimating errors can be avoided by using long term historical data. For example *Figure 4* of this work gives a possibility to evaluate the consumption on the basis of earlier years.

4.3.2 Non-revenue-water

The most important objective for the municipality is to reduce the volume of NRW. Methods for this are explained in their own chapters (4.1-4.2, 4.4-4.8). Future research to determine the composition of NRW more accurately is also important.

It is possible to reduce municipality's own water use by checking the condition of water fixtures and fixing the leaks. Leaks exist for example in camping area. Replacing inactive water meters improves possibilities to follow water consumption. Searching possibilities to use borehole water for all irrigation and for swimming pool may give a remarkable possibility to reduce water costs of the municipality.

4.4 Meters

Functioning meters are the fundament of billing and non-operating meters should be replaced immediately. Meter readers should report about broken meters to their foremen. Billing secretaries should also inform technical sector if they notice that consumption has been zero or exceptionally low for a month. It is possible to have an automatic warning in the computer's billing program of irregular water consumption for either exceptionally low or high values (Hardley 2013). In August 2012 there were inactive meters at least in J.A. Nel School, Suiderlig High School, Canyon Hotel, Government Stores and Transnamib (second meter).

All inaccurate meters should be replaced immediately when the inaccuracy is noticed. According to container tests in 2012, inaccurate meters are: both meters of P.S.K. (schools meters, hostel not tested), the meter of Kammalielie School and one meter in Suiderlig High School. They should be replaced and more testing of other meters should be done. Plan for systematical testing of meters is recommended.

Testing meters by container test is possible when there is no water use in the building (night, sometimes weekend). Meter testing is also possible to carry out by connecting another meter in series with the tested meter. Decreased consumption compared to earlier readings is another way to notice inaccuracies. For example, the consumption in J.A. Nel School was 25614 m^3 in 2008 (Seppänen 2008), but in 2012 it is only 4500 m^3/year. Maybe the meter is inaccurate. Another possibility is that there are many meters in the school and information of some meter was not found from accounting in 2012. In any case the reason of decreased consumption should be solved. Also in this case an automatic warning in the computer's billing program of irregular water consumption would be useful.

Even some quite new meters seemed to be inaccurate. Quality must be taken into account when buying new meters or fixing old ones. More expensive meter may give its price back soon by being more accurate and lasting longer in good condition. The accuracy of different types of meters should be clarified and only good quality meters should be bought. The quality differences were not studied in 2012.

4.5 Leaks

4.5.1 Leaks in municipality's network

Leaks cause financial losses all the time (*Table 8*). Fixing of leaks should be done more, faster and better. Also small leaks are expensive for municipality in long term. Better equipments often pay their price back when the leak is completely fixed and the same place is not broken again after a short period. Every leak that is noticed should be recorded. One possibility is to create a new layer for leaks on AutoCAD based water distribution map.

Table 8. *Cost of water loss through different sizes of leaks. Costs are counted by NamWater's tariff 7.45 \$/m^3 in year 2011/2012.*

Leak				Cost	
l / min	**l / h**	**m^3 / day**	**m^3 / year**	**N\$ / day**	**N\$ / year**
1	60	1.44	525.6	**11**	3916
5	300	7.2	2628	**54**	19579
10	600	14.4	5256	**107**	39157
50	3000	72	26280	**536**	195786

Green bushes in dry season are maybe the best indicators of leaks in Keetmanshoop. The bushes on pipelines should be systematically removed and leaks fixed. At the same time, it is possible to estimate the volume of water loss in leaks.

According to Löppönen (2011) and many local water experts, high pressures cause pipe bursts and water losses in some parts of the network. Pressure control by pressure valves should be one of the next steps in improving the network. There are many possibilities for pressure control and also with quite simple control has been achieved high savings (Mckenzie & Wegelin 2010). Often the use of the most basic equipment may be the best solution (Mckenzie & Wegelin 2011).

Pressure control has remarkably reduced water losses in South-Africa. For example, in Khayelitsha 9 000 000 m^3/year was saved that reduced 40% total water demand. In other case in the city of Cape Town 2 400 000 m^3/year was saved and the payback time of the system was less than 6 months. In Sebokeng 1 000 000 m^3/year was saved that reduced 25% total water demand. (Mckenzie & Wegelin 2010)

Recording pressure meter would be useful in solving pressures and pressure fluctuation in network. Connected to a fire hydrant the pressure recorder is possible to be left for one day or couple of days to record pressures in high and low consumption hours.

4.5.2 Leaks in customers' water fixtures

Fixing leaks in customers' water fixtures could remarkably decrease water demand in Keetmanshoop. According to water balance calculations, leaking water fixtures seemed to be common in Keetmanshoop, but straight evidence was got only from J. A. Nel Senior Secondary School's Girls' Hostel. The Hostel's water fixtures should be replaced. The situation was reported to the Ministry of Work and Transport of Karas in September 2012.

Several other properties have same kind of leaks and it would be useful to check toilets, showers and taps of biggest consumers, such as schools and police. Reducing leaks in customers' water fixtures reduces the total need of water, reduces water lost by metering inaccuracies, and helps customers to cope with their bills. Customers should be informed about the possibilities of reducing leaks and water use.

4.6 Water balance of Keetmanshoop

Estimating water balance of Keetmanshoop is important background knowledge for controlling water losses. In this work the water balance has been estimated as accurately as possible according to available data. Still, margins of error are wide in those estimations, and the water balance should be updated, if more reliable information is available. Many research methods of this work are usable tools in estimating the water balance in the future.

4.7 Reservoirs

In Donkie draai, digging pipes visible and putting new valves to right places are the next steps to improve the reservoir's reliability. Changes must be updated on the water distribution map. Isolating the whole Donkie Draai out of network, for example for washing, should be possible. Also measuring night flow to Krönlein and Tseiblaagte by using only Donkie Draai should be possible.

Water level measurements of municipality's reservoir on Oxpass Hill would be useful to do also on Mondays when water demand is the greatest. Levels should be measured every second hour from morning to evening. This reservoir may be useless. Fixing the bypass line and leaving the reservoir out of use decreases maintenance work of municipality. Too long delay of water in the reservoir may be the reason of low chlorine levels in Southern Westdene (Bonhuys 2012, NamWater 2012b), and low chlorine levels may also cause health problems. Leaving the reservoir out of use should be tested.

4.8 Finance

Current billing system is not handy. Newer system or more efficient use of current system increase possibilities to follow water consumption and billing. Clear system helps to find mistakes in billing, leaks in network and inaccuracies in measuring. An economy student from Finland or Namibia could possibly be utilized in developing a more effective billing.

The same system that is currently used in Keetmanshoop is used also in Ondangwa. For example, the system reports automatically if a meter reading differs remarkably from earlier readings and function of the meter should be checked (Hardley 2013). Also summaries of water demand and billing and unpaid bills should be got easily. Sorting of different types of consumers should be possible to do automatically, for example, according to consumption volume or location. These kinds of summaries make controlling of water sector easier and reduce mistakes in billing. Nowadays finding the data is difficult in Keetmanshoop. Also, numbers of different summaries like vote, summary of water sales and summary of unpaid bills does not match with each other. These summaries should be easily comparative.

4.8.1 Prepaid water meters

Prepaid water meters are not a good investment in current situation. The most important thing is to get the maintenance of big meters working. When the maintenance of current meters works perfectly it may be possible to get also the maintenance of more complex prepaid meters working. In any case, if prepaid meters are installed, the only possibility is to put new meters only for customers who had not paid their bills, as it is uneconomical to replace all existing meters with prepaid meters.

Staff of Swakopmund (Demasius 2012) told good experiences about cutting off water immediately from everyone having unpaid bills. When starting up the system they got negative feedback but the situation calmed down quite soon. Afterwards they were surprised that the total amount of negative feedback was so small and the system started to work well. Maybe this kind of strict system would be the best solution in Keetmanshoop, too.

One possibility for unpaid bills could be magnetic valves for customers who have not paid their bills regularly. The valves can be closed so that maximum flow is about 0.1 litre/minute ($5m^3$/month). This solution does not leave customers totally without water, but encourages them to pay their bills.

It is also possible to change the water billing system progressive by giving the first $5m^3$ for free for everyone. The price of next cubic meters could be raised a bit from current rate. Government of South Africa established "free basic water" policy in 2001. The first $6m^3$ per month is delivered by free in many regions. The system has been controversial but the basic idea has worked well despite of some problems in implementation (Muller 2008, Szabo 2010). Even the progressive billing has helped many poor families, the water bills of some poor consuming more than $6m^3$ have raised because of too high prices of next cubic meters (Bond 2004). The progressive system must be organized so that only prices of high consumptions may raise remarkably. One problem of "free basic water" is that households with no water connection at all are really unequal if their neighbours get some water for free. Still, with good implementation, "free basic water" helps to achieve social equity and may decrease the amount of unpaid bills.

4.8.2 Investing in maintenance of network

Calculations of comparing municipality’s money losses and the salary of water sector coordinator show clearly that investing for planning is profitable. Permanent water sector coordinator should be hired, and also hiring other engineer or technician for water sector could be worthwhile. Improved water sector management and water supply significantly increase the productivity within economic sectors (SIWI & WHO 2005).

Education of employees has been identified as an important part in reducing water losses (Kovac & Charalambous 2012, Dickinson 2009). Getting the plans into practice requires education of employees also in Keetmanshoop. Hiring a water sector coordinator is a good start for the education project. At first he should be educated to monitor water balance of the municipality, update the water distribution map and to plan the network dividing to sectors.

Some plumbers are also interested in educating themselves. The most important topics to teach to plumbers are using the water distribution map and updating it. Map using training for plumbers was started by a three days session in September 2012 (Hamuteta 2012). Meter readers should be taught to report about broken or possible inaccurate meters and maybe also to test the functioning of meters.

Quality of equipment is important in maintenance of network. Investing in good quality equipment and spare parts almost always pays itself back in long term. Enough valves, meters and other basic equipment should always be in municipality’s stores. Important valves and meters should be replaced immediately if they are broken. In other case the price of the equipment is lost quite soon through water losses and extra work.

5 Conclusions and evaluation

5.1 Conclusions

The municipality of Keetmanshoop has a lot to do to get its water distribution system reliable and easy to use. Though, Namibia is one of the driest countries in the world, water distribution is technically quite easy to implement at least for Keetmanshoop. Rainy season gives enough water to reservoir lake for whole year, soil is sandy and easy to dig and pipes do not need to be dug deep because temperature is always on plus degrees.

Even if there are tens of technical problems with water distribution, some of them are easy to solve. For example, replacing an inactive meter takes only some hours and few hundred dollars per meter, and it increases municipality's income with thousands of dollars immediately after replacing. After the tens of inactive and inaccurate meters are replaced, municipality will have more resources to improve its water distribution network systematically. Replacing and adding important valves should be one of the next steps. Workable valves give also financial advantages by simplifying the maintenance of the water network.

As calculated in this study, investments in planning are profitable. With such big water- and economic losses like in Keetmanshoop, a water engineer can find even 10-20 times more savings for municipality than the municipality invests in his/her salary. At least in 2010-2012 the salary would have been possible to earn by only ensuring that 20 biggest water meters are reliable.

Planning has been in a small role in water network management in Keetmanshoop. Still, the water sector has a good chance to lead the way of effective planning also for other fields of society. Everyone's need of water, big budget of water sector compared to other fields and several improvement possibilities with current budget give a good background to operate. Simple calculations of payback time prove the importance of investments also for policymakers.

After first steps of hiring a water sector coordinator and replacing the inactive water meters, replacing the most important valves and taking the water distribution map in use are next in line. When suburb water meters and pressure reducing valves are installed, it is time to start systematically rebuilding the network road by road.

High NRW is common also in many other places in the world, and similar methods can be utilized when tackling with the high NRW. First, the easiest improvements and investments in planning should be done, and then gradually proceed forward to more complicated action. Simple calculations of money savings are almost always the easiest way to reason the importance of investments. Presented methods of calculating water balance in Keetmanshoop are also possible to use elsewhere. Even low accuracy calculations show the magnitude of different losses, which often are sufficient arguments for decision makers to start developing the water distribution system.

5.2 Evaluation of the research

Planning to work in foreign county in the other side of the world was challenging, even quite good information about the water distribution system of Keetmanshoop was available. I had good prior reports of researches made in Keetmanshoop. I also got information how culture and political issues in Keetmanshoop differ from Finland. Prior information was correct except few things. The main problem was the water distribution map that was not at all as reliable as thought.

My first plan was to measure pressures and model the network for installing pressure reducing valves, but I was prepared for changing my research plan if any problems occur. The water distribution map is so important part of water network management that I needed to change the plan and use lots of time to update the map. Measuring water pressures in the network proceeded slowly because I did not get workable equipment and I used my time with other things like updating the map, analysing the reliability of water meters and collecting data about water users. It was a good way to try to start many studies during first two weeks and then concentrate in those that were most important and possible to carry out during two months field work.

Because of inaccuracy of the map and broken pressure measuring equipment, my first plan of concentrating in a single part of water network management changed to general perspective. Even two master thesis of general water distribution in Keetmanshoop were done before, my work with more practical approach is a useful supplement of earlier studies. Maybe with help of this work’s supplementary and more practical perspective in water network management, future studies are possible to concentrate in more detailed things.

One main aim of my field work was to find out some simple and viable improvements in water network management in Keetmanshoop. I did not want to give only a research report but also wanted that something really happen in practice during my visit or immediately after it. Concentrating in this practical part was a right decision even it reduced my resources to concentrate in doing deeply scientific master thesis. Some improvements were done as a result of my studies and locals kept many of my ideas important even recommended improvements are mainly not implemented yet.

As a whole, I am satisfied with this project and the results achieved in limited time. I liked the work and got good experience of working in Africa. Planning, field work and reporting succeeded as well as I thought. In fact, it is strange that afterwards I have not noticed things that should have been done differently. Even the report could be better with paying attention to needs of staff of Keetmanshoop and on the other hand filling the requirements of master thesis, it is still valid for both purposes.

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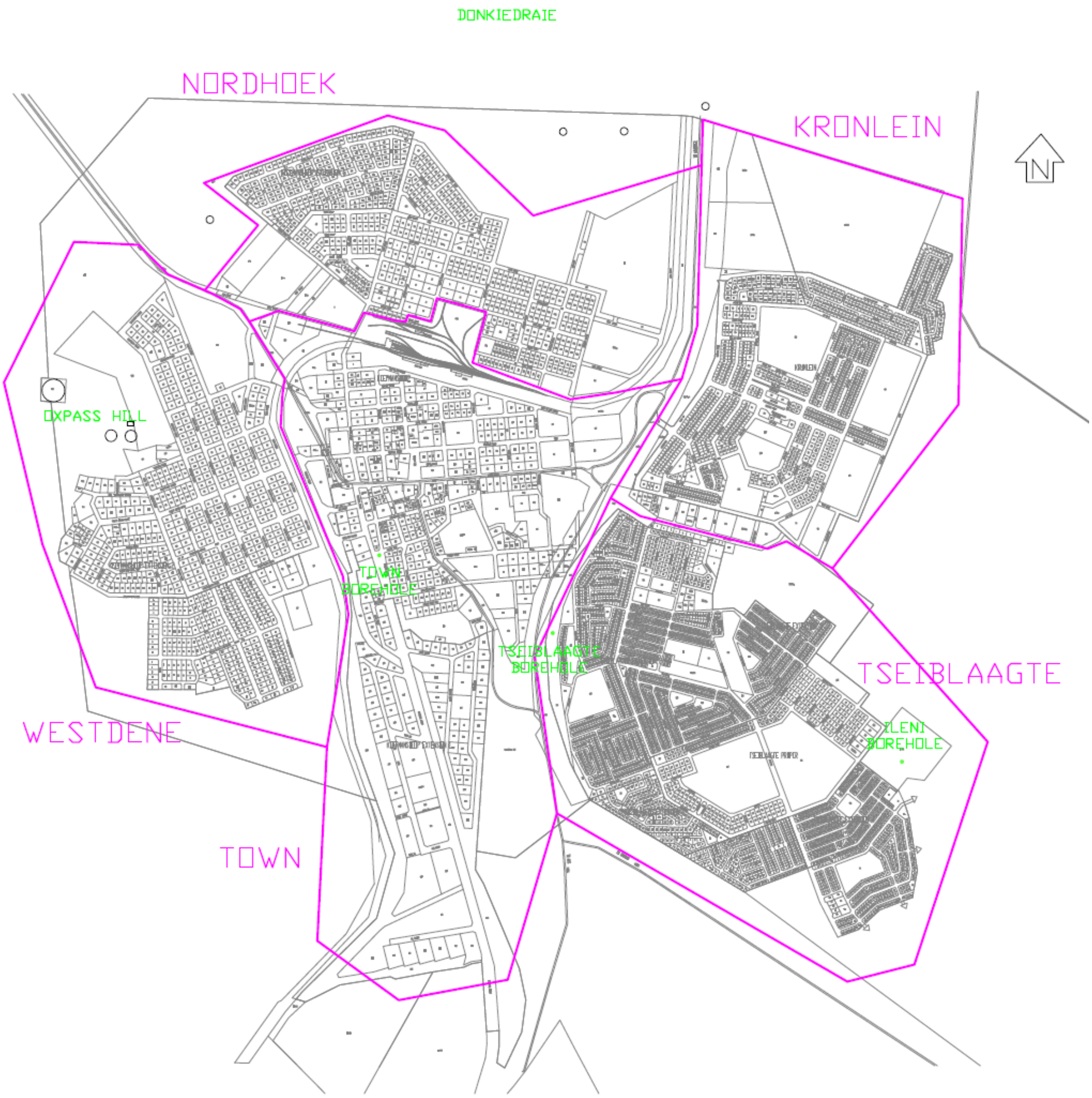
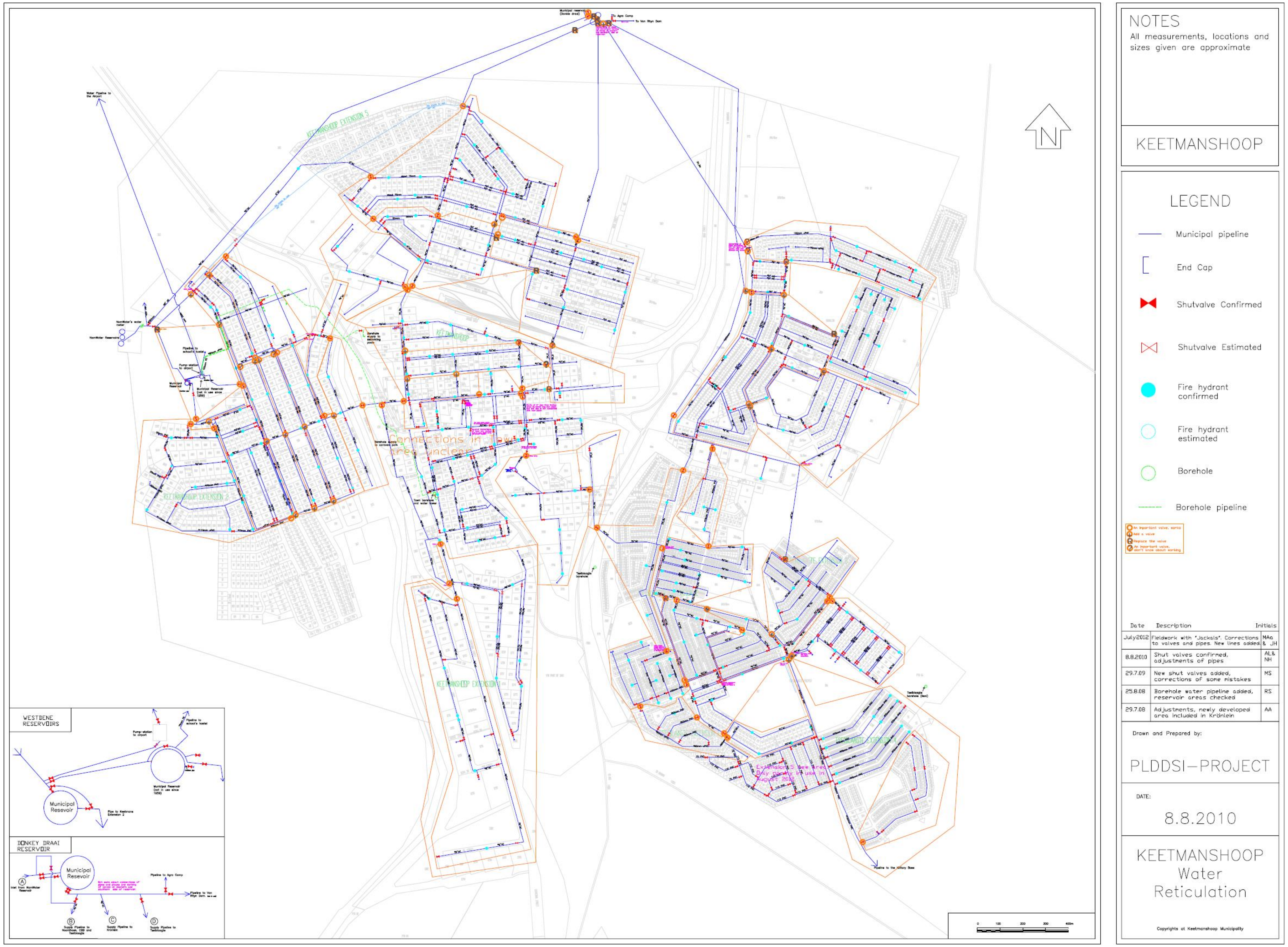
Appendix 1: Map of Keetmanshoop



Appendix 2: Keetmanshoop water network divided in zones



Appendix 3: The biggest water consumers of Keetmanshoop and their billed consumptions

The list is not comprehensive, but probably all of 15 biggest consumers are on it. Billed (metered) consumptions are checked from municipality's accounting. Numbers are bolded, if the meter has been inactive during the year. Consumptions of 2008 are from Seppänen's (2008) list of 14 biggest consumers. Unmetered consumptions (two last columns) are evaluated on the basis of metered months in 2008-2012. Some consumers have more than one meter (many consumption points).

Consumer (meter and name)		Billed consumption (m^3/year)			Meter inactive (m^3/year)	
		2008	2010/2011	2011/2012	2010/2011	2011/2012
1	Hospital	62435	**0**	**7747**	40800	33053
2(1)	P.K. De Villiers Boys Hostel		18538	**13657**		3777
2(2)	P.K. De Villiers SSS	33703	**4131**	3022	376	
2(3)	P.K. De Villiers Girls Hostel		8016	9332		
3(1)	Suiderlig Hostel		9823	5929		
3(2)	Suiderlig School (536)	29981	1997	1304		
3(3)	Suiderlig School (741)		25121	**5717**		**19404**
4(1)	P.S.K. School hostel (456)		7171	6546		
4(2)	P.S.K. School N (101)		**1000**	**8727**	14600	6873
4(3)	P.S.K. School S (264)		5571	8583		
5(1)	J.A.Nel School (8)	25614	3087	**1286**		1801
5(2)	J.A.Nel School (185)		1435	**598**		837
6(1)	Police station		11010	10145		
6(2)	Nampol Police	16809	933	760		
6(3)	Police Barracks (Tseiblaagte)		1584	1848		
7	Prison	12587	12910	11664		
8	NIMT		9571	8815		
9	Min. of Fin. Inland&Rev.		7672	3901		
10	Multipurpose Youth Center	5520	6811	**5208**		**1100**
11	Ons Tuiste Old age home	5526	6746	5966		
12	Canyon Hotel	8272	**5616**	6150	991	
13	St. Mathias PS	2995	5494	7789		
14	Transnamib Station building	5749	5407	8655		
15	Daan Viljoen Klinic	4674	5283	9459		
16	Jaselra Prop. (Badmintons)		4616	4145		
17	Rural Water (Ministry office)		3334	2252		
18	Oosthuizen J. (O.K. Shop)		3252	3139		
19	Smit M M /Louis C (House)		2281	2361		
20	Karma Prop. (Central Lodge)	6990	1990	1411		
21	Nuwe Welkom (Spar)		1796	1975		
22	Judith M. (J.J. Supermarket)		1737	1775		
23	Maritz Country Lodge		1623	3862		
24	La Rochelle (Bed&Breakfast)		1404	1634		
25	IGL PTY LTD t/a Afrox		1156	1320		
26	Keetmanshoop Privaatskool		1059	1363		
27	Bird's Mansion Hotel	3593				
	TOTAL		**189175**	**170298**	**15967**	**33792**
	Inactivity %				**7.8 %**	**16.6 %**

Appendix 4: Municipality's metered water use

	Readings			Consumption	
Place	**2010**	**2011**	**2012**	**2 years**	**1 year**
Tseib. Graveyards	30454	30454	30454	0	**0**
Tseib. Stadium	953	963	963	10	**5**
Tseib. Office	494	2144	3712	3218	**1609**
Krönlein park	165	349	394	229	**115**
Tuin van Herinnering	2699	3961	5453	2754	**1377**
Karavaan park	31449	31449	31449	0	**0**
Van Rensburk park	54812	54993	55102	290	**145**
Museum klipkerk	6448	6448	6448	0	**0**
Mun garage	4595	4882	5159	564	**282**
Book handel	3364	3420	3492	128	**64**
Central park	217480	222400	227036	9556	**4778**
Mun. Stores	not runn.	1172	4878		**3706**
Swimming pool	682289	718160	759408	77119	**38560**
Karavan park	28506	33213	39641	11135	**5568**
Westdene eiland (1169)	545	558	632	87	**44**
Westdene eiland (1170)	5299	5468	5981	682	**341**
Westdene eiland (1171)	15148	15169	15458	310	**155**
1176 b	5332	5371	5486	154	**77**
Westdene playground (1172)		0	128		**128**
Westdene playground (1171a)	7633	7681	7776	143	**72**
Parker park show grounds		154	1494		**1340**
Parker park show grounds E	12637	16172			**3535**
SK't kraan	1656	3086	3628	1972	**986**
Rugby fields Keetmas Stadium	448974	452675			**3701**
Perde Själle	3640	8640			**5000**
Show hall	7258	7439	9157	1899	**950**
H.Nel Eiland	5320	5434	5532	212	**106**
Palm planning	20366	20382	20388	22	**11**
Palm planning2	2501	3639	3895	1394	**697**
W.K. Rover saal		7491	7527		**36**
W.K. Rover saal2		8824	9394		**570**
TOTAL/year					**73955**

Appendix 5: Container tests of household meters

10 liters container filled from a tap while there was no other water use in the property.

Suburb	Date	Meter	Flow (l)	Leak during test (l)
Nordhoek	Sep.14.2012	Kent 15mm	9.7	
Nordhoek	Sep.14.2012	Kent 15mm	10.5	
Nordhoek	Sep.14.2012	Castle 20mm	9.8	
Nordhoek	Sep.14.2012	Kent 15mm	9.85	
Nordhoek	Sep.14.2012	Kent 15mm	8.5	
Westdene	Sep.15.2012	Meinecke 15mm	10.3	
Westdene	Sep.15.2012	Zenner 20mm	9.4	
Westdene	Sep.15.2012	Kent 15mm	8.8	
Westdene	Sep.15.2012	Zenner 20mm	9.5	
Westdene	Sep.15.2012	Sensus 15mm	9.8	
Westdene	Sep.15.2012	Sensus 15mm	9.2	
Westdene	Sep.22.2012	Aqua 20mm	9.6	
Westdene	Sep.22.2012	Aqua 20mm	7.75	0.8
Westdene	Sep.22.2012	Zenner 20mm	9.92	0.6
Westdene	Sep.22.2012	Castle 15mm		not constant
		Mean flow (l)	**9.47**	
		Mean error (l)	**0.53**	

Appendix 6: Amounts of meters and valves in municipalitys stores in october 2012

Product	Size	Amout
Meters	15mm	29
	20mm	27
	25mm	6
	40mm	4
	50mm	11
	75mm	0
	100mm	11
	150mm	7
Stopcocks	20mm	80
	25mm	29
	40mm	0
	50mm	9
Valves	75mm	0
	100mm	2
	150mm	4
	200mm	0

Appendix 7: Checked meters of big consumers

Meters of big consumers checked at least visually in July 2012. It was checked if the meter was running or stopped. Also general condition was evaluated visually. Type of the meter was written down in some cases. Three last meters were only planned to check.

Place	Running	Condition	Meter type
Airport	Yes	Good	Elster 50mm
Bird´s Mansion Hotel	Yes	Good	50mm (blue with air valve)
Canyon Hotel, meterN (not Hotel's)	No	Bad	probably 50mm
Canyon Hotel, meterS	No	Bad	probably 80mm blue
Central Lodge	Yes	Good	Elster Kent 20mm
Dan Viljoen Clinic	Yes	Good	Kent 50mm
Don Bosco Primary School & Hostel	Yes	Good	Spanner Pollux Chem 32mm
Government Stores	No	Bad	
Hospital	Yes	Good	
J.A. Nel Senior Secondary School	No	Bad	
Kammalielie School	Yes	Good	Elster Kent 32mm
Military base	Yes	Good	Elster Kent 50mm
Multipurpose Youth Center	Yes	Good	
Ons Tuiste Old Age Home	Yes	Good	
P.K. De Villiers High School	Yes	Good	
P.K. De Villiers hostel of boys	Yes	Good	Elster Kent 50mm
P.K. De Villiers hostel of girls	Yes	Good	
Police	Yes	Good	Elster 50 mm
Primary School Keetmans. hostel	Yes	Good	Elster Kent 50mm
Primary School Keetmans. meterN	Yes	Bad	Zenner 50mm (350101)(2005)
Primary School Keetmans. meterS	Yes	Bad	Invensys 40mm (23052264)(2003)
Prison	Yes	Good	
St. Mathias Primary School	Yes	Good	
Suiderlig High School, hostel	Yes	Good	
Suiderlig High School, meterE	Yes	Bad	
Suiderlig High School, meterW	No	Bad	
Transnamib, meterE	Yes	Good	Elster 80 mm
Transnamib, meterW	No	Bad	Zenner 80 mm
Keetmanshoop Privaatskool	not visited		
Minna Sachs school	not visited		
NIMT	not visited		

Appendix 8: Suburb consumptions

Water consumption (m^3) of numbered billing areas according to meter reading books in financial year 2011-2012.

Area	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	MEDIAN
1	1747	1504	980	2531	1331	1928		2212	1590	1473	2321	1258	1590
2	1095	934	1550	1152	671			1116	884	855	879	862	909
3	2892	2261	2347	2013	1222			2884	2514	2503	1844	1436	2304
4	1409	1135	635	2035	1347	1376		2378	1447	2125	2380	1315	1409
5	2894	2409	2056	2375	2385	2988		3748	2826	6265	3347	2628	2826
6	3457	3612	5203	3718	4318			3671	3757	4091	3712	3075	3715
7	2330	2661	2661	5251	2873			7214	2951	3720	2305	2183	2767
8	1884	1502	2192	3691	1351			3525	2535	2704	2126	1990	2159
9	2600	2375	2847	4975	3690			3624	3861	3333	3925	2273	3479
10	2574	2726	2519	2944	3518								2726
11	2251	2626	2560	2852	3205			4514	2671	3117	2569	1712	2649
12	5599	5637	6397	11741	3969			10946	8216	8570	6383	6637	6517
13	831	776	1038	1240	1488			1568	1906	1188	1314	789	1214
14	1862	1946	1038	4905	1353			3109	2342	2028	1721	1321	1904
15					3518			5529	3273	3178	3388	2490	3331
16	642	639	809	648	905			1085	844	1940	1175	2158	875
17					905	1339							1122
20	14908	16542	19919	13751	18388	9397		17162	15117	20075	594261	13964	16542
50	1371	2045	4975	2024	1595		1482	1822	1436	1528	1151	1181	1528
51	1402	1233	1872	1652	1167		1732	2243	2359	2284	2123	995	1732
52	4226	5124	4703	4552	8128	3669	6743	6850	6113	5005	4819	4731	4912
53	650	633	950	1001	605		824	924	829	716	612	1833	824
55	1437	1473	1326	1464	1951		1863	2915	2314	1300	1548	1185	1473
71	1310	849	1328	1577	768		1377	1475					1328
73	955	655	1113	2394	2915		1113	4376					1113
76	801	591	689	821	470		971	1075					801
77	1205	640	1474	681	1492	6988							1340
79	2819	8252	1100	1024	1265								1265
82	2168	1245	1507	1606	1294	1231							1401
83	1074	958	1270	2044	1929								1270
84	75928	6179	8472	5296	9973								8472
												Total / month	**85494**
												Total / year	**1025928**