STRATEGIC ASSESSMENT OF HOUSEHOLD ON-SITE WATER AS SUPPLEMENTARY RESOURCE TO POTABLE MUNICIPAL SUPPLY – CURRENT TRENDS AND FUTURE NEEDS

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

Background

Water resource managers, water demand managers and water infrastructure planners alike, are faced with an acute lack of knowledge regarding on-site household water use as additional water source to potable Municipal supply. The most common on-site household water sources (HWS) of this nature include:

- groundwater abstraction by means of garden boreholes or any other type of groundwater abstraction point (GAP)
- rainwater harvesting systems (RHS) that gather water from rooftops
- greywater reuse (GWR).

Greywater, rainwater and groundwater as sources of free water available to every homeowner on-site have been noted in the past elsewhere (Milne, 1979), but this is the first research in South Africa into these water sources at household level.

Problem Statement

The nature and extent of HWS-application by individual water users in residential areas impacts on all infrastructure elements of the water supply and waste cycle. Application of a HWS creates an apparent load reduction on piped reticulation systems, treatment works and on water resources. Unfortunately HWS are often neglected during urban and resources planning exercises. A critical question is addressed by this research, "To what extent and in which way could water demand and wastewater flow be influenced by the application of these on-site sources?"

Key Objectives

This research project addressed the matter at a strategic level with the following key objectives:

- to strategically assess the status quo of HWS, with a focus on the Western Cape by means of a desk-top review
- conceptually describe an end-use model incorporating HWS and assess the theoretical impact of HWS on the average annual daily water demand (AADD)
- identify trends and future research needs

- summarise the knowledge gained, describe the HWS model and document key findings.

Legal implications with regards to HWS application

At household level in serviced areas consumers typically obtain water from a water service provider, which is normally the local municipality. With ever increasing water tariffs and water restrictions consumers frequently make use of HWS, or try to do so. The legal status of the use of these resources is contained indirectly in the National Water Act (NWA) (Act No 36 of 1998) and to a limited extent also in the Water Services Act (WSA) (Act No 108 of 1997). Despite HWSs not being dealt with directly in the NWA or the WSA, it could be concluded from this study that HWSs for domestic purposes in a serviced area could be deemed "legal" in the general case. No registration of the particular use is required, unless a municipality has followed procedures by which by-laws have been put in place, thus regulating the registration of such use – in such a case a home owner may be required to register use of a HWS, with consequences if not registered.

Groundwater abstraction

A groundwater abstraction point (GAP) may be for example a well-point, garden borehole or a shallow well. The cost of installing a GAP varies greatly depending on the GAP-type and geology, but it could be concluded that GAPs are relatively expensive to install. One GAP on a residential property could easily supply the entire average annual water demand (AADD) for a property based on estimates for the yield from this preliminary work and the most recent empirical guidelines for AADD. However, due to plumbing complexities and water quality concerns GAPs are commonly used exclusively to meet outdoor needs, mainly garden irrigation.

Groundwater use seems to be relatively common in residential areas of the Western Cape today, but incidence is limited to low-density high-income areas. Analysis of the data for Cape Town suggests that about 15% of residential properties with area exceeding 1000m^2 registered a GAP during the water restriction period of 2003-2004. Presuming that only half were registered at the time, the incidence of properties with GAPs could easily be about 30%. Previous research in Pretoria (Simpson, 1990) estimated that 38% of properties in the study area in Pretoria had GAPs – a similar finding at the time.

This relatively large percentage of properties with GAPS combined with the relatively large yield from GAPs is expected to have a notable impact when AADD analyses are performed on municipal water meter readings, such as with recently published AADD-guideline studies (Jacobs et al., 2004; Husselman and Van Zyl, 2006; Van Zyl et al., 2008). Consumers artificially reduce the consumption from the municipal water distribution system (WDS), leading to under-estimates for AADD.

Rainwater harvesting

Rainwater use seems to be uncommon in residential areas of the Western Cape today, mainly due to the relatively high cost of storage tanks, the negative visual impact of rainwater harvesting systems and, most importantly, the fact that the high-demand summer period corresponds to the dry season in the Western Cape. It is apparent from information gained during this study that rainwater use is more prevalent in other areas of the country, for example the central Karoo, where the negative seasonal effect is less pronounced.

As is the case with groundwater, gaining knowledge about the presence of rainwater use is often hampered by uncooperative home owners. In contrast to GAPs, it is relatively easy to obtain theoretical estimates of the volume (yield) from a RHS. Theoretical estimates of the available yield are a function of the impervious area (typically the roof), storage tank size and rainfall.

Houses in low density residential areas in the Western Cape are generally not limited with regard to catchment area (relatively large roofs), but tank yield during summer months when the water is needed is low. In contrast, houses in high density residential areas are limited due to catchment area (small roofs), and therefore can only yield low volumes of rainwater. This study suggests that the financial benefits of a RHS are limited and households would typically reimburse the initial capital expenditure after many years only. In agreement with this study financial analysis by Ward et al. (2008) revealed that RHS of smaller domestic systems are not particularly viable in the UK.

However, from a water conservation point of view, notable potential water saving can be achieved via implementation of RHSs, despite the poor financial incentive.

Greywater reuse

Grobicki and Cohen (1999) provided results regarding the projected impact of water reuse on urban water demand in South Africa a decade ago, but their work did not address on-site household reuse. This study earmarks residential on-site greywater reuse as a contentious yet promising alternative water source to urban communities, particularly in the low-density high-income suburbs where health concerns are less pronounced and the generation rate is notably higher than for high-density townships. Greywater reuse is economically viable if not treated in any way. However, when treated and disinfected prior to reuse the product water becomes relatively expensive and the option is less attractive financially.

The required greywater reuse quality is discussed by Jackson and Ord (2000) for reuse in the UK, and it is suggested that the water standard meets the UK's bathing standards if it is used for toilet flushing. When it is used for irrigation the natural rate at which pathogens die off when exposed to the natural environment (e.g. when wastewater is used for irrigation) is a valuable safety factor and is encouraging for reuse of greywater for garden irrigation.

The volume of water available from greywater reuse is relatively small compared to groundwater sources.

Yield of household water sources

The greywater generation rate of a typical suburban property considered for analysis in this study is about 280 ℓ/stand/d and is significantly less than the typical yield from GAPs. The yield from RHS in the Western Cape winter-rainfall region is even less and, considering a realistic tank size, RHS are not useful to meet garden irrigation demands. A typical GAP-yield of 1000 ℓ/h seems to be the "best guess" based on this knowledge review and data from the Western Cape coastal areas. A yield of 1000 ℓ/h is considered to be relatively high in relation to the garden irrigation demand for most typical gardens. If a garden were irrigated for say one hour per day the daily abstraction would be 1000 ℓ/d. This is in agreement with other reports of GAP abstraction in the range of 1000 to 2000 ℓ/d. It could thus safely be assumed that a property with a GAP would meet 100% of its garden irrigation demand from this source and no other HWS would be needed in combination with a GAP to meet garden irrigation demand.

Estimated impact of HWS on water demand

This research suggests that broad and extensive application of HWS in a relatively low-density residential area could lead to a reduction of as much as 40% in the AADD. This is a significant fraction and the corresponding impact on the WDS and sewer system could be significant. An upper limit of about 40% reduction in AADD (water saving) was reported after analysis of water use in Cape Town (Jacobs et al., 2007) and is also in broad agreement with savings reported elsewhere. A 46%

saving was achieved during drought conditions in California (Loaiciga and Renehan, 1997) and a saving of up to 50% is reported by Hunt et al. (1998) for gardens that are extensively xeriscaped.

A reduction of up to 40% in residential water use could thus be expected if HWS were used at all properties to meet outdoor water needs. This statement is based on the assumption that the initial status of users' gardens would be similar to the pre-water restriction state of users in the Cape Town study reported on by Jacobs et al. (2007).

Typologies and Trends

It is clear from this study that strategic capability cannot be viewed in a static way. What customers value varies with time and the use of water is no exception. At some periods in time certain water sources are valued more highly than at other times. The following typologies and trends could be identified based on this research:

- once a HWS is in use it typically remains in use long after the "need" for it (say to carry the user's garden through a period of water restrictions) has passed
- groundwater use is the only notable HWS in terms of penetration and available volume
- the preliminary results from this study suggest that anything from 0% (no groundwater) to 60% (typical upper limit) of users in a particular suburb might have access to groundwater via some type of GAP, with 30% of low-density users with access to groundwater considered typical in Cape Town
- the yield from a typical GAP is about 1000-2000 ℓ/d and is considered to be relatively high compared to other HWS yields and to water demand of residential properties
- rainwater harvesting is heavily influenced by spatial aspects, with some regions finding RWS uncommon (Cape Town metro) and others viewing it as an essential part of water supply (e.g. DWAF-sponsored RHS projects for low-cost housing units in the arid Karoo)
- RHSs were commonly employed locally in days when supply to urban dwellings was unreliable or not available; since the inception of reliable municipal WDS in urban areas of South Africa about 4 decades ago the use of rainwater tanks has become less prevalent
- in most regions of South Africa rainwater tanks are relatively low-yielding and are not viable from a financial viewpoint of the home owner
- on-site greywater reuse in serviced municipal areas is considered to be a relatively new trend; this study reports that greywater reuse as HWS is relatively uncommon, is a contentious issue in terms of community health (Barnes, 2006) and should arguably not be

encouraged on a large scale until further research has been conducted with regards its wider impacts on health.

Discussion and Conclusion

The commissioning of a HWS by a private home owner is often drought-driven. This study confirms findings from previous reports that water restrictions/droughts are the main driver behind HWS application. When installed the HWS typically remains in use, even after the water supply situation via the WDS returns to normal. Given a sufficient and relatively inexpensive supply of water from a municipal source few users consider HWSs. However, there seems to be a developing trend where consumers with a concern for the environment use HWS merely to be "green" – despite poor economical returns.

The only HWS found to have notable incidence during this study is groundwater use. Probing studies performed as part of this work show that 15% of low density residential properties in Cape Town registered a GAP during the water restriction period of 2003-2004, but the actual incidence of GAP is expected to be closer to 30% (findings during a Hermanus case study reported in this research pointed towards similar levels). The use of GAPs as a HWS in the Western Cape is relatively common. Previous research in Pretoria (Simpson, 1990) estimated that 38% of properties in the study area in Pretoria had GAPs at the time, with a maximum of up to 60% incidence in some areas.

In the few reported cases where GAP yields could be estimated, the delivery of water from the GAP is notable – often meeting all garden irrigation demand. The use of RHSs and greywater reuse systems are significantly less common and produce notably less water than GAPs.

Climate change would influence the yield of GAPs and RHSs, but should have little impact on the greywater generation rate. The possible impact of climate change on HWS, and particularly water use from GAPs, has not been investigated as part of this study and is clearly a future research need.

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ABBREVIATIONS AND ACCRONYMS

AADD	-	Annual Average Daily Demand
DWAF	-	Department of Water Affairs and Forestry
ET	-	Evapotranspiration
GAP	-	Groundwater abstraction point (e.g. well, well-point or borehole)
GI	-	Garden irrigation
GWR	-	Greywater reuse
HDLI	-	High density, low income
HDRA	-	High density residential area
HWS	-	Household water source
IDP	-	Integrated development plan
LDHI	-	Low density, high income
LDRA	-	Low density residential area
LOS	-	Level of service
NWA	-	National Water Act
NWCA	-	National Water Consumption Archive
POSWAR	-	Personal on-site water resources / sources
RHS	-	Rainwater harvesting system(s)
WDS	-	Water distribution system
WSA	-	Water Services Act
WSDP	-	Water Services Development Plan
WSP	-	Water service provider

1. INTRODUCTION

1.1 Background

On-site household water sources, conveniently described by the acronym HWS in this study, are available to all residential consumers in South Africa. The most common HWS, include

- groundwater abstraction via some type of groundwater abstraction point (GAP) such as a well, well-point, or borehole
- rainwater harvesting systems (RHS) for capturing rain from rooftops
- greywater reuse (GWR).

Other HWS are available, but are less common and are not addressed in this study. These are for example the use of water from irrigation channels along streets (common in many towns in the Boland region of the Western Cape province), the use of air conditioner condensate and even systems intended for capturing fog and/or dew. One property bordering a mountain stream in Gordon's Bay, Western Cape, displays a sign reading, "stream water", suggesting that water is abstracted directly from the mountain stream for urban use.

These alternative water sources are commonly applied to meet garden irrigation (GI) demand, where water quality issues are often not a concern and/or the quality from the HWS source is acceptable in view of its use (Fraser and Weaver, 2000). The application of HWS by individual water users, particularly in residential areas, impacts on all water infrastructure. It creates an apparent load reduction on all piped reticulation systems. If managed properly this could be an advantage since HWS could be seen as a means to reduce water demand on the Municipal supply system. In contrast, however, it could be a concern in cases where guidelines for estimating water use are based on analyses of data from consumer water meters, not accurately reflecting the water needs of residential consumers.

Recent projects undertaken by the WRC, as well as independent research, focused on the analysis of Municipal water meter readings to gain knowledge of the average annual daily water demand (AADD). Although out-dated guidelines for estimating the AADD are still used (CSIR, 1983), recent publications (Jacobs et al., 2004; Van Zyl et al., 2007; Van Zyl et al., 2008) provided updated guidelines for estimating AADD in South Africa. These guidelines provide the engineering fraternity with practical methods for estimating AADD. The AADD is used as a basis for estimating peak water demand and it is considered to be a critical parameter in the design of water and sewer services. In addition to these studies, information from Municipal water meters was used by Van Zyl and Geustyn (2006) to compile a National Water Consumption Archive (NWCA). The AADD data contained in the NWCA is based on consumer meter readings and does thus not provide information to the analyst about any other water use on a property, supplied from an alternative source such as HWS.

Over-estimation of the AADD (and peak flow) in the design stage of a water distribution system (WDS) could lead to unduly expensive infrastructure; money that could rather have been spent to reduce the supply backlog in regions with no service. On the other hand significant under-estimation would lead to an unacceptable level of service with water networks having, for e.g. insufficient pressure. The use of HWSs by residential consumers would reduce the water abstracted via the consumer meter from the piped Municipal WDS. HWSs are often used to irrigate gardens, e.g. with garden use comprising a significant portion of the total residential water need. This reduced water need due to HWS application would create the impression that less water is used than is actually applied on-site.

Knowledge regarding current HWS trends and future needs is critical. Researchers primarily need to understand the impact that HWS might have on the AADD. This study is a strategic assessment of HWS, with a focus on the Western Cape province of South Africa. This province is particularly water stressed due to the winter rainfall combined with hot-dry summers, when water is needed for garden irrigation.

Figure 1-1 shows a typical generic home supplied with water from three water sources in addition to the Municipal supply network (pipes indicated in the background):

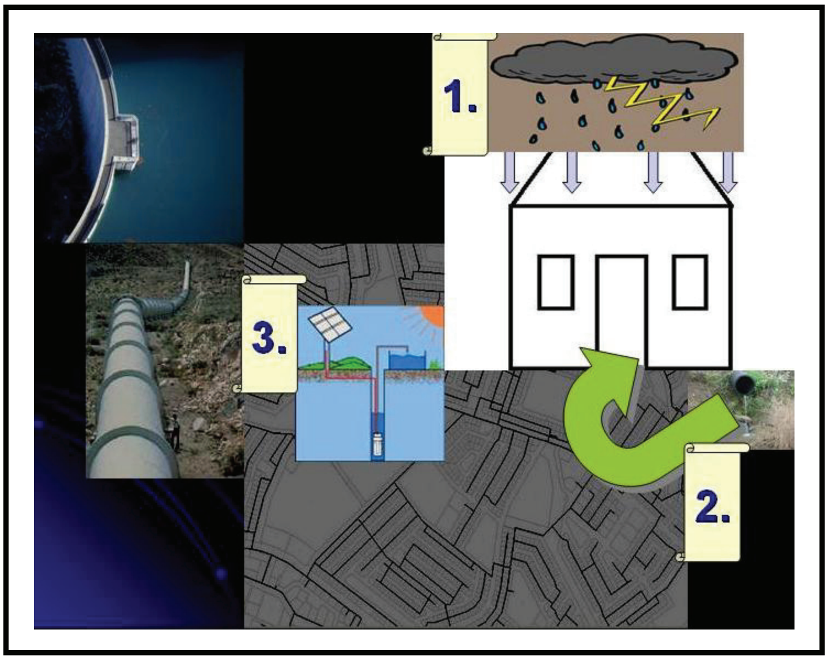


Figure 1-1: HWS – three alternative water resources available to a residential consumer

1.2 Focus and limitations

The focus of this study was on residential areas in the Western Cape province of South Africa. Only urban areas supplied with water by a piped WDS via an individual consumer meter are included. This is because these properties are typically the ones used during analysis of AADD-values in the compilation of guidelines for estimating residential AADD.

The types of HWS considered by the project team to be "the most notable", namely groundwater use, rain water harvesting and greywater reuse were exclusively addressed. The WRC is currently funding numerous parallel studies into greywater reuse and the focus of this study is subsequently on the groundwater and rainwater sources – although greywater is also included.

This study is limited in the sense that it provides strategic knowledge, rather than technical research outputs. It was aimed at identifying the most critical future research needs in this field.

The focus on HWS (and saving of water needs from the municipal network) would inevitably be on low-density areas with larger stand sizes and particularly those with large garden irrigation demand, although there is no way of gaining the latter knowledge without a site-inspection.

This study is based on the assumption that all HWS application would result in a direct reduction in water use from the municipal system. In other words, the users' demand is said to remain constant with only the source changing. In actual fact the theory of price elasticity of water suggests that HWS use, which appears to be "free", would in fact lead to the perception of reduced water price and subsequently to an increased demand.

The availability of HWS at a property could thus theoretically lead to an increased total consumption and might in the extreme case have no impact (no reduction) on the municipal supply. Knowledge regarding this aspect could only be obtained by metering the actual use from the HWS abstraction (or reuse) point at a property for which the consumption record prior to its application is also available.

Finally, this study does not address legal implications regarding water rights to any of the water sources under study.

1.3 Key Objectives

This study had the following key objectives:

1. Strategically assess the status quo of HWS, with a focus on the Western Cape by means of a desk-top review.

2. Conceptually describe an end-use model incorporating HWS, develop and apply an electronic version of the model (in MS Excel) to perform basic analyses to assess the theoretical impact of HWS on AADD.

3. Compile a project report to summarise the knowledge gained, describe the HWS model and document key findings.

1.4 Methodology

1.4.1 Desktop review

The study was based on a desktop review. Due to the limited nature of work regarding HWS published in peer reviewed journals and books, the study also extends to include grey literature, thus also assessing work that was conducted, but never formally published. Personal communication with experts in the field and practitioners involved in some areas of the country where HWS is commonly used, was also included in the project scope.

1.4.2 Model development and analyses

An end-use model incorporating HWS was developed to assist with the theoretical assessment of HWS impacts.

1.5 Strategic approach

This study had a strategic approach, in other words the intent was to provide long-term direction with regards to HWS, particularly in view of future research needs. Most people make sense of complex situations by viewing them in more than one way, or through different "lenses". Johnson and Scholes (2002) describe three such lenses of strategy development:

- a design lens, that views strategy development as a deliberate positioning through rational, analytic, structured and directive processes
- an experience lens that views strategy development as the outcome of individual and collective experience and the often taken-for-granted assumptions; in this manner the strategy could develop on the basis of a series of strategic moves each of which makes sense in terms of previous moves.
- an ideas lens that sees strategy as the emergence of order and innovation from the variety and diversity of ideas.

Strategic capability cannot be viewed in a static way, because what customers value varies with time. As an example, a residential water consumer in 1950 may have had limited or no water service, encouraging HWS use in those days (e.g. use of a rainwater tank). In other words some type of HWS may have been more prevalent merely because reliable water supply was limited. Today homes are relatively sure of a reliable water supply and expect a certain level of service (LOS) – at a cost. Rising block tariffs has increased the cost of water to a point where the water account may now be a concern to the typical home owner, which would again lead to HWS application for entirely different reasons.

Johnson and Scholes (2002) provide directions for strategic development, one of which is to protect and build on the current position. It is thus critical that current knowledge be reviewed and summarised in order to strategically assess HWS. Also, strategies often develop from ideas that "bubble up" from within a team. They may develop because people interact with a changing environment (typical of the South African water sector) or they may develop as diverse or even maverick ideas become attractive. Such ideas may be post-rationalised into a strategic plan. A good example of this concept is presented in the section on groundwater use: when the project team was faced with the challenge to gain knowledge regarding groundwater use on individual properties some "wild ideas" were needed. Some paid off, while others did not. It is worth noting at this point that "strategies emerge through doing" (Johnson and Scholes, ibid.) and one road (or personal contact) often leads to another.

In line with the strategic approach this research seeks to identify the status quo and goes on to identify typologies and trends for each HWS, while maintaining an open-mindedness.

1.6 Notation

1.6.1 General

The acronym HWS was developed as part of this study to describe personal on-site water resources. These sources are often considered to be tools in a water demand manager's toolkit, leading to them to be tagged "water conservation" or "demand management" measures. However, a valuable and detailed description of the terminology surrounding the WDM/WC topic is provided by Butler & Memon (2006). The following is a brief summary of their notation promoted by the IWA, that is also adopted in this study:

- water conservation = "doing less with less" and is particularly applicable in drought scenarios / water restrictions (example: take shorter showers; do not irrigate the lawn)
- water efficiency = "doing the same (or more) with less" (example: fix leaks; hydraulically efficient toilet pan and cistern design – not just flush volume reduction)
- water sufficiency = "enough is enough" (example: automatic shut-off of taps; dual flush toilets; careful garden watering)
- water substitution = "replace water with something else (say air)" (example: waterless urinals; vacuum drainage; dry cleaning)
- water reuse, recycling and harvesting (example: RHS and greywater reuse on-site; shared bath water; groundwater abstraction on-site). For the purpose of this study it is called "water source substitution".

Based on the above descriptions it is apparent that HWS is classified under "water source substitution" and it is thus not viewed as a "demand management" initiative *per se*. The word "saving" is however loosely used in this report to indicate a reduced demand on the municipal WDS, although the customer would not actually reduce their demand; the outdoor share is merely supplied from an alternative on-site source.

1.6.2 Groundwater

Groundwater is abstracted via one of various "structures" delivering it from under the ground surface to above the surface (e.g. borehole, well point, shallow well or even a fountain/spring). This report does not elaborate on the definition of these various terms. However, to avoid confusion the term "groundwater abstraction point" (GAP) is instead used in this report to describe any type of abstraction of water from the ground for use on the surface.

1.6.3 Greywater and reuse

Greywater is a term often used to describe sullage. "Sullage" is defined in the Oxford dictionary as, "waste from household sinks, showers and baths, but not toilets". Thus the term greywater is similar to sullage, but greywater excludes wastewater from kitchen sinks/basins.

The return flow from a dwelling is sometimes classified as being “grey” or “black”, depending on its origin. Different definitions for greywater are provided in various literature sources. Domestic greywater is defined by Kreysig (1996) as effluent from washbasins, showers and baths, and could include washing machine water. According to Zeisel and Nolde (1995) black water includes wastewater from the toilet, dish washing and food preparation, but return flow from the latter two end-uses is sometimes included with greywater.

1.6.4 Rain water

In order to prevent creep the project team had to limit the scope of what is meant by "rainwater use". The term rainwater harvesting system (RHS) implies the intentional diversion of rainwater from roofs to a storage tank. This definition does not include indirect application of rainwater, even if intentional, if it is not stored prior to application. In other words, the (possibly intentional) diversion of gutters into a garden bed would not constitute rainwater harvesting for the purpose of this study.

1.7 Legal aspects with regards to HWS use

1.7.1 Legal rights to water

At household level in serviced areas consumers obtain water from a Water Service Provider (WSP), which is normally the local municipality. With ever increasing water tariffs, and often driven by drought measures and water restrictions, consumers frequently make use of HWS, or try to do so. In a number of municipalities, old irrigation channels are still in use to which some owners have "water rights".

The legal status of the use of these resources is however not well delineated and infrequently discussed. When so, it is often a contentious issue. The legal position is contained in the National Water Act (NWA) (Act No 36 of 1998) and to a limited extent also in the Water Services Act (WSA) (Act No 108 of 1997).

1.7.2 Water Services Act

The main objectives of the WSA are described in section 2 of the Act and include:

> *"The right of access to basic water supply and the right to basic sanitation necessary to secure sufficient water and an environment not harmful to human health or well-being..."*

This right is further emphasized in section 3 of the Act and "basic water supply" is also defined in the Act as:

> *"...the prescribed minimum standard of water supply services necessary for the reliable supply of a sufficient quantity and quality of water to households, including informal households, to support life and personal hygiene..."*

In subsequent policy documents from DWAF, this has been defined as 25 ℓ/p/d, but it is also expected from each municipality to define these values in their own Water Services Development Plans (WSDP), which forms part of the municipal Integrated Development Plan (IDP). These minimum standards can be used in the evaluation of what constitutes a domestic use allowed for in the NWA.

1.7.3 National Water Act

The main objective of the NWA is to make provision for the management of the water resources in South Africa through the relevant management structures. Of specific interest to the household user – and this project – is the identification of what is considered as a permissible use and the procedure associated with this use. It is considered essential to at least obtain some basic knowledge as to the legal implications concerned where a home owner intends on using groundwater, rainwater or reusing greywater.

Section 21 of the NWA states that, among others, the "taking of water from a resource", constitutes a water use. In general terms a licence is required for any water use and the procedures are dealt with in the NWA. The NWA simultaneously also empowered the Minister in section 26 to make regulations to enforce the registration of all water uses. These regulations (Regulation 1352 published in Government Gazette No 20606, 12 November 1999) were issued and it effectively requires the registration of all water use activities within a specific time frame. At this point it may seem that it is necessary for a home owner to register HWS use with DWAF.

The only water uses exempt from the registration process are provided in section 10 of the Regulation and include:

- Schedule 1 use
- If not required in terms of a general authorisation issued
- If water is obtained from a bulk water supplier or other management structure.

There is however a number of situations where water can be used without a licence as stipulated in section 22 of the NWA:

"A person may only use water –

(a) without a license -

(i) if that water use is permissible under Schedule 1;

(ii) if that water use is permissible as a continuation of an existing lawful use; or

(iii) if that water use is permissible in terms of a general authorisation issued under section 39"

With reference to section 22 above, Schedule 1 water is defined in the NWA as a user who is to:

(a) take water for reasonable domestic use in that person's household, directly from any water resource to which that person has lawful access;

(b) take water for use on land owned or occupied by that person, for -

(i) reasonable domestic use;

(ii) small gardening not for commercial purposes; and

(iii) the watering of animals (excluding feedlots) which graze on that land within the grazing capacity of that land, from any water resource which is situated on or forms a boundary of that land, if the use is not excessive in relation to the capacity of the water resource and the needs of other users;

(c) store and use run-off water from a roof.

It is clear that most household water uses could be considered to fall within these categories. Rainwater from roofs, and boreholes for domestic purposes as stated above, could therefore be used without the requirement of a licence or the registration thereof at DWAF. On the other hand it is still necessary to ascertain whether a municipality could enforce registration of HWS sources in its area of jurisdiction.

An existing use, as is the case of a possible water right registered on an owner's title deed, does not need to go through an application for a licence process, but can be continued until a verification or renewal of the licence is requested by the authority. Water rights to irrigation channels in some towns are an example. In most cases the water use from these types of systems has been dealt with through the registration process by the responsible municipality or other relevant associated water management body. The registration of an existing use is compulsory in terms of section 151(1)(g) of the NWA, stating that:

(1) No person may -

(g) fail to register an existing lawful water use when required by a responsible authority to do so;

The issuing of a licence will subject the water use to critical questions such as whether the existing use is in fact a beneficiary use. The issuing of a licence will depend on these evaluation criteria and might influence the final volume for which a licence will be issued, but this will not be dealt with here as it falls beyond the scope of this study.

Where no licence is required according to section 22 a general authorisation would have been issued, regulating the water use in specific areas. These authorisations stipulate the quantities of water that can be used in each area without a licence, but the use must still be registered and the final issuing of a license will once again be subjected to a number of critical evaluation criteria.

1.7.4 The "legal rights" of a home owner to HWS

In view of the above, the request for the registration of boreholes or the use of any "personal" water resource by an individual within the municipality area for that matter, is not dealt with directly in the NWA or the WSA. However, it could be regulated through the issuing of appropriate by-laws from the specific municipality, thus enabling the authority to apply "good water governing principals" as stipulated in the law.

In other words:

- use of any HWS for domestic purposes by any individual home owner in a serviced area could be deemed "legal" in the general case and no registration of the particular use is required, unless
- a municipality has followed the necessary procedures by which by-laws have been put in place thus regulating the registration of such use – in such a case a home owner may be required to register with consequences if not registered.

1.8 Report structure

- This report is structured around three HWSs considered to be the most common in residential areas, namely groundwater, rainwater and greywater reuse. Subsequently the end-use model used to theoretically assess the viability of the sources from a qualitative viewpoint is described. The results are presented to theoretically assess the impact of HWS on the AADD. In addition a case study was conducted to assess the significance of using groundwater and to gain detailed knowledge about the trends in one particular region, namely Hermanus. Based on the findings conclusions are finally presented with regards to the current trends and future needs.

2. GROUNDWATER

2.1 Overview

The use of on-site groundwater abstraction in South Africa is relatively common. Water is abstracted by means of personal boreholes, well points and even shallow wells. Groundwater abstraction in South African residential areas has been investigated in the past, but an acute lack of knowledge still remains regarding this water use in residential areas.

This desk-top review addresses a few specific case studies, not reported on before, as well as previously published work. Various methods were employed during this study to gather data regarding groundwater use, including:

- Physical collection of raw data from previous work, for example obtaining the questionnaires distributed by the City of Cape Town (CCT) to home owners during the registration process in 2003-2005 to learn more about who had boreholes/well points, information about how often it is used, what time of the day it is used, how long it is used at a time, what it is used for and the installation date (the information was never converted to electronic format, suggesting limited use and value of the data subsequent to the registration process). No information was available during this study on whether these boreholes/well points were operational at the time, and it was assumed that all those registered remain in use.

- Personal networking proved valuable. It was possible to approach geo-hydrological consultants, DWAF, the CSIR and specialists in the field to gain whatever information was at hand.

- It was initially hoped that local borehole and well point contractors ("drillers") would assist in providing information and possibly access to records kept over the years, since they have started to install residential boreholes/well points within the Cape Peninsula. This often proved unsuccessful due to such records either not being available or not being made available to the project team.

- Survey of selected homes / homeowners via email.

The remaining sections of this chapter are dedicated to previous studies and previously gathered data sources that could be analysed further as part of this work. The studies are listed chronologically.

2.2 Ground breaking work (1970-1978)

The first work addressing the matter of groundwater use in residential areas was conducted by the University of Pretoria in the period 1970-1978 (Van Duuren, 2008). The regions covered in the early work included Kroonstad, Rustenburg, and Pretoria. Unfortunately the only two publications in peer reviewed journals relating to the water use in Pretoria at the time (Gebhardt, 1975; Ellis and Van Duuren, 1974) did not address the impact of groundwater use. Some of the work was later included as a minor component of a masters' thesis published by the same University (Van Duuren, 2008; Garlipp, 1978). However, the latter thesis does not include detail with regards to groundwater use.

Additional information was gained during this research project that was presented to the project team as hard copy "slides" (Van Duuren, 2008). This information was converted to electronic format and is included in Appendix A of this report for future reference. The inclusion of the slides in unchanged format is considered appropriate since it was never published before, is the first report of this nature and relates directly to the topic under study. The information is out-dated and was not peer reviewed at the time. However, it provides a very useful foundation with regards to the presentation of the results (e.g. where AADD is plotted against stand size in the case of Rustenburg for homes with/without GAPs and where a time series of the results is presented).

2.3 WRC-research (1990-1996)

About a decade later a WRC study was conducted and ran over a period of about 3 years in the municipal area of Pretoria (Simpson, 1990). More than 2000 properties with GAPs were evaluated for location, abstraction rates, groundwater levels and municipal/potable water use. The geographical region is the interior summer rainfall part of the country. The 1990-study is particularly applicable to this investigation since it reports significant detail and lists specific conclusions and identifies future work/issues.

The number of properties with boreholes was estimated by applying a stratified cluster sampling technique, with 9 clusters of about 100 properties each. It was found that about 37% of 80536 properties in the study area had GAPS, with a maximum of up to 60% incidence in some areas (Simpson, 1990).

The groundwater volumes used were plotted graphically as well as the municipal water use of properties with groundwater abstraction versus that of properties without GAPs. From these results, definite conclusions were made by the authors (Simpson, ibid.) as to the impact of residential groundwater use and the subsequent reduction in municipal water use in cases where these alternative sources were used. The work could be considered somewhat out-dated, although some of the conclusions of the 18-year old project are reinforced by this study (e.g. the fact that home owners remain uncooperative in providing information).

Reference to a study by Lomberg et al. (1996) in the Port Elizabeth Municipal area was identified at a late stage in the review process. Simpson (1990) also cited a study in Port Elizabeth (the date of the citation source indicates that this study was different to the former one), but no reference to it could be found at the time of printing this text. The report could subsequently not be obtained in time for publication of this text. Bar that one, the research team could not locate any publications regarding groundwater use in residential areas for about another decade, when various studies on the topic ensued.

2.4 Detailed hydro-census Hermanus, Western Cape (2000)

In 2000 a mini hydro-census was completed for the town of Hermanus (Overstrand Municipality) in the Western Cape (Tennick, 2008). Due to the fact that the initial report (Tennick, 2000) is not available from the Overstrand Municipality and was not published elsewhere, it is included in Appendix B for future reference (the original formatting was maintained to underline the fact that the work did not form part of this project). As part of this project the raw data was obtained by the project team and was analysed. A description of the work, the findings and some lessons learned from the study are presented as a separate chapter later in this report.

2.5 Comparative study – Cape Town and Perth (2001)

Cape Town (South Africa) and Perth (Australia) share various attributes, particularly with regards to geography (e.g. similar latitude, longitude and altitude) and climate. A detailed comparative study was done by the CSIR in 2001 (Saayman and Adams, 2001) with regards to groundwater use in urban areas in these two cities. The extensive study by those researchers included a visit to both cities during their research. The report compares the annual precipitation, hydrogeology, status of water supply and current groundwater management of the two cities. Estimated costs, construction methods, advantages versus disadvantages and groundwater quality are then also discussed in their work.

The study reports that groundwater use in residential areas is more common in Perth than in Cape Town and concludes with remarks as to what has to be done politically and socially in order strategically place Cape Town in a position for the use of groundwater to become a more popular and sustainable source of water.

Their work does not contain any detailed information with regards to water use, hydro-census or surveys as to where boreholes/well points are located and/or the municipal water use at such properties. From this perspective the findings reported are considered valuable from a strategic point of view, but limited technically.

2.6 Cape Town water restrictions of 2003/2004

2.6.1 Groundwater abstraction registration process (2003-2004)

The City of Cape Town undertook an extensive registration process for groundwater usage during 2003 and 2004 when Level 2 water restrictions were imposed throughout the greater Cape Peninsula. A detailed account of the water usage and savings during this specific period of water restrictions is given by Jacobs et al. (2007). The Cape Town groundwater usage registration process is the largest exercise of its sort conducted to date that could be found during this review. Almost 4500 property owners/occupiers completed hard copy registration forms during the Cape Town registration process. Previous research has indicated that many groundwater users did not voluntarily register boreholes/wellpoints in Pretoria (Simpson, 1990; Elphinstone and Van der Linde, 1989) and in Port Elizabeth (Lomberg et al., 1996) during a similar study. The same is considered to be true in the case of Cape Town, although this could not be confirmed by measurements/surveys.

The position of the person who was responsible for this registration process is the Water Demand Manager for the City. Unfortunately three different individuals held this post over the relatively short period of 3 years (none of whom remained employed by the City). However, discussions with all three these individuals during this study proved to be of value.

During this time the registration process was widely advertised in the media and home owners were encouraged to take part through articles/notices in local newspapers and on notice boards at all municipal offices within the City of Cape Town area. The message/appeal that owners/occupiers of all residential and commercial properties throughout the Peninsula had to register any groundwater use on these stands by filling in a registration form at their local municipal office indicating the date, home owner/occupier name, address, suburb, stand number and the type of groundwater source (i.e. borehole, wellpoint, well or fountain) was clear at the time and well advertised. In addition, the City also conducted a door-to-door survey by which home owners/occupiers who failed voluntary registration during the first round had another chance to register any groundwater usage.

The reason residents had to register any groundwater use was because it would allow them to water their gardens freely during the period of water restrictions without being suspected of using municipal water for these purposes and subsequently be fined. Each person who registered groundwater usage was issued with an A4 sized poster to be put up on-site (at stand for which groundwater use was registered for) in a place where it would be clearly visible and indicate to the public and water managers that the water used for garden irrigation at the specific originates from a groundwater source.

Part of this ongoing process (conducted by the project team) was to capture the City of Cape Town data electronically, something that was never done after the initial registration process. However this capturing process (including address verification, suburb and groundwater source type classification etc.) was completed by the project team during this project and the data is now set to be processed further. The task of capturing all these records electronically was not part of the project proposal and it was not initially envisaged realistic to complete the process during the time frame of this study. With the data available to the team it was possible to draw some preliminary conclusions.

2.6.2 Data capturing, verification and categorising

The original registration data forms were collated and physically collected (after a substantial search). The research team obtained a total of 4487 registration forms from Mr John Potgieter of the City of Cape Town's Technical Operation Centre (TOC) in Bellville. The information was found to be in very rough and often illegible, hard copy format. All the data was captured electronically and each suburb, street name and street extension was verified (with regards to existence at the time, correctness and spelling) by means of a one-by-one verification in a Map Studio street guide and the Yellow Pages website (see www.yellowpages.co.za).

Each entry was then categorised with regards to type of stand and the zoning thereof. This resulted in the following spread of different categories:

- Residential stands with groundwater use: 4273 properties
- Residential stands noting greywater reuse: 71
- Residential stands noting rainwater use: 11
- Residential stands making use of some other source: 10
- Blocks of Flats/Farms/Small Holdings: 33
- Commercial stands: 23
- Schools/Tertiary Institutions: 29
- Churches/Convents: 18
- Sport Fields/Sport Clubs: 16
- Hospitals/Clinics: 3.

For the purposes of this study only residential stands using groundwater, according to the registration data, will are relevant. The rest of the entries were not considered and were eliminated from further evaluation. This left 4273 records.

These residential stands were then categorised further to give the following sets of data:

- Entries deemed to be good, usable data after verification: 4134
- Entries with unknown street names: 38
- Entries with no street/stand numbers: 29
- Entries of stands within security estates: 72.

The entries of stands with unknown addresses (139) could possibly be identified by looking up the owner/occupier's name in records dating the time of registration (as supplied with registration process). Old Cape Peninsula telephone directories from the period when the registration process was conducted could be used for this purpose. These directories have already been collected by putting up adverts at local supermarkets, visiting the Bellville landfill site and by contacting various paper recycling depots. After verifying these records a final sample size in excess of 4300 is expected, which could then be used for further evaluation regarding AADD, stand size and actual metered water use of each entry. A case study in Hermanus was conducted as part of this project to test the viability of the procedure.

2.7 Groundwater yield

The information presented in Appendix C shows the typical yield (and depth) of some well points and boreholes in Cape Town. From the table in Appendix C it is evident that only 7 properties have a yield of less than 500 ℓ/h with 8 properties having a yield of between 4000 ℓ/h and 8000 ℓ/h. The typical yield exceeds 1000 ℓ/h. Assuming that the yield could be supplied for about 15% of the day (4 hours) a daily yield of about 2000 ℓ/day for the low-yielding properties and 20 000 ℓ/day for the high yielding properties. The typical yield of a relatively shallow GAP based on the Cape Town information is about 4000 ℓ/day.

In the analysis of data gained during the Hermanus hydro-census Tennick (2000) estimated the yield from one shallow GAP to be 1000 ℓ/h (it was a typical WellPoint only 2.2m deep). This yield was reported to be "the average abstraction rate for a WellPoint", in other words it was considered to be typical for GAPs in Hermanus.

The yield of 106 boreholes in Pretoria was recorded for a period of 24 months in the period 1988-1990 (Simpson, 1990). The water depth in boreholes was found to be about 30m in most cases. The average yield for boreholes on the properties analysed was found to be 1780 ℓ/d per borehole over the 2 year period. In addition the same properties also used 820 ℓ/d on average from the municipal WDS.

Based on the data from CCT and Hermanus it seems that a yield of 1000 ℓ/h could be used as a conservative estimate for the yield from "a typical GAP" (although no GAPs are typical). In order to estimate a daily abstraction volume it is necessary to estimate a duration for use of the GAP. If a garden were irrigated for between one and two hours per day on average the daily abstraction would be 1000-2000 ℓ/d. The recorded abstraction of 1780 ℓ/d in Pretoria is also within this range.

The volume from the GAP is consistently relatively large in relation to the AADD obtained by analysing consumer water meters (Jacobs et al., 2004; Van Zyl et al., 2008) where values for the total AADD of a typically property range between 1000 and 1500 ℓ/d in the summer rainfall region (for stand sizes 1000m²-2000m²). Rationally based end-use estimates are shown in Figure 2-1 for a "typical home", underlining the range of AADD for a typical property stated above.

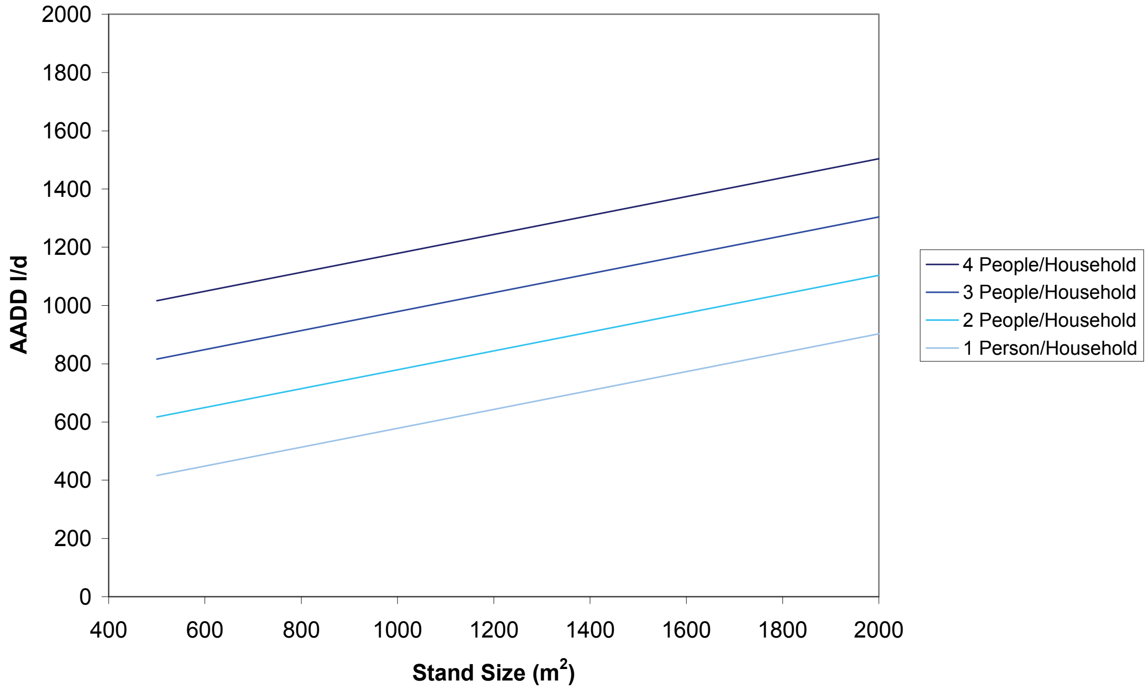


Figure 2-1: Theoretical end-use results for AADD of a typical property

2.8 Discussion

One GAP on a residential property could easily supply the entire water demand (AADD) for a property based on estimates for the yield from this preliminary work and the most recent empirical guidelines for AADD. However, due to plumbing complexities and water quality concerns GAPs are commonly used exclusively to meet outdoor needs, mainly garden irrigation.

Groundwater use seems to be a common HWS in residential areas of the Western Cape today. Analysis of the data used in a previous study by Jacobs et al. (2007) shows that there were about 30 000 residential properties in the administrative areas of Cape Town in 2005 with stand area > 1000m². By making a crude assumption that only properties with a stand area > 1000m² have GAPs, the registration of 4273 properties suggests that about 15% of properties registered a GAP during the water restriction period of 2003-2004. Presuming that only half the GAPs were registered at the time, the value for properties with GAPs could easily be about 30%. This points to a significant fraction, although it is based on a crude estimate. It could suggest that the use of GAPs as a HWS in Cape Town are relatively common. Previous research in Pretoria (Simpson, 1990) estimated that 38% of properties in the study area in Pretoria had GAPs – a similar finding at the time.

This relatively large percentage of properties with GAPS combined with the relatively large yield from GAPs is expected to have a notable impact when AADD analyses are performed on municipal water meter readings, such as was the case with recently published AADD-guideline studies (Jacobs et al., 2004; Husselman and Van Zyl, 2006; Van Zyl et al., 2008). A notable fraction of consumers seem to make use of GAPs and thus artificially reduce the consumption from the municipal WDS, which would lead to under-estimates for AADD – the actual AADD used on-site would be higher than that estimated with empirical guidelines.

Gaining knowledge about the presence of groundwater use is often hampered by uncooperative home owners. This aspect was noted in all previous reports and also during this investigation. This unwillingness of home owners to provide information creates the perception that the registration process in Cape Town would only have recorded a relatively small fraction of the total – only that portion represented by the "cooperative" owners.

In cases where the former knowledge is gained, it is hard to obtain even a rough estimate of the volume (yield) used from each individual source. Theoretical estimates of the abstraction from a borehole/well point is complicated by various factors, including for example significant variation in geology, soil conditions, equipment ratings and the depth of the groundwater table. The only sufficiently accurate method for gaining this knowledge is considered to be direct measurement, by for example the placing of an in-line water meter in the pipe at the point of abstraction.

The "typical yield" of 1000 ℓ/h seems to be the "best guess" for the yield from a garden borehole in the Western Cape coastal areas. The value is based on two previous studies where yields were recorded. A yield of 1000 ℓ/h is considered to be relatively high in relation to the garden irrigation demand for most "typical" gardens. It could thus safely be assumed that a property with a GAP would meet 100% of its garden irrigation demand from this source and arguably, no other HWS would be needed in combination with the GAP to meet garden irrigation demand.

Although the DWAF have a so-called municipal borehole data base, the registration of personal residential GAPs are not normally included in the DWAF data set. DWAF focus on knowledge of boreholes (and not other types of GAPs) that are used by Municipalities for water supply to the area serviced. In other words, this study has a higher resolution than is recorded in the DWAF data set. No GIS-based data set could be found during this project for personal residential GAPs.

3. RAINWATER

3.1 Background to rainwater harvesting

Domestic rainwater harvesting involves the collection of rainwater from a collection surface, usually the roof of a house, which is then stored in storage container for various selective domestic uses. A rainwater harvesting system consists of a number of integrated system components, including a catchment area, a storage vessel and a distribution system. External factors such as climatic conditions, rainfall patterns and the end users of rainwater, could drastically influence the viability of domestic rainwater harvesting systems (RHS).

The harvesting of rainwater as an alternative water source for selective urban water consumption, is a technology that has not been explored nor developed to its full potential in South Africa and specifically in the Western Cape. The main focus of this section is to examine the viability of domestic rainwater harvesting systems, with specific reference to domestic consumption in serviced residential areas in the Western Cape. The following factors are discussed:

- Origin and history.
- Potential advantages of rainwater harvesting.
- Typical RHS components
- Variables that influence viability of Rainwater Harvesting Systems (RHSs)
- Various user regimes
- Rainwater quality for domestic consumption purposes
- Western Cape rainfall statistics, and the potential of rainwater harvesting systems in the Western Cape.
- Strategic assessment of rainwater harvesting.

3.1.1 Origin and history

Rainwater harvesting has been adopted in many areas of the world where water supply systems have failed, or could not meet the required demands. The technique originates in ancient times, and can be found in many of the great civilizations throughout history. Archaeological evidence confirms the harvesting of rainwater as far back as 4,000 years ago. Ruins of reservoirs built as early as 2000 B.C. for storing runoff from hillsides for agricultural and domestic purposes are still visible in Israel.

3.1.2 Local application

In South Africa and specifically in the Western Cape, rainwater harvesting is not a new concept. In coastal and other small towns where there are no reticulation networks supplying water to domestic consumers, rainwater harvesting for full domestic consumption is a frequent occurrence. In some other towns where the water supplied via the municipal reticulation network is brackish and thus has a bad taste households harvest rainwater for the sole purpose of drinking water. Interestingly, in these situations, rainwater harvested from roofs and gutter systems that are cleaned infrequently, and often stored in old asbestos-cement tanks for a couple of months, is deemed to be of a better quality and better tasting than water supplied via municipal reticulation networks. Local application of RHS is discussed later in this chapter in more detail.

3.1.3 Water quality concerns

Despite rainwater being of a naturally "good quality" *per se* (it is distilled water falling from the sky!), the lay term "drinking water tank" used for a rainwater tank is in fact a misnomer in some cases, given the water quality concerns noted by others. The issue of poor water quality from RHS has been noted in the past (Butler and Memon, 2006). The most notable quality concerns typically originate from the first rain after a dry period. First flush diversion systems are available to improve the water quality. Investigation into the quality of RHS is not the focus of this study, but limited attention to the topic is needed and is included as a sub-section of this chapter.

3.1.4 Potential advantages of rainwater harvesting

Rainwater harvesting has various potential benefits and advantages (Krishna, 2005). RHSs could potentially:

- Provide a source of free water; once the initial capital outlay associated with erection of storage and distribution systems have been discounted.
- Provide a source of water in areas where there are no municipal water supply systems.

- Provide water of a good quality in areas where groundwater quality or even municipal water quality is unacceptable or undesirable. Rainwater is naturally soft, pH neutral (7) and sodium-free.

- Help reduce peak water demands on the water distribution system

- Delay the expansion of water treatment plants and construction of additional capacity in reticulation networks.

- Reduce demands on groundwater resources.

- Result in potential financial benefit to end users due to lower consumption from the municipal water mains.

- Serve as a good secondary water source for landscape irrigation.

- Conserve natural water resources.

- Reduced storm water runoff in urban environments (Khastagir and Jayasuriya, 2009).

3.1.5 Typical RHS components

Domestic RHSs vary in complexity, with the amount of water captured being a function of roof area and rainfall. Various publications address design aspects of a RHS (Krishna, 2005; McCarton, 2009), with some sophisticated RHSs incorporating intelligent computer management systems, submersible pumps, and links into the mains of domestic water supply systems.

In the most basic form a domestic RHS will usually comprise of a collection surface, conveyance system, storage, and plumbing distribution system. Other secondary components might also need to be incorporated, such as first flush systems (divert water containing roof debris), filtration systems (removing debris and contaminants before entering the storage container) and pressure pumps (depending on elevation).

3.2 Variables that influence viability of rainwater harvesting systems

Variables that could potentially influence the viability of RHSs include:

- Rainfall quantity (mm/year) – The total amount of water available to the consumer is a product of the total available rainfall and the collection surface area (given some provision for losses).
- Rainfall pattern – The rainfall pattern and seasonal distribution.
- Collection surface area (m^2) – The size of the catchment area, typically a roof structure.
- Storage capacity (m^3) – Calculation of the optimum storage capacity is required.
- Daily consumption rate (litres/capita/day) – High daily consumptions can normally not be supported reliably by a RHS.
- Alternative water sources – The availability of alternative water sources (e.g. groundwater).
- Demand management strategy – Managing of domestic demands could influence consumers to consider alternative sources, such as RHSs.
- Cost – The affordability and financial benefit of the RHS.

3.3 Various user regimes

There are four types of user regimes, classified by the amount of 'water reliability' that a RHS can ensure. Classifying the various common user regimes can help to develop a better understanding of the type of RHS that is required. Four types of user regimes are presented by Thomas (2004):

- Occasional (opportunist) – Water is collected frequently with a small storage capacity, allowing the user to store only enough water for a maximum of one or two days.
- Intermittent – This type of pattern is one where the requirements of the user are only met during a part of the year. A typical scenario may be where there is a single long rainy season, and most or all of the user needs are met. During the dry season an alternative water source has to be utilised.

- Partial – This type of pattern provides for a partial water supply to the user requirements throughout the year. This type of user pattern is applicable to areas with a uniform rainfall pattern and a small to medium sized storage capacity, or in areas with a single wet season and larger storage capacity.

- Full – With this system the total water demand of the user are met throughout the year. A strict water management strategy is normally required when such a system is used, to ensure a permanent water supply.

3.4 Rainwater quality for domestic consumption purposes

Although rainwater is one of the cleanest forms of water, it can still become contaminated during the rainwater harvesting process. Contamination of rainwater is potentially caused by one or more of five main contributing factors.

- Pollution of rainwater during its passage through the atmosphere.

- Dry deposits of atmospheric pollutants onto the collection surface during dry periods.

- Chemical or physical reaction of rainwater with the collection surface, or other system components.

- Bird and animal faeces deposited onto the collection surface.

- Fouling of water due to storage devices and conveyance systems not cleaned regularly or water becoming stale in tanks due to age.

The quality of rainwater has been extensively investigated by a number of researchers throughout the world, but the literature on health aspects of RHS is limited, even in countries where RHS has been practiced for many years. Nonetheless, maximum concentrations of total coliforms for non-potable indoor use of rainwater are suggested to be less than 500 cfu/100 ml, and faecal coliform levels should be less than 100 cfu/100ml (Krishna, 2005).

Residents in the lower Breede River valley can be classified as partially reliant on RHSs for all their potable water demand. They mostly have holiday houses, and although the houses are visited during weekends and holidays only, reliance on RHSs for potable water supply is complete (100 %).

Most of these residents employ certain measures to ensure that water quality remains safe for full potable use. They typically:

- Maintain the roofs and gutter systems of their houses to be clean and free of lichens and bird faeces. Roofs are scrubbed clean and painted every 5-8 years.
- Completely consume or let run out all stored water on a yearly basis.
- Keep tanks sealed off to prevent animals and mosquitoes falling in or breeding inside respectively.
- Clean tanks every 5-8 years.
- Add disinfectants (such as Milton) to the water stored in tanks.

By following these basic steps residents are generally able to drink water from RHSs without suffering any ill effects related to poor water quality.

3.5 Application of RHSs in South Africa

In South Africa and specifically in the Western Cape, rainwater harvesting is not a new concept. In coastal and other small towns where there are no reticulation networks supplying water to domestic consumers, such as residential developments next to the lower Breede River (near the small holiday towns of Malgas and Infanta), rainwater harvesting for full domestic consumption is a frequent occurrence. In some other towns where the water supplied via the municipal reticulation network is brackish and thus has a bad taste, such as Stilbaai, close to the town of Riversdale, many individual households harvest rainwater for the sole purpose of drinking water. Interestingly, in these situations, rainwater harvested from roofs and gutter systems that are cleaned infrequently, and often stored in old asbestos-cement tanks for a couple of months, is deemed to be of a better quality and better tasting than water supplied via municipal reticulation networks. Stilbaai residents affectionately refer to these tanks as "drinking water tanks".

In the small town of Van Wyksvlei, in the Northern Province, most of the residents have RHSs. Discussions with the local municipality (Mr Bruwer) revealed that the municipal water supply used to be fairly unreliable. In addition, the water from some sources in the area has a high fluoride content and does not taste well. The RHSs in this town was therefore constructed to serve as an emergency water supply (during times when municipal supply failed) and to provide water of better taste for drinking. Some residents also use this water for watering their gardens.

Van Wyksvlei's distribution network, sources and bulk infrastructure were in the process of being upgraded at the time of this report.

Recently, 100 low cost housing units were erected in Van Wyksvlei (Note: some informal sources refer to this project as "100 low cost houses in Carnarvon"). DWAF provided funds for supplying each of these households with a RHS, in addition to their normal municipal water connections. Each of these consumer's RHS comprise a 32 m^2 roof, a gutter system with downpipes and a 2.5 kℓ tank (DWAF funded the tanks only). It was expected that the residents would purchase and fit their own yard taps onto these tanks. However, most of the residents living in this development are extremely poor, and in most cases these taps have not been installed to date. All of these tanks are equipped with bottom outlets, and with no yard tap installed, the water that is captured by the RHS simply flows straight out of the tanks again. At the time of writing of this report, measures were being put in place to rectify this problem. Unfortunately, Van Wyksvlei recently experienced three periods of abnormally high rainfall, and all the water that could have been stored by the RHSs, has been lost.

A survey of the database of all borehole applicants in the City of Cape Town (about 4000 records), revealed that there are only 11 users who reported having RHSs installed. This number is considered to be very low and might be unreliable, because the focus of that registration process was on groundwater use. Many more are expected to exist, but no record of such is available. The project team contacted two of these users personally to learn more about their reasons for using RHSs. The one indicated that the previous owner had installed the tank, that it serves no benefit to him and that he intends removing the tank from his property. The other owner indicated that he had the RHS installed at the time of the severe water restrictions that was enforced by the City of Cape Town in October 2004. The owner also added that he now knows that it does not make economic sense to install such a system and he would not have done it if given the opportunity to reverse the decision and the knowledge gained since. These two probing investigations are in line with other findings, underlining that:

- the installation of RHSs are generally drought driven, or pre-date the current relatively reliable water supply from municipal WDSs.

- RHS are relatively expensive and do not make economic sense, particularly in the Western Cape.

Another example of a domestic RHS is one in Monte Sereno, Somerset West, Cape Town. The owner had two 5500 litre tanks installed, equipped with a pump and flow switch, connected to a separate plumbing system in the house, supplying water to the toilets only. This property was one of very few examples where the project team could identify a property where rainwater is used for any other purpose than GI. The residents state that they are happy with their RHS and that they have not experienced any problems with it yet. They can however open a valve to also feed the toilet system from the municipal supply, but maintain that they only very rarely had to do that. Because they live in the house for less than 50 % of the time during the year, it is very difficult to draw any conclusions in terms of year round supply from their experiences with the particular RHS. Their total tank volume of 11 000 ℓ of rainwater (accepting full tanks) would probably be good for 1100 x 10 ℓ toilet flush events. At 5 flushes per person per day, assuming no additional water is fed in to the system from a rain event, the storage would last for 110 days. Even in summer one would expect some rain at least once every two months, and with them being away often, their system is expected to see them through (as reported during the interview).

3.6 Potential and yield of rainwater harvesting in the Western Cape

3.6.1 General

Rainfall throughout South Africa generally occurs seasonally, implying that adequate storage capacity must be ensured so that the water collected during the rainy season, could last through the dry season. This cannot always be met, due to the fact that some residences might be constrained by the collection surfaces area or inadequate storage capacity volume.

This seasonal distribution of rainfall is particularly applicable to the Western Cape. The Western Cape's climate differs distinctly from the climatic conditions in the rest of South Africa. Most of the province experiences a climate, characterised by cool, wet winters and long, warm and dry summers. Winter rainfall is dominant in the south-western part of the province, but up to 25 % of the province's rainfall occurs during summer (October to March). In the extreme east of the province the prevailing summer rainfall patterns, like over most of South Africa, occur, and a small area of the province even receives year-round rainfall.

Mean annual rainfall for the Western Cape is 348 mm, but varies drastically, ranging from 100 mm in arid interior and west coast, up to 3 000 mm in some mountainous areas. Monthly average rainfall figures throughout major South African cities are contained in Table 1 below.

This table clearly indicates that rainfall in the Western Cape is mostly a winter occurrence (compare Cape Town figures to that of Johannesburg).

This problem is compounded by the fact that most Western Cape gardens have to be irrigated during the long and dry summer months, increasing the already high summer demands even further.

Table 3-1 Monthly average rainfall (Jacobs and Haarhoff, 2004a)

Average monthly rainfall (mm)				
Month	**Location**			
	Johannesburg	**Bloemfontein**	**Durban**	**Cape Town**
Jan	132.7	79.4	132.1	12.0
Feb	105.7	84.3	131.1	13.9
Mar	94.5	81.9	129.5	15.3
Apr	51.6	53.6	69.9	38.4
May	20.0	21.3	54.3	62.0
Jun	8.4	10.1	33.1	77.5
Jul	8.3	9.5	26.3	71.4
Aug	7.2	13.1	42.9	64.6
Sep	24.4	21.2	72.2	39.8
Oct	67.9	46.5	99.8	28.7
Nov	112.6	65.0	123.1	17.2
Des	119.3	65.6	118.6	13.1

RHSs in the Western Cape would therefore receive rainwater mostly in winter, with very little rainfall during summer months. Given the high demand during summer, water stored in storage devices would be consumed quickly, and not be replenished in order to be a sustainable water source throughout summer. During winter the domestic demand becomes very low and storage devices would fill up rapidly and overflow, resulting in the loss of water that could otherwise be used for consumption in the long dry summer months.

A first order estimate of the total monthly yield from a RHS for a roof size of 200m² (corresponding to a relatively large house in a low-density suburban area) and "unlimited tank size" could be obtained by simply considering one summer month (say December) in each of the four regions listed in Table 3-1. The average monthly yield for each city is given in brackets:

- Johannesburg (24 kℓ/month; 774 ℓ/d)
- Bloemfontein (13 kℓ/month; 423 ℓ/d)
- Durban (24 kℓ/month; 774 ℓ/d)
- Cape Town (2.6 kℓ/month; 84 ℓ/d).

The major limitation with RHSs in South Africa, particularly in the Western Cape winter rainfall region, stems from lack of synchronisation between rainfall and garden irrigation demand. In those regions where a RHS would be relatively high yielding (e.g. Johannesburg and Durban) the water is not required in that season due to the summer rainfall, while in Cape Town where it is required in summer, the yield is extremely low.

The tank size plays a major role in limiting the yield even further. Sizing of rainwater tanks is discussed in more detail by others (e.g. Butler and Memon, 2006), who also present different methods for determining tank size. It is not practical nor aesthetically acceptable to install a tank that is "too large". Tanks larger than 5 kℓ on a residential stand are considered to be relatively large and inappropriate. Typically, a total storage capacity of 20 kℓ therefore consists of 4 x 5 kℓ tanks. Tank sizes typically seem to vary between 2 and 5 kℓ.

As part of this study calculations were performed by means of a model to evaluate the yield and cost for high density and low density residential areas. The potential feasibility of RHSs, based on theoretical analyses, could thus be evaluated. Optimum tank sizes were calculated through evaluating the relationship between tank yield and tank size, where the optimum tank size, is the tank that could yield the largest volume of water, with the smallest possible tank size. In addition, most economic tank size was calculated, based on tank cost in relation to the volume of rainwater yielded. The most economic tank would thus be the tank with the lowest tank yield cost.

3.6.2 High Density Residential Areas (HDRAs)

Through the above-mentioned calculations, it became apparent that, in high density residential areas (such as low-cost developments), no additional tank yield is attained beyond a certain tank size. This is due to the fact that the catchment area of a high density house is relatively so small, that it restricts the volume of rainwater that can potentially be yielded, as shown in Figure 3-1. Another observation that deserves mentioning is that the optimum tank size for all high density residential areas is larger than the economic tank size (as shown in Figure 3-2). From the results it can be noted that the optimum tank size, given the input parameters for Cape Town and Bloemfontein, is 2.5 kℓ. In the case of Johannesburg and Durban the size is 5 kℓ, while economic tank size is 1.5 kℓ for all regions.

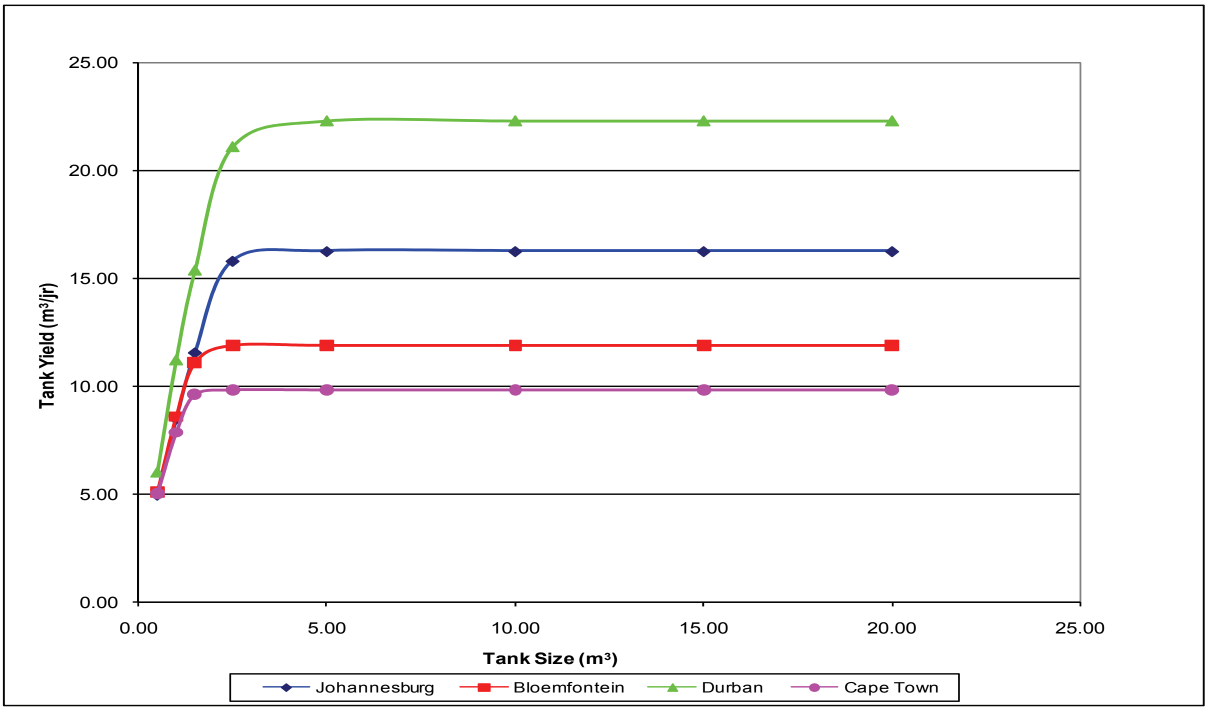


Figure 3.1 – Optimum Tank Size for HDRA

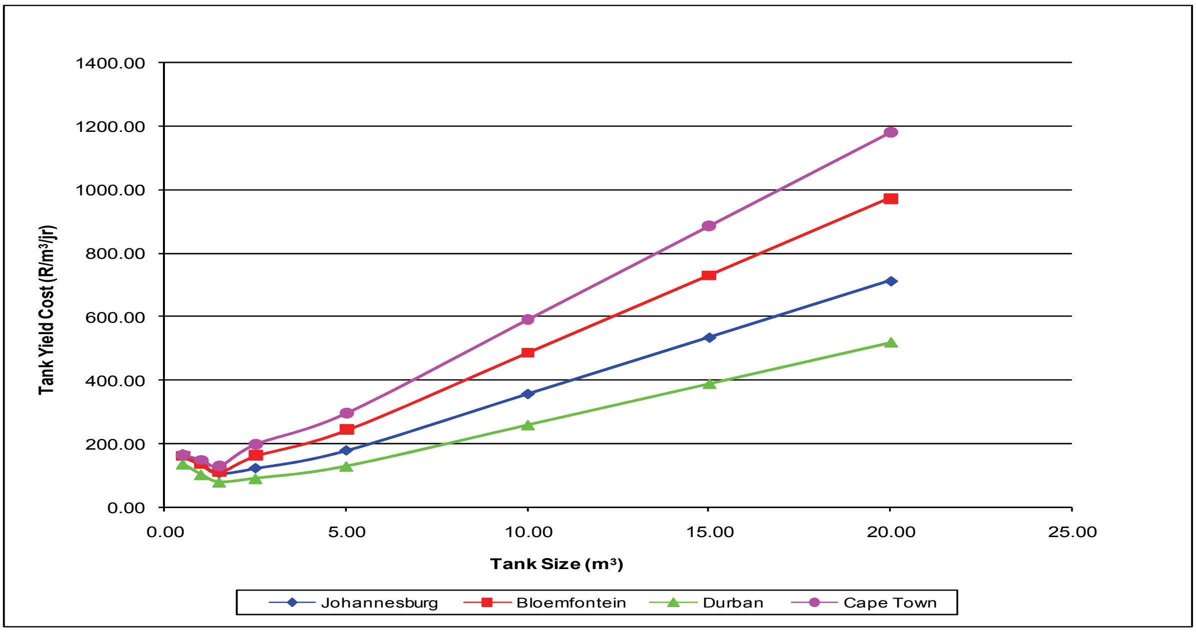


Figure 3.2 – Most Economical Tank size for HDRA

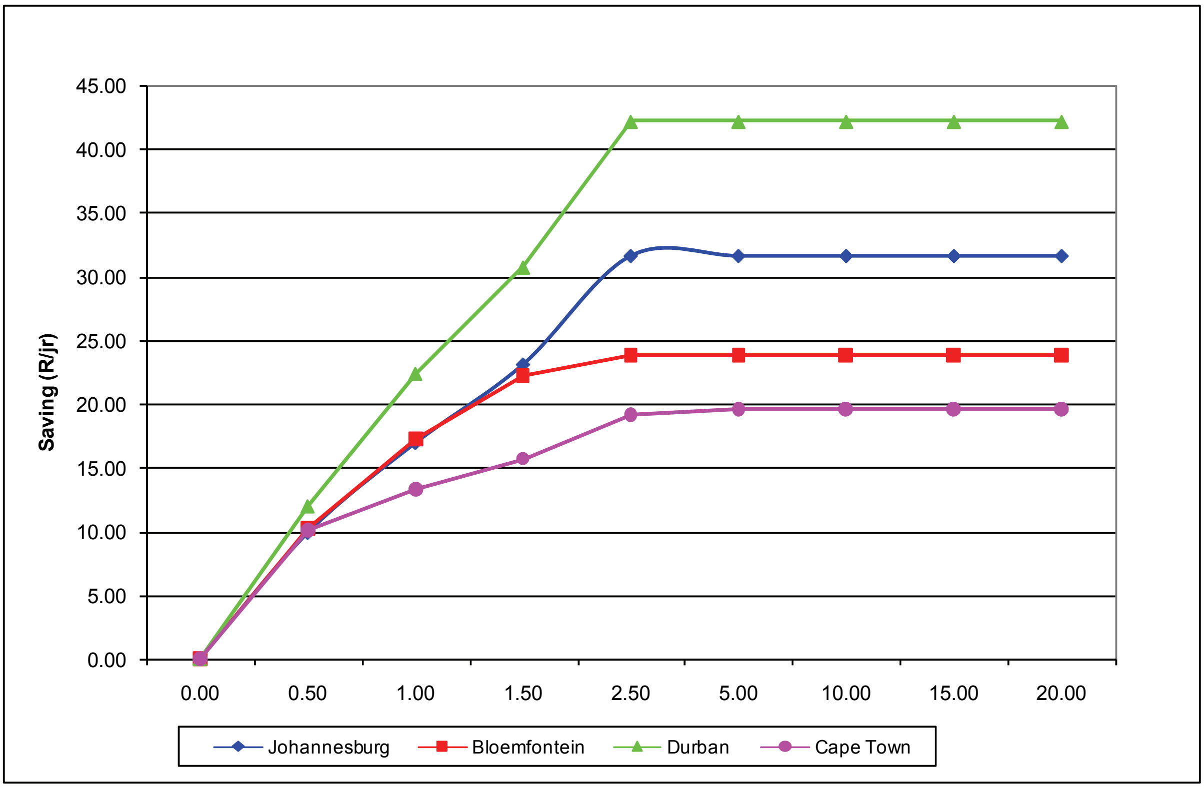


Figure 3.3 – Financial Saving achieved implementing a RHS in a HDRA

It was also determined that, in terms of financial benefits, the areas subjected to a higher annual rainfall yield significantly larger savings in municipal water bills when implementing domestic RHSs (see Figure 3-3 above). With a financial saving on the monthly water bill of 70 % for Durban and 53 % for Johannesburg, domestic RHSs installed in these areas could provide significant savings on domestic water bills. However, comparing the optimum tank cost (5 kℓ tank @ R2 903.00) for Durban, with the average annual water bill saving (R42.22), the average high density household could require 69 years to reimburse the initial capital expenditure. Bearing in mind that Durban yields the largest potential saving, areas such as Bloemfontein and Cape Town could require much longer periods to settle the initial capital expenditure. For this reason, the individual high density household would not benefit financially – at all – by installing domestic RHSs.

3.6.3 Low density residential areas (LDRAs)

The optimum tank sizes for LDRAs are considerably larger than that for HDRA. This increase in optimum tank size is as a result of bigger catchment areas associated with houses in low density residential areas. Catchment areas (roofs) of houses in LDRAs are almost a factor of ten larger than those associated with HDRAs.

When comparing tank yield with tank size for LDRAs, it became apparent that an increase in tank size will result in a potentially higher tank yield. This was not the case for HDRA, where no additional tank yield was attained beyond a certain tank size. It was decided, for practical reasons, to consider 20 kℓ as the upper limit for total tank size, as more than four 5 kℓ tanks could become inconvenient and unsightly on the average size residential plot.

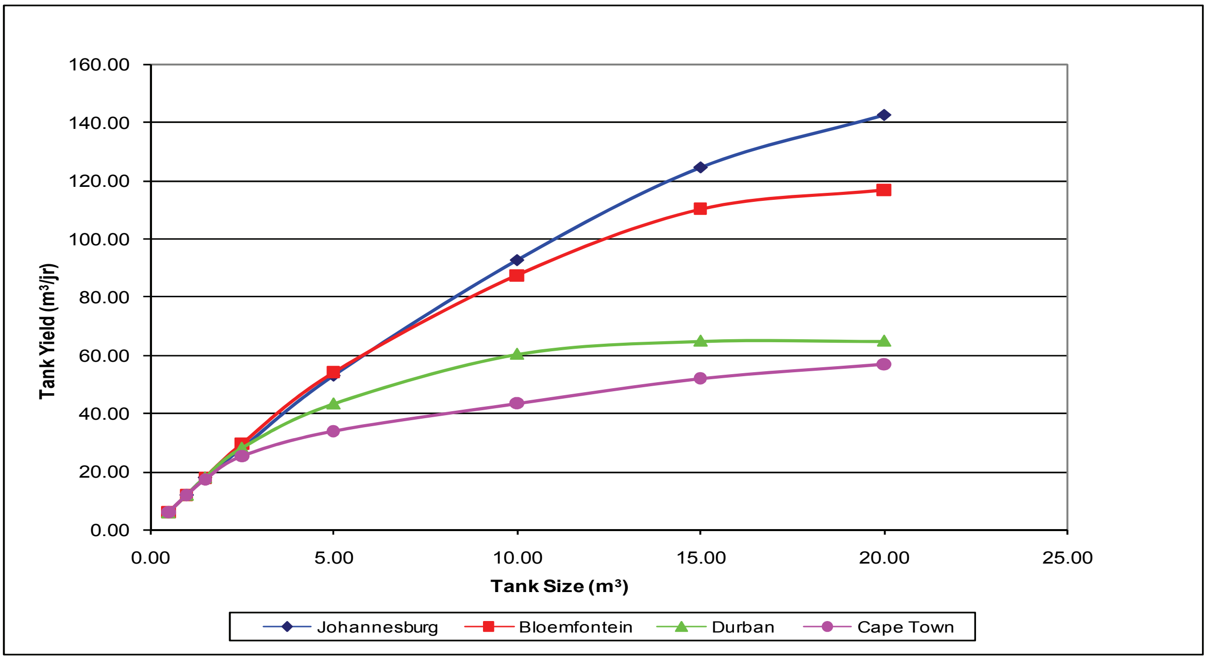


Figure 3.4 – Optimum Tank Size for LDRA

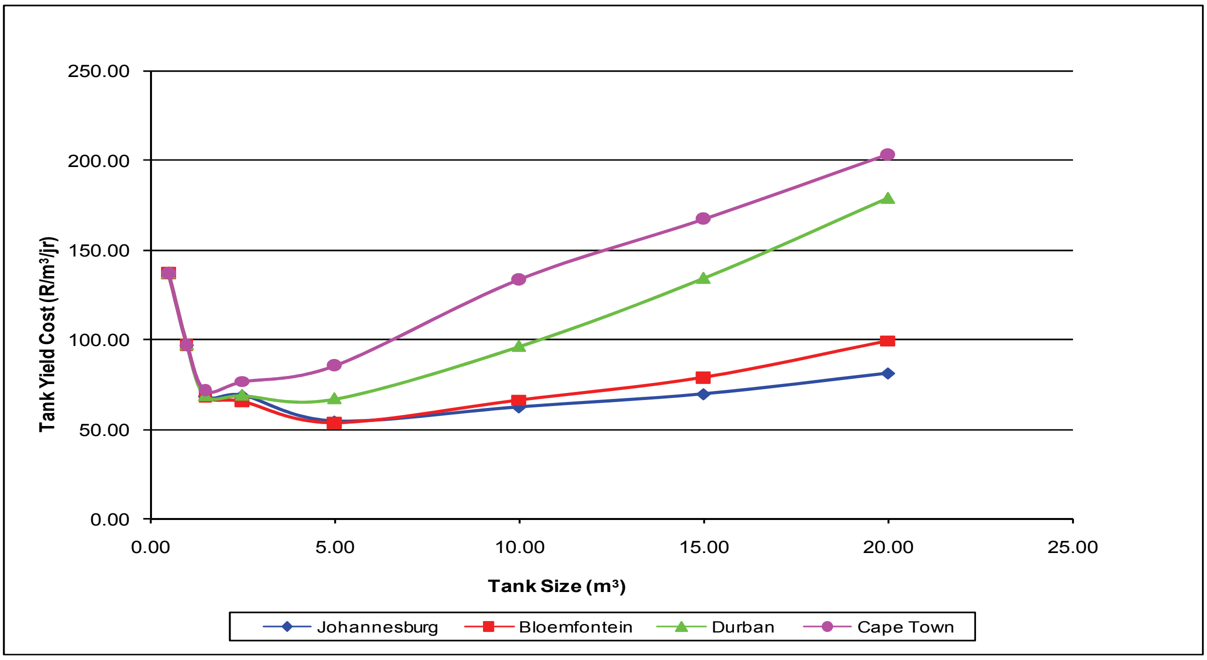


Figure 3.5 – Most Economical Tank size for LDRA

From Figure 3-4 above it is clear that the optimum tank size for Cape Town, Johannesburg and Bloemfontein is equal to the predetermined maximum of 20 kℓ. For Durban it is 15 kℓ, due to the low external summer water demand assumed for Durban. The most economical tank size for Cape Town is 1.5 kℓ, while for the other three regions it is 5 kℓ, as illustrated graphically in Figure 3-5.

Guillon et al. (2008) estimated that in Paris, France, a 4 kℓ tank and 100m² roof would satisfy 50% of the mean annual watering demand for a 100m² garden. This is somewhat more than the findings from this study. As an example, it can be deducted from Figure 3-4 that a 5kℓ tank in Johannesburg would yield 55 m³/year. Theoretical end-use modelling of a typical property in Johannesburg by Jacobs and Haarhoff (2004b), with 125m² lawn, suggested that the GI demand would be 0.21 kℓ/d, or 153 kℓ/year for the property reported (the values here are half that reported in the original work for a garden twice the size). The local RHS would thus satisfy 36% of the total annual GI-demand.

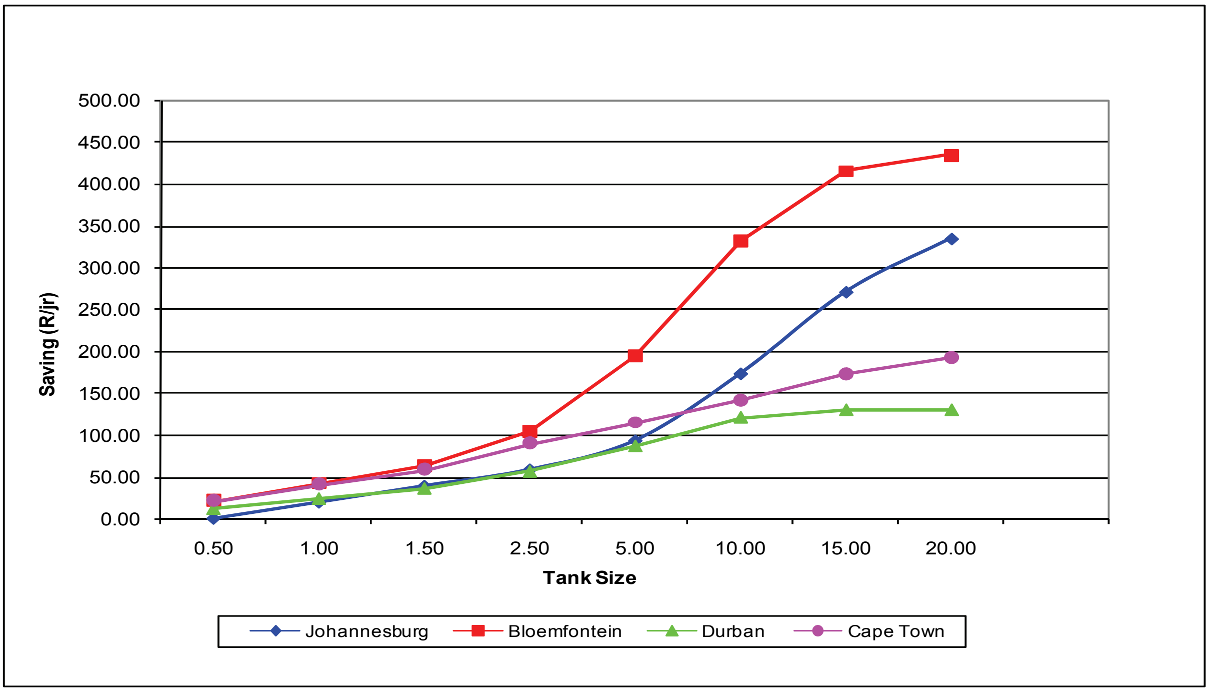


Figure 3.6 – Financial Saving achieved implementing a RHS in a LDRA

In terms of financial benefits, LDRA tank yield cost figures show a 50% decline compared to HDRA tank yield costs, also as a result of larger catchment areas associated with LDRAs. Furthermore, LDRAs subjected in the model runs to a higher annual rainfall did not yield more financial savings in municipal water bills. Financial savings on municipal water bills of 57% for Johannesburg and 47% for Bloemfontein were calculated. Durban yielded a financial saving of only 33%, as a result of Durban being situated in a higher rainfall region, thus outdoor demand is continuously met throughout the year.

Contrary to what might be expected for Cape Town, the calculations showed that a very low financial benefit was to be gained from RHSs. During the summer months, Cape Town has a higher outdoor water demand than the other geographical regions of the country and being situated in a winter rainfall region, tank yield during these months is extremely low, thus resulting poor financial savings. The potential monetary saving is shown in Figure 3-6 in Rand per year.

By considering optimum tank size costs, and average monthly water bill savings, financial reimbursing periods for low density residential areas are shown below:

- Johannesburg – Reimbursing period = 31 years (4 x 5m³ tanks @ R 2 903 ea)
- Bloemfontein – Reimbursing period = 27 years (4 x 5m³ tanks @ R 2 903 ea)
- Durban – Reimbursing period = 67 years (3 x 5m³ tanks @ R 2 903 ea)
- Cape Town – Reimbursing period = 60 years (4 x 5m³ tanks @ R 2 903 ea)

It is therefore clear that individual low density households would not benefit financially by installing a domestic RHS.

From a water conservation point of view, an average of 35% of the total household water demand could be saved, 57% in Johannesburg, 47% in Bloemfontein, 33% in Durban and 22% in Cape Town, given that the optimum tank size is used, thus maximizing the yield for given financial input. This represents a significant saving. Therefore, given that South Africa is a semi-arid country, prone to water restrictions, RHSs become an attractive measure simply from a conservation viewpoint.

It can therefore be concluded that domestic RHSs have reasonable water conservation potential, for both HDRAs and LDRAs in South Africa, but are not economically viable in view of individual households' financial savings. From a financial perspective, reimbursing the initial tank and installation expenditure only out of monthly water bill savings would not be attractive for the residential consumer. In order to utilize the potential water conservation associated with RHSs, government incentives and initiatives should be launched to make implementation of RHSs more attractive for domestic consumers. This should, of course, be weighed against other water conservation options.

3.7 Strategic assessment of rainwater harvesting

3.7.1 Trends and Developments

Some three years ago, severe water restrictions were imposed on residents living in the City of Cape Town. Watering of gardens was only allowed on certain days, and then only by hand-held spray and not by using automated sprinkler systems. The cost of water soared and residents had no choice other than to conserve water. Water savings of ±40% were achieved in LDHI regions and about ±10% in HDLI areas (Jacobs et al., 2007). During that time many Capetonians started considering water-wise gardening for the first time, and some started implementing greywater reuse systems, groundwater abstraction and the harvesting of rain water. These alternative sources seem to be drought driven in the case of Cape Town, as reported for other regions in earlier studies (Simpson, 1990). A recent report by White (2009) showed that social aspects regarding the adoption of RHS at household level could successfully be modelled, but such modelling is beyond the scope of this study.

The fact that rainwater tanks are unsightly and often impractical seemed to deter some residents questioned during this research from using a RHS. In some local group housing areas home owners associations in fact prohibit the siting of rainwater tanks on properties.

Probing around hardware stores and nurseries in Cape Town revealed that greywater reuse seemed to be fairly popular at the time and seemed to be preferred above rainwater systems, according to equipment suppliers. Various hardware stores sold kits and pumps for this purpose, and staff had knowledge of how to implement these systems or assist customers to do DIY installations. However, the period of severe water restrictions soon went by and greywater systems and greywater pumps were not selling in these stores any more. For example, discussions with one local pump supplier (D&D pumps; Brackenfell; Mr Eric Turner) revealed that 1000 greywater pumps were ordered from a Chinese manufacturer, of which only 50 could be sold at the time.

Currently the cost of water in Cape Town is not exorbitant, and no water restrictions are in place. There are no incentives in place to utilise RHS. The findings of this project point to a reduction in the implementation and use of RHSs in the Cape Town area, rather than these systems becoming more common. Local trends often follow certain international trends. In the UK, Ward et al. (2008) note that the rate of uptake of RHS in the UK has been slow to date, but is expected to gain momentum in the near future due to improved technology. The design of two RHSs is evaluated by those authors, using a state-of-the-art continuous simulation modelling approach. The RHS were shown to fulfil between 36% and 46% of toilet flushing demand. This trend is not necessarily considered to be one directly applicable to South Africa, because the rainfall locally is notably more variable/seasonal, limiting its application for toilet flushing to special cases (such as the one case discussed in this report).

Looking further northwards to the small town of Van Wyksvlei, water has always been a very scarce commodity. All its residents are very aware of this and are very pro-active in conservation of water. Given the historic unreliability and bad taste of municipal water supply, a large percentage of the local inhabitants have installed RHSs already. In the case of indigents, such as most of the people living in the 100 recently constructed low income houses (discussed earlier), DWAF provided funds for installation. Without funding most of these houses would not have had RHSs, as many residents could not even afford to purchase the yard tap required to seal the tank and abstract water from it.

In places where no municipal water supply exists, such as on farms and in some holiday towns, borehole water seems the most frequently utilised source, and in some instances, it is supplemented by water from a RHS. Very rarely do residents rely on RHSs as their sole water supply. In serviced urban areas RHS are uncommon and where they are still in use the origin seems to be drought-driven. No organisations could be identified that specialise exclusively in the design and installation of RHSs.

3.7.2 Summary

Rainwater use seems to be uncommon in residential areas of the Western Cape today, mainly due to the relatively high cost of storage tanks, the negative visual impact of rainwater harvesting systems and, most importantly, the fact that the high-demand summer period corresponds to the dry season in the Western Cape. It is apparent from information gained during this study that rainwater use is more prevalent in other areas of the country, for example the central Karoo, where the negative seasonal effect is less pronounced.

As is the case with groundwater, gaining knowledge about the presence of rainwater use is often hampered by uncooperative home owners. However, visual inspection and even the use of high resolution orthophotos enable the team to spot large rainwater tanks without involving the home owner at all. In contrast to groundwater abstraction, it is relatively easy to obtain theoretical estimates of the volume (yield) from each individual home. Theoretical estimates of the available yield are a function of the impervious area (typically the roof), storage tank size and rainfall.

- RHSs are currently implemented in South Africa mainly where no municipal water supply is available (e.g. farms and lower Breede River settlements), where the taste of municipal water motivates consumers to implement RHSs for drinking water (e.g. Stilbaai and other coastal towns) or where municipal supply is unreliable (e.g. Van Wyksvlei) or was unreliable and the level of service has since been improved, but the RHS has remained in place/use.

- Houses in high density residential areas in the Western Cape are generally limited due to catchment area (small roofs), and therefore can only yield low volumes of rainwater. Financial benefits are limited and households would typically reimburse the initial capital expenditure after a very long time.

- Houses in low density residential areas in the Western Cape are generally not limited with regard to catchment area (relatively large roofs). However, because of extremely high summer demands, and Cape Town being situated in a winter rainfall region, tank yield during summer months is low, thus resulting in poor financial savings. Financial benefits are limited and households would typically reimburse the initial capital expenditure after many years only. In agreement with this study financial analysis by Ward et al. (2008) revealed that RHS within large commercial buildings in the UK may be more financially viable that smaller domestic systems such as those at individual homes.

- From a water conservation point of view, a significant potential water saving can be achieved via implementation of RHSs.

- Because RHSs are generally not financially attractive to residential consumers, government should consider initiatives and incentives motivating residential consumers to implement RHSs after weighting these systems up against other WDM measures.

4. GREYWATER

4.1 Greywater as a HWS

The reuse of greywater could be considered an alternative water source at home and is probably the most contentious of the three HWSs addressed in this study. Presuming that water is used in a home, this source is available to every household. Greywater reuse is an extensive topic and addressing it could easily result in creep if the scope is not contained when it is included in a wider study, such as this one. Literature on the topic of greywater and its reuse abounds. It is the intention of the project team to review it as a HWS while limiting the depth in which it is addressed. The inclusion of greywater reuse as a HWS is considered essential, because greywater reuse is clearly becoming more common in urban areas where it is a cheap and easy source to tap into. Its reuse (disposal) could be intentional or unintentional, with corresponding causes for concern in the latter case, where its disposal is a problem in high density areas (Carden et al., 2007a; Carden et al., 2007b).

Greywater has been reused worldwide to reduce costs and even more importantly to save water supplied from other resources via potable distribution systems. Its application locally has also been researched (Jackson et al., 2006). Some of the greywater reuse systems are designed with filters or treatment processes, while others focus on greywater reuse in low-density areas where it is often used intentionally without any treatment prior to application (Jacobs and Van Staden, 2008). It was noted during the former study that filtering is often employed in cases where greywater is pumped via piped irrigations systems merely to prevent clogging, but in many instances greywater is reused on-site directly via surface application, without any treatment or filtering.

4.2 Wastewater flow volume

Greywater is one component of domestic wastewater. Per capita wastewater flow is reported on by Tchobanoglous and Burton (1991) and Lott et al. (1999). The range of values for the total wastewater flow volume from a single residence is 170-341 ℓ/c/d. The typical value from both authors is about 250 ℓ/c/d for a suburban stand, but no indication is given whether this includes leaks.

Three components for wastewater flow (domestic water use, leaks, and infiltration), based on actual measurements and subsequent system modelling, are presented for a residential area in

Alberton (GLS, 2001). The results indicate a wastewater flow of 0,617 kℓ/stand/d resulting from domestic water use plus 0,259 kℓ/stand/d resulting from leaks. The average household size for high income suburbs in Alberton at the time was 3,5 PPH (Veck and Bill, 2000). The per capita wastewater flow is thus calculated to be 0,176 kℓ/c/d, with an additional 0,074 kℓ/c/d contributed by leaks.

4.3 Greywater generation rate

Greywater generation rate was not measured as part of this study. Nevertheless, an understanding of the greywater generation rate is essential, justifying measurement of the volume at one property as well as a brief review of values reported elsewhere. According to general sources greywater comprises approximately 50 to 80% of residential wastewater (Wikipedia, 2008).

A more precise estimate of the greywater volume from the particular end-uses where greywater is generated is possible by means of end-use modelling. Jacobs and Van Staden (2008) presented an estimate for the contribution of greywater-generating end-uses in a "typical" suburban home. Their results show that the bath-shower and washing machine contribute respectively 116 and 102 ℓ/stand·d to the indoor demand of 559 ℓ/stand·d. Presuming that the water supplied to each end-use point is reused 100% effectively, the total greywater volume available for use would thus be 218 ℓ/stand·d, representing 39% of the total indoor demand. They also refer to other studies (e.g. Eriksson et al., 2003) that cite others to state that greywater contributes up to 75% of the total wastewater flow to domestic sewers. Literature also suggests that greywater generating end-uses contribute a significant fraction to the indoor water demand in a typical suburban home. In urban Australia the combined greywater from the bath, shower and basin is reported to contribute 26% to total household consumption and the washing machine an additional 15%, resulting in a greywater contribution of 41% to total demand, including outdoor use (Christova-Boal et al., 1996). The total average water consumption of the dwelling in consideration was 250 kℓ/a, thus suggesting a greywater volume of 280 ℓ/stand·d.

Another perspective is gained by considering area-wide use. Given a property size of about 1000 m² and a coverage of 75% the greywater generated per land area by properties similar to those in this study could reach a maximum of about 2000 ℓ/ha·d – if all properties in a specific area were to reuse all available greywater. These estimates of greywater volume place such residential communities in the bracket with a greywater generation rate of between 500 and

2500 ℓ/ha·d, where on-site disposal and reuse "could be considered" from a health-perspective (Carden et al., 2007b).

The greywater generation rate from one property was available to be evaluated as part of this study. On the particular property the greywater is stored in a 1 000 litre container and is subsequently irrigated onto the garden by a level-control pump and piped irrigation system when the drum is full. It was thus relatively simple to determine the frequency of irrigation events by simply counting each event, which corresponds to 1 kℓ of greywater per event. It was found that an average of ± 333 ℓ/stand·d of greywater was irrigated on-site by the home owner during summer, with about 10 applications of 1 000 ℓ/event each month. Based on end-use model estimates for the greywater generation rate on the particular property (in Cape Town with 4 people per household), the theoretical greywater yield for the property based on end-use modelling is 346 ℓ/stand·d, or 87 ℓ/c·d.

Zeisel and Nolde (1995) suggest a distribution of 90 ℓ/c/d to 65 ℓ/c/d for grey and black water respectively out of a total water demand of 160 ℓ/c/d for a West-Berlin dwelling in 1990 (5 ℓ/c/d is used for watering plants and is not returned).

A greywater generation rate – and thus HWS yield – of between 200 and 350 ℓ/d is considered realistic for a typical suburban property.

4.4 Discussion

Grobicki and Cohen (1999) provided results regarding the projected impact of water reuse on urban water demand in South Africa almost a decade ago. Although the potential for domestic reuse is discussed in their report, it is noted to be less significant than reuse of, for instance, industrial wastewater. Potential non-potable residential end-uses earmarked for reuse by those authors include car wash, toilet flushing and garden irrigation. This study identifies residential on-site greywater reuse as a contentious yet promising alternative water source to urban communities, particularly in the LDHI-regions where health concerns are less pronounced and the generation rate is notably higher than for HDLI-regions. Its reuse is economically viable if not treated in any way. However, when treated and disinfected prior to reuse the product water becomes relatively expensive and the option is less attractive.

The required greywater reuse quality is discussed by Jackson and Ord (2000) for reuse in the UK, and it is suggested that the water standard meets the UK's bathing standards if it is used for toilet flushing. When it is used for irrigation the natural rate at which pathogens die off when exposed to the natural environment (e.g. when wastewater is used for irrigation) is a valuable safety factor and is encouraging for reuse of greywater for garden irrigation.

The volume of water available from greywater reuse is relatively small compared to groundwater. The combined application of greywater with rainwater, which is also a relatively low yielding source, is viable in some geographical regions – as investigated in more detail by Dixon (2000). The strategic level of this study does not justify discussing this in further detail.

5. HWS MODEL AND ANALYSIS RESULTS

5.1 The HWS end-use model concept

The theoretical impact of HWSs on water demand from the Municipal supply could be assessed rationally. The ultimate (maximum) saving could be estimated, with various analyses to suggest more realistic scenarios if fewer customers were to make use of such alternative sources on their properties. The model is presented schematically in Figure 5-1 and the possible supply sources and waste sinks for a particular end-use "n" in Figure 5-2. In the case of this study end-use "n" would be one of the "outdoor type" end-uses such as lawn irrigation (the garden), as discussed shortly.

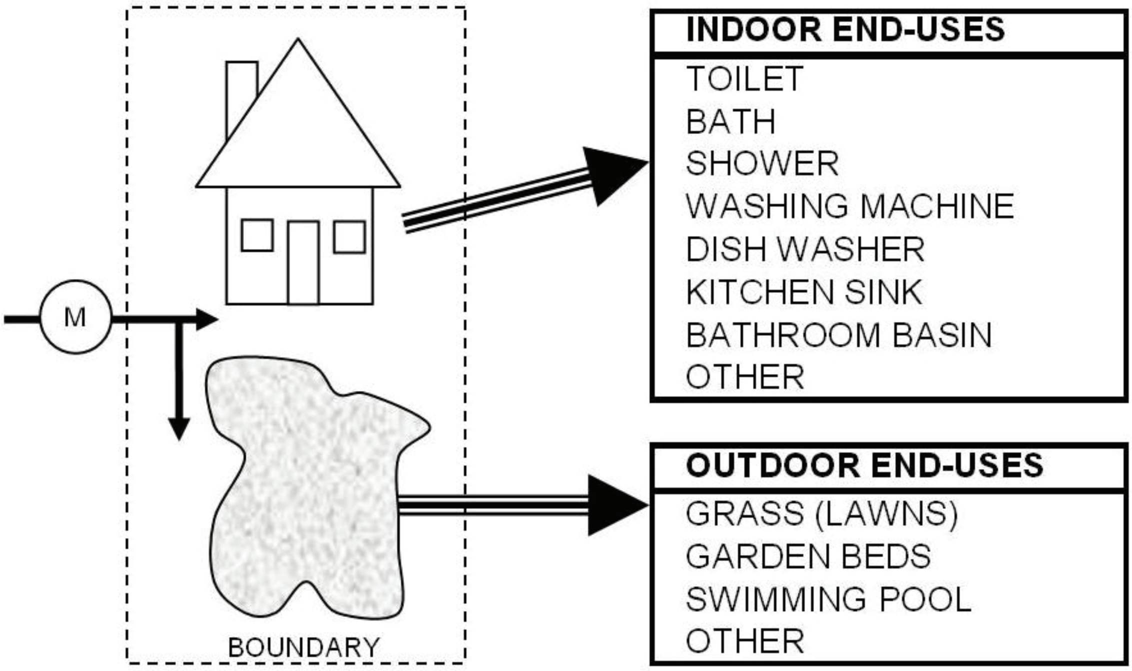


Figure 5-1: Schematic presentation of end-use model (Jacobs and Haarhoff, 2007)

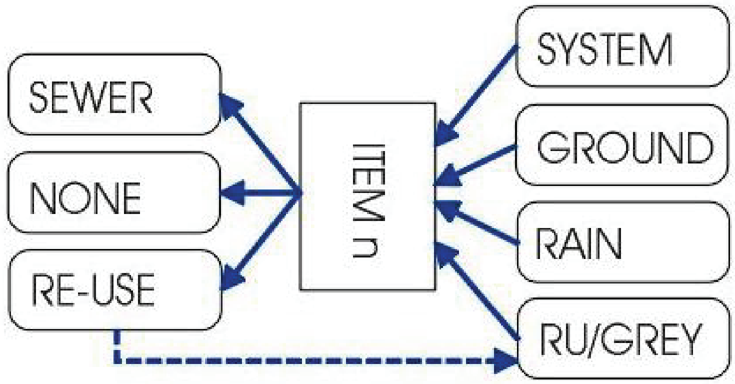


Figure 5-2: Schematic presentation of water sources for end-use "n"

5.2 Available end-use models

Two demand models that mention the incorporation of water reuse are TOPAZ-SUCO and WEAP. In both cases the models appear to be intended for comprehensive integrated water resources planning (IWRP) rather than residential end-use applications. For this reason it was considered appropriate to develop a HWS add-on to a local end-use model, reported on by Jacobs and Haarhoff (2004a). A brief review of the models is included below:

5.2.1 WEAP

WEAP was developed by Tellus, a Swedish non-profit research organisation. In 1999 WEAP was updated for the Windows operating system and now has the ability to forecast water demand based on a wide variety of elasticities. The system was designed to analyse planning activities and it incorporates wastewater flow and water quality. The methodology of the model is discussed in more detail by Van der Merwe and Barbour (2000) and Wurbs (1994). It is an IWRP tool rather than a residential end-use model and is not well suited for application in this project.

5.2.2 TOPAZ-SUCO

Two IWRP systems have been developed as computer models for use in Australia, one of which is called TOPAZ-SUCO (Gilbert and Maheepala, 1997a; Gilbert and Maheepala, 1997b). The model can assist in dealing with the complexities of management of water resources and related services in an integrated manner. The software is only available through a consulting contract with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia.

TOPAZ-SUCO is an acronym for Technique for Optimal Placement of Activities in Zones – Service Utility COsting. The TOPAZ-SUCO model was developed by SCIRO. Gilbert and Maheepala (1997b) report that the model has been tried and tested on data for an urban catchment of Northern Adelaide, Australia. The model has the ability to evaluate the effects of local water reuse, but the greatest drawback from the point of this investigation is the fact that the model is not readily available. As is the case with WEAP, both models are extensive IWRP tools and are not directly applicable for this project.

5.2.3 REUM

An end-use model called REUM, for residential end-use model, was developed locally (Jacobs and Haarhoff 2004a) and is ideal to use for this investigation due to its availability and open source code in an MS Excel environment. Other end-use models are also available locally (GLS, 2002), but only REUM has been described mathematically with a structure well suited for electronic application. REUM was used as a basis for the research in this project by extending the initial e-model to include HWS options.

From the demand-side the focus in terms of end-uses is on garden irrigation. This study reinforces the findings of previous work that garden irrigation is the primary application point for water from HWSs. Only in exceptional cases or as part of research projects could information be obtained where home owners applied the water at other end-uses (e.g. for flushing the toilet).

5.3 Lawn water demand as a micro-component

The theoretical change of a specific property's water use and wastewater flow could be evaluated by modifying only selected parameters in REUM, such as the weather variables, to model a similar property in different areas of the country. Irrigation of lawns is the main end-use resulting in such geographic significance, because its water requirement is dependent on weather variables.

However, in this study, where the focus is on alternative sources, the end-use model can be used to predict the impact of demand if a borehole were used on the property. This is possible by adjusting the parameter f, describing how much of the theoretical garden water demand is supplied from the Municipal supply system. In order to model garden irrigation four end-uses were identified that are dependent on evaporation. These include three vegetation types and the pool. Of these, the lawn is the most significant and also the most likely to end up being irrigated by water from a HWS.

5.4 Description of the model and modelling process

In REUM the outdoor demand comprises garden irrigation for three vegetation types, and pool evaporation (Jacobs and Haarhoff, 2004a). Garden irrigation requirements depend on factors influencing vegetation growth. Howe and Linaweaver (1967) reported that these factors include rainfall, run-off, infiltration, root zone storage and evaporation. Work by the above authors indicated that garden water irrigation is closely related to moisture deficit, or potential evapo-transpiration minus effective rainfall; Johnson (1987) also confirmed this locally.

A common method for calculation of evapotranspiration (ET), also presented by Green (1985), assumes that over a given period the ET is directly proportional to pan evaporation, p. In other words ET = (kp), where k is the empirical constant of proportionality known as the crop factor. Evaporation from a pool surface is also calculated by means of the same equation form, but k would represent the evaporation factor for the pool surface in that case.

Effective rainfall represents that portion of the rainfall that penetrates the soil and thus has an effect in reducing the water demand of plants. Various methods exist to estimate effective rainfall. In all cases the measured monthly rainfall, R (in mm/month), is the independent variable. The equation used in REUM to model the effective rainfall, r, originates from work by Linsley and Franzini and is reported on by Johnson (1987), who used this method to analyse the garden water demand in Port Elizabeth.

The equation states that rainfall less than 25mm is 100% effective and then decreases linearly until a point where rainfall in excess of 152mm has an effectiveness of only 89mm :

$$r = \begin{bmatrix} R & (R < 25mm) \\ (0{,}504)\cdot R + 12{,}4 & (25 \le R < 152) \\ 89{,}0 & (R \ge 152) \end{bmatrix}$$

In view of the above, the average monthly daily demand (AMDD) for an outdoor end-use e, and month m, is modelled by the following equation :

$$AMDD_{o,m,e} = (f_{m,e} \cdot s_{m,e}) \cdot \frac{(k_{m,e} \cdot p_{m,e}) - r_{m,e}}{days_m}$$

where subscript o denotes outdoor, m denotes month, and e denotes the end-use for the outdoor equation and $days_m$ refers to the number of days in a month. A value of 30,44 (the average number of days in a month) can be used to obtain average values, as was done in this study.

The equation for estimating outdoor use show a relatively simple linear relationship between the explanatory variables and the water demand. In other words, a linear result would be expected when adjusting the factor f for analysis as per this study.

The AMDD for all outdoor end-uses ($AMDD_{o,m}$ in litres/stand/d), the AADD for any specific outdoor end-use e ($AADD_{o,e}$ in litres/stand/d), and the AADD for all outdoor end-uses combined ($AADD_o$ in litres/stand/d) are obtained by summing over the 12 months, as reported by Jacobs and Haarhoff (2004a):

$$AMDD_{o,m} = \sum_{e=1}^{4} AMDD_{o,m,e}$$

$$AADD_{o,e} = \sum_{m=1}^{12} AMDD_{o,m,e} \Big/ 12$$

$$AADD_{o} = \sum_{m=1}^{12} \sum_{e=1}^{4} AMDD_{o,m,e} \Big/ 12$$

This end-use model, combined with the additional water supply from the HWS was used to analyse the effect of borehole use at low-density properties in Cape Town (where A > 1000m²), not taking into account the actual availability of HWS in that particular region. In other words, the result is a maximum potential reduction due to HWS.

5.5 Garden irrigation factor

The garden irrigation factor f is a theoretical parameter in the end-use model to describe and analyse garden water irrigation. It can be adjusted to represent changes in the efficiency of the irrigation system, the habits of consumers regarding over- or under-irrigation of vegetation, or as is the case here, to model water use from alternative water sources.

The value of f could be considered to vary between 0 and some higher value. If the factor were set equal to zero (f = 0) this would imply that:

- the garden is not irrigated at all

- the garden is irrigated entirely with water from the groundwater source, or
- the garden is irrigated with water from some other source (e.g. greywater reuse or rainwater use)

On the other hand, if the factor is set to unity (f=1) at the property is tells the reader that the irrigation volume for the garden is equal to what would be expected based on theory. In the upper extreme, the upper value of f is determined by over-irrigation of vegetation. At some upper limit of water addition the plant will drown, because no oxygen can reach the roots.

Considering potential garden watering from HWSs, as well as direct abstraction of groundwater by deep-rooted vegetation (such as trees), it could be expected that less than the ideal irrigation requirement of vegetation on a stand will have to be supplied by the municipal supply system. It is also safe to assume that most consumers do not water their lawns during winter. This is both true in the interior parts of the country where frost is common and in winter rainfall regions, such as the Western Cape. Thus, it is likely that $f < 1.0$.

5.6 Results – Theoretical saving for various scenarios

For the purpose of this modelling exercise, which is essentially a comparison between different HWS scenarios, it is not that critical to select any "correct" value for parameter f. This parameter is in fact adjusted between realistic boundaries (say 0 to 1) in order to theoretically assess the impact of HWS use on the Municipal supply. It is also important to note that it does not matter from a modelling perspective which type of HWS source is used; what is important is that water is used from "an alternative source" and not from the piped Municipal WDS.

Parameter f is used to describe:

- the fraction of all properties in a particular area that make use of HWS and
- the fraction of the total garden irrigation demand met by HWSs.

For this modelling exercise the following parameters were investigated and assumptions were made:

- the household size is set equal to 3 people per household (although a setting of zero people would provide the same insight into HWS, because the household size does not impact garden water use in the model). This is considered to be realistic for the stand size range under investigation at the relatively course resolution of this study.

- the total stand area is 1000m².
- In all cases (including larger stands) 25% of the area is considered to be covered by irrigated lawn and 10% by garden beds. Combined this vegetation makes up the basis for the GI demand.
- other model input parameters are set to the values reported for Cape Town in previous research (Jacobs and Haarhoff, 2004b), which also allows for an average water surface area (e.g. pool or ponds) of 10m² per property over the study area.

The results of the analysis are summarised in Table 5-1 and Figure 5-3.

Table 5-1: Theoretical saving potential for different scenarios – tabulated results.

Theoretical AADD-reduction for different POSWAR application scenarios						
% Of properties with access to POSWAR	% Of garden irrigation (GI) demand met by POSWAR source					
	0	20	40	60	80	100
0	0	0	0	0	0	0
20	0	2	4	7	9	11
40	0	4	9	13	18	22
60	0	7	13	20	27	33
80	0	9	18	27	35	44
100	0	11	22	33	44	55

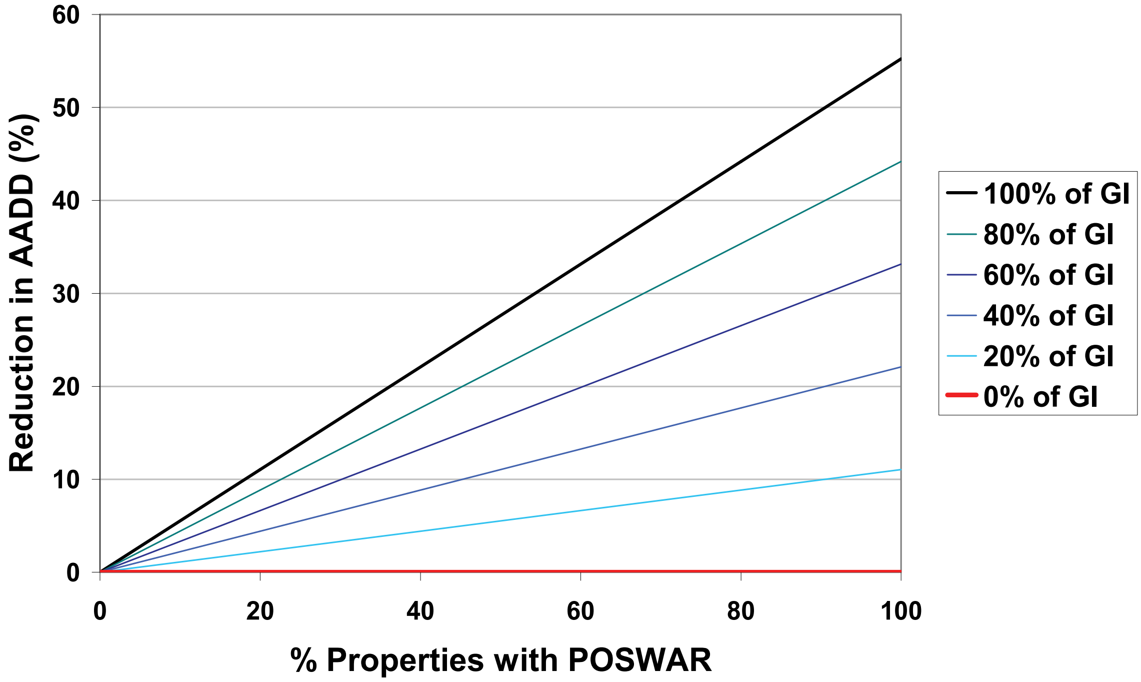


Figure 5-3: Theoretical saving potential for different application scenarios.

With reference to these results for a property of 1000m², if 100% of the consumers were to use a HWS source, or combination thereof, to meet 100% of the garden irrigation, a theoretical reduction of 55% in Municipal water use could be achieved compared to the baseline value (i.e. the normal demand with exclusive municipal supply via a WDS). This is considered to be unlikely and is an maximum upper limit. On the other extreme, if 0% of the consumers were to have access to HWS 0% of the outdoor irrigation would be met from such a source, then 0% reduction would be achieved (all water would be supplied from the municipal network).

5.7 Theoretical garden irrigation demand

Referring back to the previous section, it is necessary to determine what percentage of the garden irrigation could typically be supplied by the HWS source. When considering the yield a sufficient volume from the HWS is needed to meet not only the average annual garden irrigation demand, but the peak irrigation demand (peak summer day), which is a greater concern. The peak day demand could be estimated by the end-use model. The model and limited tests at the Stellenbosch University shows that each 1m² of lawn needs ± 5 litres of water on a hot summer's day in the Cape Town region. Garden beds are assumed to have the same demand. For the 1000m² property described above this would equate to a peak garden irrigation demand of ± 1750 litres/day, presuming 25% coverage by lawn and 10% garden beds.

In the cases surveyed during this study the yield from the HWS source exceeds (or far exceeds) the total garden irrigation (GI) demand in the case of groundwater. Rainwater supply is often insufficient in view of GI in the Western Cape, as is the case with greywater reuse. For these reasons these HWSs are often used in combination. Thus, for users with access to groundwater the "100% of GI" curve from Figure 5-3 could be used, neglecting all the other curves that would apply if the yield were not sufficient to meet the garden irrigation demand (e.g. for RHS and greywater reuse).

5.8 Results for HWS meeting 100% of garden irrigation demand

The model was used to re-analyse the results for the case where the HWS source meets 100% of the demand in all cases. Two additional property sizes were added to provide estimates of potential savings for a 1000m², 1500m² and 2000m² stand. The results are shown in Figure 5-4.

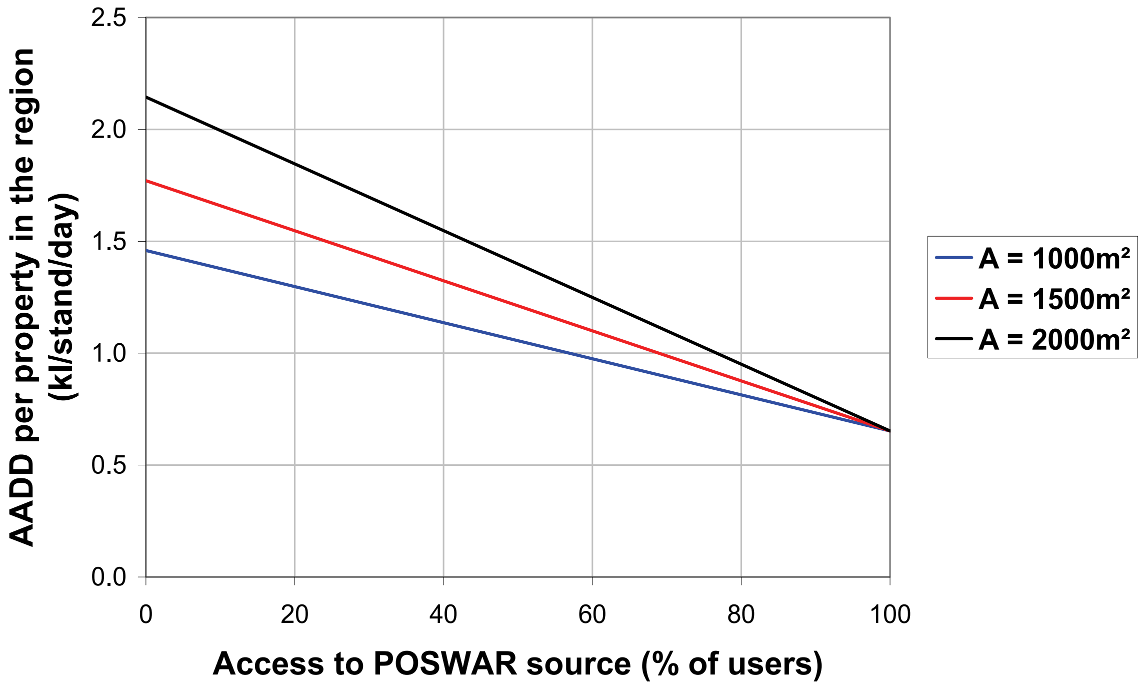


Figure 5-4: Modelled AADD for three property sizes (with 100% of GI met by HWS)

From Figure 5-4 it is clear that all three lines converge to a point at about 650 ℓ/d that is representative of indoor use only. In this case 100% of the garden irrigation demand is met and 100% of users in the region have access to a sufficiently large HWS to meet the GI, thus suggesting that no garden use would be supplied from the municipal system. Although this may be true for one property it is considered to be unlikely for all consumers in an entire neighbourhood. The maximum saving is for a 2000m² property where the AADD would reduce from 2.1 kℓ/d (2100 ℓ/day) to 0.65 kℓ/d (650 ℓ/day), resulting in a reduction of almost 69% with HWS use. The question remains as to what fraction of users would be likely to apply HWS – a topic clearly in need of additional research.

5.9 Strategic direction gained from HWS model

The HWS end-use model and subsequent results are valuable in addressing the strategic level of this project in the sense that it provides a means to prioritise the different aspects in a rational way. Referring to the different strategic "lenses" described earlier (Johnson and Scholes, 2002) strategy development is specifically influenced by the modelling when viewed through the design lens, that views strategy development as a deliberate positioning through rational, analytic, structured and directive processes. With reference to Table 5-1 and information presented earlier in this report the following could, for example, be deducted for strategy development from the modelling process:

- if the number of properties with GAPS were considered to be between 20% and 40%, meeting 100% of the GI from the particular source, it would significantly impact the AADD leading to a reduction in AADD of respectively 11% and 22%. Viewed from the other angle, empirical guidelines based on water meter readings for such a neighbourhood would under-estimate the AADD by between 11% and 22% in this case.

- if greywater were to be used by 20% of the properties described by a specific stratum, and the source were to meet say 20% to 40% of the GI, the effect would be relatively small with only 2% and 4% reduction in AADD respectively.

- a similar scenario as the one above would result from rainwater use, given a realistically sized rainwater tank (say 2 kℓ). Unless the tank were to be "impractically large", i.e. larger than 5 kℓ, the system would not have the capability to transfer water yielded late in winter for application in the garden by spring and early summer.

Based on the model results groundwater is the only HWS considered to have the required penetration and intensity to notably impact water demand in residential areas.

6. CASE STUDY: HERMANUS GROUNDWATER USE

6.1 OVERVIEW

6.1.1 Background and scope

Groundwater abstraction in some urban areas of the Western Cape has been studied in the past by means of hydrocensuses – as could be established during this one-year project and corresponding literature review none of the results were ever published (Conrad, 2008). This chapter presents a case study of groundwater use in Hermanus, a popular coastal holiday resort town about 100km east of Cape Town.

The team investigated the AADD of stands with private GAPs and compared the measured water use of these properties to measured use of other properties in the region. The study area was chosen due to the availability of groundwater access (from hydrocensus records) per property and also corresponding metered municipal water use (from an electronic GIS-based water management system).

The study is based on a hydro-census that was initiated in May 2000 by a retired Geohydrologist from Zimbabwe, Mr Frank Tennick. He was at the time appointed by Overstrand Municipality to undertake a mini hydro-census in the town of Hermanus in order to determine the number of boreholes/well points and the groundwater levels in this area (Tennick, 2008). The initial report (Tennick, 2000) is included in Appendix B for future reference.

6.1.2 Objective

The objective of this case study was to use available data to compare the average AADD values of stands with private GAPs with the overall average of all stands within a certain stand size category in order to assess whether stands in Hermanus with GAPs have a lower than average water use. This was considered necessary to confirm theoretical findings that properties with GAPs abstract notably less water from the municipal supply than those properties that do not have GAPs.

6.2 STUDY AREA

The study area for this investigation is the town of Hermanus, approximately 120 kilometres east of Cape Town and situated within the Overberg district along the south coast of the Western Cape.

The greater Hermanus area is mainly a holiday/tourist destination and comprises the Hermanus area, Zwelithle, Mount Pleasant, Sandbaai, Onrus, Vermont, Hawston and Fisher Haven. The suburbs of Northcliff (Town Centre), Westcliff, Eastcliff, Kwaaiwater, Hermanus Heights, Kwaaiwater, Fernkloof and Voëlklip in the Hermanus area form the focus of this study and are shown in Figure 6-1.

Figure 6-1: Map of the suburbs of greater Hermanus for HWS case study

6.3 METHOD OF INVESTIGATION

The mini hydro-census conducted by the Overstrand Municipality (Tennick, 2000) in the town of Hermanus set out to determine the number of residential boreholes/wellpoints in the area (in this study the term GAP is preferred to avoid confusion).

The study initially comprised a door-to-door survey and a questionnaire to be filled in at each house in the area. It was soon established that the majority of wellpoints in Hermanus were installed by a local borehole driller, Mr John Marriott, during a period between 1969 and 1990. This person kept record of all GAPs installed in a log book which included the dates, addresses, erf numbers, owner/occupier at the time, depths, geology, the type of pumps used for each and the installation date.

Despite the above being available, the questionnaires were still distributed to all other houses not listed in the "driller's" records to try and retrieve the details of the houses where GAPs were installed at a later stage.

All the information was captured on a spreadsheet as part of the hydro-census study and conclusions were made with regards to the number of GAPs, approximate groundwater levels, yields and the quality of the water. The initial report, raw data and spreadsheet file were obtained by the project team as part of this research project.

The original log book data (see Annexure A) as well as the subsequent report submitted to the Overstrand Municipality were obtained from Mr Tennick in electronic format for the purposes of this study and evaluated as described in this chapter.

6.4 DATA VERIFICATION

6.4.1 Complete data set

The original data set contained a total number of 378 entries. Each entry was scrutinised and verified as the first step of data processing. This included arranging the data set into columns with only the imperative information such as the date installed, street address, erf number (if given), suburb and the owner/occupier at the time shown. The data is included in Appendix C.

6.4.2 Filtering of data

This enabled the elimination of entries of GAPs installed in areas outside Hermanus (18 such were found) and entries with insufficient information such as no street address, no suburb name or simply an entry with owner/occupier (73 such were found). These were marked in colour and eliminated from the data set.

Furthermore, entries of which the naming/description clearly represented stands used for non-domestic purposes i.e. commercial stands, entries indicated as being schools or churches, sport fields, farms or developments and government/municipal institutions (22 such were found) were also eliminated.

Entries which only contained the street names and the names of occupiers at the time, but no street or erf numbers (97 were found) were not eliminated but marked in a different colour. The remaining data, being those entries with complete addresses (168 such records), were also marked. The “eliminated” and marked entries were categorised in separate sets after which all obvious duplicate entries were marked and grouped together as shown in Appendix D. These duplicate entries possibly represent stands where additional boreholes/wellpoints were sunk subsequent to the first installation.

6.4.3 Assessing lost useful data

The known information of those entries where only street numbers were missing was used to look up the full addresses by means of visual inspection and old archive records of property-owner linked information. An old telephone directory for the Boland and West Coast region was the only source that could be found and used for this purpose (year 1988/89). This inspection was possible for cases where the occupier at the time of installation was listed in the particular old telephone directory. The records for which the addresses could be found using this method (44 of these) could then be added to the set of entries with complete addresses (street name and number, suburb etc.) to form a set of usable data consisting of 212 entries, as shown in Appendix D. The size of the data set was considered relatively good in relation to the study area.

6.4.4 Matching water use to data from the hydrocensus

The Infrastructure Management Query Station (IMQS) commercial software package is a GIS-based management tool (a licence for using the software was provided to the project team at no charge by IMQS). IMQS was used to scrutinise the “usable” data set in order to verify the addresses and obtain the average annual daily demand (AADD) (kℓ/day) and stand size (m^2) for each of these entries. Although the software suite allows for SQL-based queries it was necessary to search for the 212 individual records in the GIS-database on a one-by-one basis.

All duplicate entries that surfaced with this process, stands which were listed on IMQS as being zoned for non-domestic use and stands of which the addresses simply weren’t found on the IMQS database, also had to be eliminated from the data set for comparative evaluation. This left the team with 168 records (individual properties) for which hydrocensus data and water consumption (AADD) was available. The AADD values for each stand obtained from IMQS are based on actual metered water consumption over a period of 2-3 years (2003 to 2006) and represent the average daily water demand for the specific stand over the period for which continued data is available.

Therefore stands of which the water consumption pattern was suspected to be that of domestic type water usage (possibly due to irregular or faulty meter readings) were marked as shown in

Annexure D. These were considered to be non-domestic properties incorrectly identified as residential land use type in the GIS data base.

6.4.5 Holiday influx and atypical seasonal water use

The greater Hermanus area is a popular holiday destination. It was considered appropriate (yet time consuming) to visually inspect the monthly water consumption pattern of each property in the selected data set. Those for which the pattern represented that of a typical holiday home (high water usage during summer months, Christmas season and Easter period with low or no water usage during rest of the year) were also marked. It was decided to eliminate these as this feature would otherwise result in relatively low and inaccurate AADD values for the applicable stands.

6.4.6 Final (filtered) sample size

The usable data less all marked, eliminated entries, as described above, ultimately resulted in data set of 114 stands in total. For these properties it was known that a GAP had been installed at some time, the AADD (kℓ/day) was known and the corresponding present day stand size (m^2) could be obtained for each from IMQS. The data is shown in Appendix E.

6.5 DATA PROCESSING AND RESULTS

The addresses of all the entries in the final data set (Appendix E) were looked up in the IMQS data base in order to obtain the AADD (kℓ/day), stand size (m^2) and municipal suburb in which each is located (for those entries which did not already include this information from the original log book inscriptions).

Once this list of data was compiled (with each entry's AADD and stand size), all the data required was available. The data was processed and compared using two separate methods as discussed below.

6.5.1 Method 1

This method entails the comparison of the average AADD of stands with private GAPs within a certain suburb of Hermanus with the overall average AADD of all stands in that specific suburb. The percentage of stands with GAPs is relatively small, and for this reason it was not compared to the dataset containing only stands without GAPs as well. Table 6-1 shows the number of entries for each suburb in the final data set.

Table 6-1: Method1 - Number of stands per suburb

Suburb Name	No. of Stands
Northcliff	77
Eastcliff	31
Voëlklip	3
Westcliff	2
Kwaaiwater	1

The entries for the suburbs of Voëlklip, Westcliff and Kwaaiwater were eliminated for the purposes of this method since their sample size was considered too small to attain a true reflection of the situation. Two entries were located in Westcliff and were treated separately: the one entry in Westcliff was grouped under the suburb of Northcliff for these purposes only since this stand is located along Main Road which forms the boundary between these two suburbs; the same did not apply to the other Westcliff entry which was located close to the beach.

The stands from Voëlklip and Kwaaiwater around the Mossel River (see map, Figure 6-1) are considered to be situated too far east to be grouped with the suburb of Eastcliff, or any other. Therefore, only the stands from Northcliff and Eastcliff were used for further evaluation with this method. The average AADD for all domestic stands of suburbs within the Overstrand Municipality region were extracted from SWIFT suburb report included in IMQS. The pre-project analysis was based on certain pre-determined stand size categories for each suburb, as shown in Table 6-2 below:

Table 6-2: Method1 - Area spread per stand size category

Category No.	Area Spread (m^2)
1	$A < 750$
2	$750 < A < 1200$
3	$1200 < A < 1500$
4	$A > 1500$

The data sets of AADD values for both suburbs (Northcliff and Eastcliff) were then grouped separately based on the above mentioned stand size categories. The sample size of data for each category of both these suburbs is shown in Table 6-3. This enabled the data to be grouped not only by suburb, but also by stand size. The intention was to evaluate the results and compare the findings to other published stand-size based guidelines for AADD, as discussed shortly.

Table 6-3: Method1 - Sample sizes per suburb and stand size category

Suburb Name	Category No.	Sample Size
Northcliff	1	11
	2	62
	3	1
	4	2
Eastcliff	1	11
	2	18
	3	1
	4	1

The sample size of available data for stand size categories 3 and 4 of both suburbs are too small (< 3) for any evaluation purposes and were subsequently not used for comparison. The average AADD values for all entries within categories 1 and 2 of both suburbs were then calculated and compared to the overall average AADD of all domestic stands within the specific suburb (obtained from the IMQS-published suburb report) as shown in Table 6-4.

Table 6-4: Method1 - Comparative results for each suburb

Suburb Name	Category No.	Area Spread (m^2)	Average AADD (kℓ/d) for stands with private boreholes	Average AADD (kℓ/d) for all stands within suburb
Northcliff	1	A < 750	0.640	0.744
	2	750 < A < 1200	0.549	0.626
Eastcliff	1	A < 750	0.676	0.723
	2	750 < A < 1200	0.550	0.980

The results of Method 1 are presented graphically in Figure 6-2.

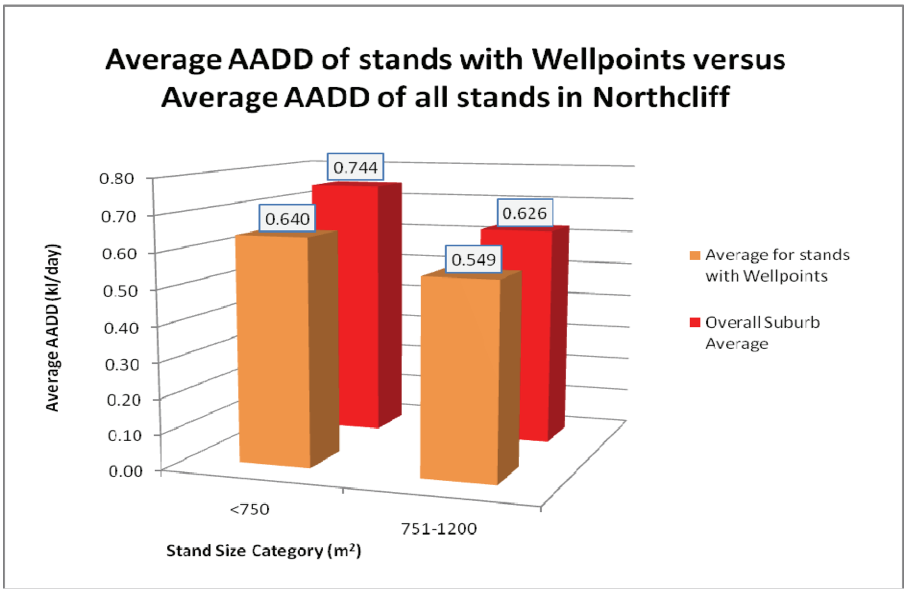


Figure 6-2: Graphical representation of results for Northcliff suburb

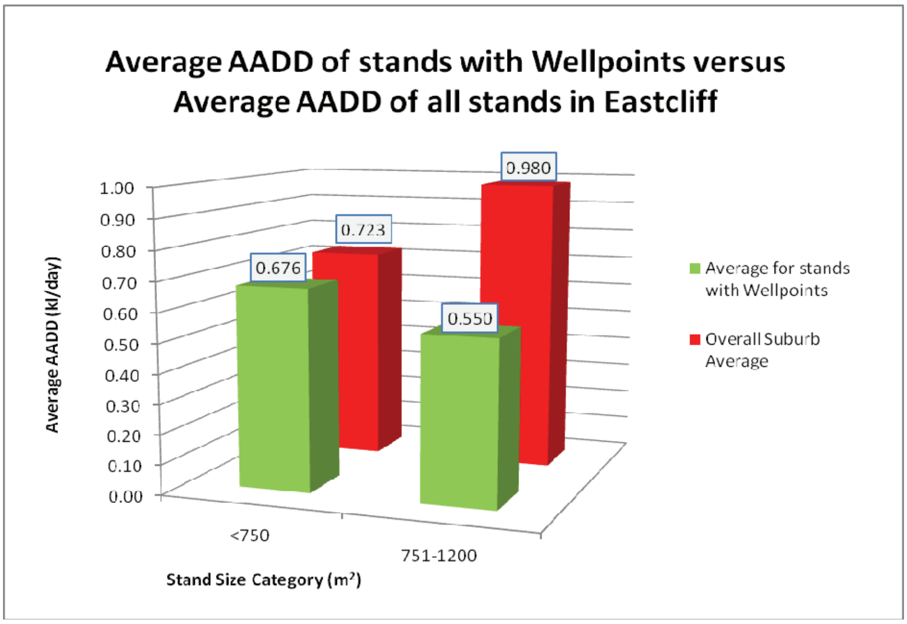


Figure 6-3: Graphical representation of results for Eastcliff suburb

It is clear that the stands with GAPs use less municipal water that those without, on average. In the case of the large stand size category in Eastcliff the water use with GAPs is 44% less than stands with no access to groundwater – a significant "saving". It could be argued that the water is not necessarily "saved", because it is still used by the consumer. However, the supply from the municipal WDS is reduced thus creating the impression of a saving from the viewpoint of the municipality due to the reduced reading on the individual consumer meter used for billing purposes.

6.5.2 Method 2

This method involved the comparison of the average AADD of stands with private GAPs with the estimated average AADD of all the stands obtained from published guidelines (Jacobs et al., 2004) for AADD of stands in the coastal winter rainfall region, where Hermanus is located.

The equation presented by Jacobs et al. (2004) to estimate the AADD of the stands in this region is:

$$Q = \begin{Bmatrix} (0.00110595) \times A + 0.287, \left(50m^2 \leq A < 840m^2\right) \\ (0.00056253) \times A + 0.745, \left(840m^2 \leq A < 2050m^2\right) \end{Bmatrix}$$

where

Q = average annual water demand (kℓ/day)
A = single residential stand size (m^2)

The estimated AADD (Q) for the stand size (A) of each stand in the final data set (as presented in Annexure E) was calculated using the above equation, regardless of the suburb it is located in. All the data was then categorised according to stand sizes for regular intervals based on the frequency of stand size occurrence. The different stand size categories used for the purposes of this method are shown in Table 6-5.

Table 6-5: Method2 - Area spread per stand size category

Category No.	Area Spread (m^2)
1	A < 700
2	700 < A < 850
3	850 < A < 1000
4	1000 < A < 1150
5	A > 1150

The average of the actual AADD values (obtained from IMQS data base) for stands with private GAPs and the average AADD values based on the guidelines for the AADD of stands within a coastal winter rainfall region were calculated for each stand size category. The results are summarised in Table 6-6 and presented graphically in Figure 6-3.

Table 6-6: Method2 - Comparative results for each stand size category

Category No.	Sample Size	Area Spread (m^2)	Average AADD (kℓ/d) for stands with GAPs	Average AADD (kℓ/d) for stands based on guidelines and stand size
1	12	A < 700	0.642	1.001
2	63	700 < A < 850	0.542	1.149
3	27	850 < A < 1000	0.612	1.248
4	6	1000 < A < 1150	0.659	1.345
5	6	A > 1150	0.872	1.647

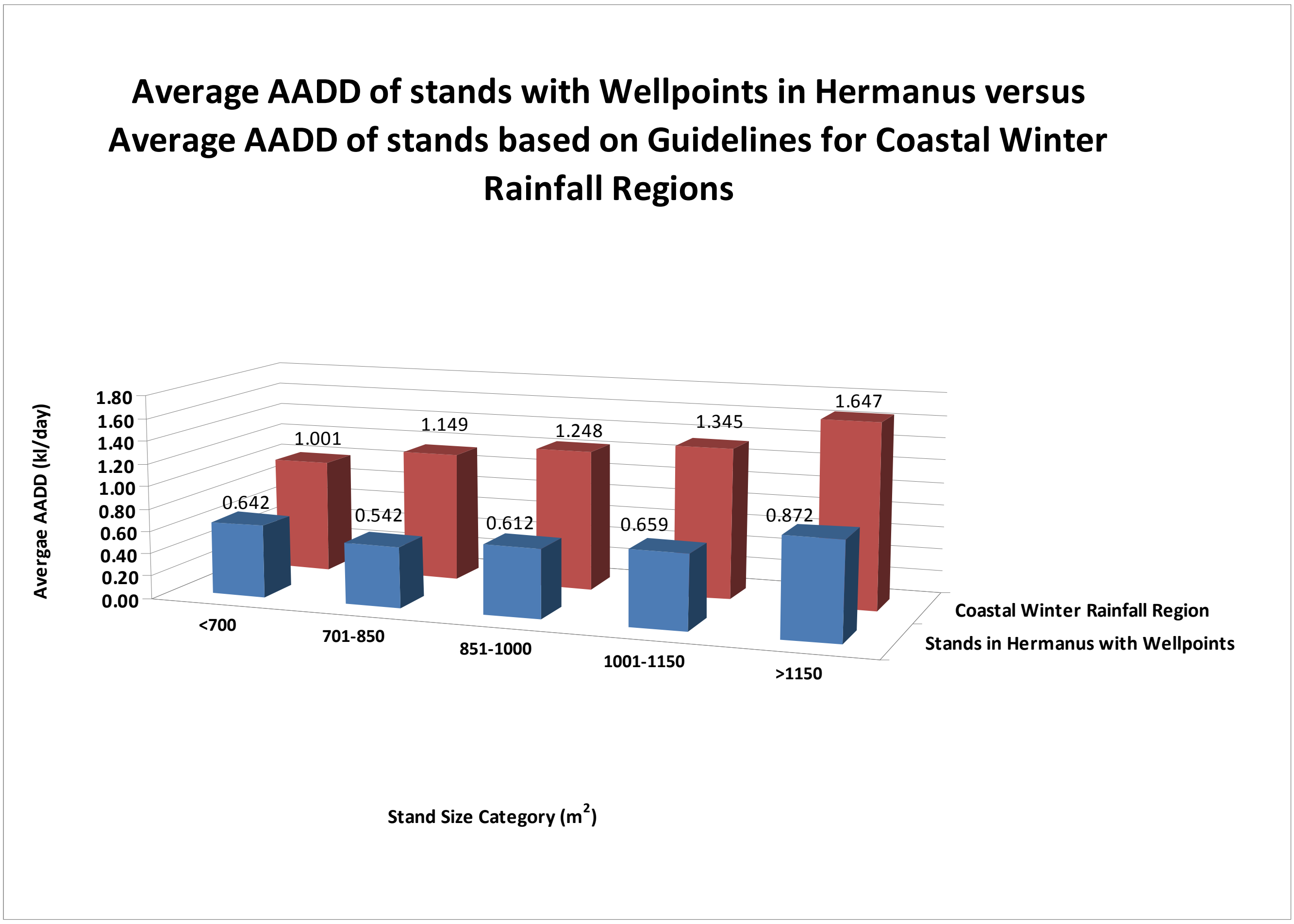


Figure 6-4: Graphical representation of results for Hermanus

The actual water use, only for properties with access to groundwater, is much lower than the guideline values intended for WDS. The guideline over-estimates average water use by more than 100% in some cases.

6.6 DISCUSSION OF RESULTS

It is evident from the results that there is a definite trend of lower AADD for stands with private GAPs, for this specific study area, based on the outcome of both methods. This result is in agreement with previous research elsewhere in the country (Simpson, 1990) and confirms that groundwater is a viable alternative water source in view of meeting GI demand.

The following comments could be made regarding the AADD (municipal water usage) of domestic stands with private GAPs (residential utilisation of groundwater) in this case study:

- The results obtained using Method 1 show a smaller estimated reduction in the average AADD for stands with wellpoints in Hermanus than that of Method 2. Since each suburb is analysed separately with this method and because it compares the subsequent results for each stand size category with measured water consumption data, it is believed to be a true representation of the actual conditions. This method and the outcome thereof are preferred above that of Method 2.

- Method 2 was included to investigate and illustrate the impact that GAP use has in relation to published stand-size based guidelines for AADD, based on analysis of a much larger data set for the entire winter rainfall region. The results obtained with Method 2 show a much larger discrepancy in the AADD for stands with GAPs than was obtained with Method 1. Various reasons could be provided for this, but it is considered to be mainly due to the relatively high average AADD values calculated for each stand size category (from Jacobs et al., 2004) in relation to what is typical in Hermanus. It could be noted that the guidelines by Jacobs et al. (2004) are notably less conservative than the well known "Red book" guidelines for AADD (CSIR, 1983), that are still widely used.

- Hermanus is mainly a holiday destination, with numerous properties remaining empty for large parts of the year, thus skewing the AADD-data. A filtering process was included to prevent the data set from being skewed by these false "low AADD"-properties. In addition, the town is also a popular place for retirement. These features combined make Hermanus atypical and thus direct comparison to more general guidelines could be considered less appropriate.

- Entries in the final data set with suspect AADD or stand size data (e.g. relatively high AADD for relatively small stand size and vice versa) were not eliminated in the verifying process since these erven are zoned for domestic use, are not used as holiday homes exclusively and because the recorded data is continuous. It was considered inappropriate to simply remove data from the set simply because it does not fit a certain expected trend or desired distribution. Therefore all entries with valid data were included in the calculations for both methods, regardless of the outcomes.

- The sample size of the final data set (114 records.) was considered to be an acceptable size to draw conclusions, considering the total number of erven in the Northcliff and Eastcliff suburbs is only 1053 in total. From this it could also be learned that about 10% of all properties in these suburbs are known to have GAPs, although the total number of entries in the initial data base (378) suggests a percentage of about 35%.

- Another argument may be that with Method 1 (the more preferred method for comparison as stated previously) the data of those stands with private wellpoints as listed in the final data set (Annexure E) is compared to the overall average AADD (for each stand size category and suburb) regardless of the fact that these stands as well as other stands also with GAPs (i.e. entries with incomplete addresses eliminated during verifying process or stands with private wellpoints installed by different contractor than person from whom original logbook data was obtained) is included in these overall average AADD values and is therefore not an accurate approach. It is a conservative approach followed with this preferred method and the actual reduction in the average AADD of stands with GAPs would thus be slightly more than found with this study. This was not considered a problem due to the fact that only 10% of the stands in Northcliff and Eastcliff would have been duplicated in this manner in the analysis.

7. CONCLUSION

7.1 Discussion

This research study strategically assesses the status quo of HWS in South Africa and goes on to identify typologies and trends for each HWS in view of future research needs. The study focuses on the Western Cape province in South Africa, but the literature review covers the rest of the country and international sources. Greywater, rainwater and groundwater as sources of free water available to every homeowner on-site have been noted in the past (Milne, 1979).

The commissioning of a HWS by a private home owner is often drought-driven. This study confirms findings from previous reports that water restrictions/droughts are the main driver behind HWS application. When installed, the HWS typically remains in use, even after the water supply situation via the WDS returns to normal. Given a sufficient and relatively inexpensive supply of water from a municipal source, few users consider HWSs. However, there seems to be a developing trend where consumers with a concern for the environment use HWS merely to be "green" – despite poor economical returns.

The only HWS found to have notable incidence during this study is groundwater use. Probing studies performed as part of this work show that 15% of low density residential properties in Cape Town registered a GAP during the water restriction period of 2003-2004, but the actual incidence of GAP is expected to be closer to 30% (findings during the Hermanus case study pointed towards similar levels). This points to a significant fraction, although it is based on a crude estimate. It clearly suggests that the use of GAPs as a HWS in Cape Town is relatively common. Previous research in Pretoria (Simpson, 1990) estimated that 38% of properties in the study area in Pretoria had GAPs, with a maximum of up to 60% incidence in some areas.

In the few reported cases where GAP yields could be estimated the delivery of water from the GAP is notable – often meeting all garden irrigation demand. The typical yield of a relatively shallow GAP based on the Hermanus information is about 1000 ℓ/day. The use of RHSs and greywater reuse systems are significantly less common and produce notably less water than GAPs.

Climate change could influence the yield of GAPs and RHSs, but should have little impact on the greywater generation rate. The possible impact of climate change on HWS has not been investigated as part of this study.

7.2 Typology and trends of HWS

It is clear from this study that strategic capability cannot be viewed in a static way. What customers value varies with time and the use of water is no exception. At some periods in time certain water sources are valued more highly than at other times. The following typologies and trends could be identified based on the work to date:

- Once a HWS is in use, it typically remains in use long after the "need" for it (say to carry the user's garden through a period of water restrictions) has passed. This seems valid for all parts of the country and all social classes of residential water users.

- Groundwater use is a notable HWS in terms of penetration and available volume. Installing a GAP (e.g. well point or borehole) is often relatively expensive and its application implies the use of a pump to abstract and distribute the water on-site. GAPs are considered to be limited to high-income (or at least medium-income), low-density properties and seem to be more prevalent in areas of "suitable geology". Future research is needed to quantify the incidence (e.g. how many properties have GAPs?) and also the yield (volume of water abstracted).

- The preliminary results from this study suggest that anything from 0% (no groundwater) to 60% (typical upper limit) of users in a particular suburb might have access to groundwater via some type of GAP, with 30% of low-density users with access to groundwater considered typical in Cape Town. The yield from a typical GAP is about 1000 ℓ/d and is considered to be relatively high compared to other HWS yields and to water demand of residential properties.

- Rainwater harvesting is heavily influenced by spatial aspects, with some regions finding RWS uncommon (Cape Town metro) and others viewing it as an essential part of water supply (e.g. DWAF-sponsored RHS projects for low-cost housing units in the arid Karoo). It was commonly employed locally in days when supply to urban dwellings was unreliable or not available. Since the inception of reliable municipal WDS in urban areas of South Africa about 4 decades ago the use of rainwater tanks has become less prevalent. However, in some regions of the country rainwater tanks seem to be common and remain in everyday use, despite the availability of water via the municipal WDS. Three reasons could be identified for its use: quality/taste concerns of municipal water; unreliable water supply (e.g. regular water restrictions or intermittent supply from the

WDS); environmentally oriented consumers who want to conserve water wherever possible despite it being less viable than other sources.

- In all areas of South Africa rainwater tanks are low-yielding and thus not well suited to meet garden irrigation demand. In some areas where the municipal supply is brackish, rainwater tanks are used exclusively for potable water and are commonly referred to as "drinking water tanks". On a limited scale rainwater use is also being re-employed by residential consumers in the Western Cape metropolitan area – either by those who have a "green" lifestyle and/or by developers who encourage home owners to install rainwater tanks in new up-market developments. Thus the pressure on existing infrastructure is potentially reduced.

- On-site greywater reuse in serviced municipal areas is considered to be a relatively new trend. It has recently been encouraged in the media during periods of drought/water restrictions (e.g. 2004 in Cape Town). In the same breath other media reports during the same period have warned against negative impacts of greywater reuse. A limited e-search and e-survey exercise conducted during this investigation could identify only 19 residences, all home owners with a technical background, where greywater is reused directly for garden irrigation. A total of 71 properties (of over 4000) reported using greywater during the registration process in 2003/2004 in Cape Town. Clearly greywater reuse is not common and in addition, is a contentious issue (Barnes, 2006) and should arguably not be encouraged on a large scale until further research has been conducted with regards its wider impacts on health. Some developers (e.g. Schonenberg Estate, Somerset West) encourage the installation of greywater reuse units as integral elements to a home in architectural guidelines, but stipulate its treatment and disinfection prior to use.

7.3 Possible impact of HWS on water demand

An upper limit of about 40% reduction in AADD (water saving) was reported after analysis of water use in Cape Town (Jacobs et al., 2007) and is also in broad agreement with savings reported elsewhere. A 46% saving was achieved during drought conditions in California (Loaiciga and Renehan, 1997) and a saving of up to 50% is reported by Hunt et al. (1998) for gardens that are extensively xeriscaped. Extensive xeriscaping of gardens in Cape Town might hold promise for additional savings in cases where garden irrigation is common. Broad and extensive application of HWS in a relatively low-density residential area could lead to a reduction of as much as 40% in the AADD. This is a significant fraction and the corresponding impact on the WDS and sewer system could be significant.

A reduction of up to 40% in residential water use could thus be expected if HWS were used at all properties to meet outdoor water needs. This statement is based on the assumption that the initial status of users' gardens would be similar to the pre-water restriction state of users in the Cape Town study reported on by Jacobs et al. (2007).

7.4 Overview of HWS yield

It is clear that the greywater generation rate of about 280 ℓ/d/stand is significantly less than the typical yield from GAPs (1000-4000 ℓ/d/stand). The yield from RHS in the Western Cape winter-rainfall region is even less and, considering a realistic tank size RHS are not useful to meet garden irrigation demands. Groundwater is considered to be the only "high yielding" source and should receive research focus in terms of alternative water resources, WDS and sewers.

7.5 Existing knowledge versus the need for knowledge

This study concludes by summarising the various recommendations for further work. The existing knowledge, based on findings from this study, are summarised in Table 7-1 together with what is considered necessary to know. These two scores are combined in Table 7-1 to present a subjective set of strategic research priorities scoring between 1 (lowest) and 9 (highest). Those items that score low on existing knowledge and high on need obtain the highest scores, and vice versa.

Table 7-1: Strategic overview of trends and needs

Strategic overview: Existing knowledge (local & international)

POSWAR	Source yield	Water distribution system	Sewer system	Water quality	Environ-ment	Health	Social
Groundwater	2	3	3	2	3	2	2
Rainwater	1	2	2	1	2	1	1
Grey water	2	2	2	1	2	2	3

1) Good
2) Reasonable
3) Poor

Strategic overview: Local knowledge need (level of "urgency to know")

POSWAR	Source yield	Water distribution system	Sewer system	Water quality	Environ-ment	Health	Social
Groundwater	1	1	1	2	2	3	2
Rainwater	1	1	1	2	3	2	2
Grey water	1	1	1	1	1	1	1

1) High (urgent need)
2) Average
3) Low (no pressing need)

Strategic overview: Future research priority (integration of existing knowledge and need to know)

POSWAR	Source yield	Water distribution system	Sewer system	Water quality	Environ-ment	Health	Social
Groundwater	6	**9**	**9**	4	6	2	4
Rainwater	3	6	6	2	2	2	2
Grey water	6	6	6	3	6	6	**9**

9) Maximum score indicating a very high research need
1) Minimum score indicating very low research need

The three items with the highest score achieved the maximum score of 9 and are:

- The impact of groundwater abstraction on WDS and ditto for sewer systems; this is ascribed to the low level of existing knowledge with regards to the yield from these sources and the notable impact on water and sewer systems
- Social acceptability of greywater reuse (on-site, without treatment);

Those items with a relatively high score of 6 are:

- investigation into the source yield from GAPs
- environmental impact of GAP use
- the impact of RHS on both the WDS and sewer system
- all aspects of greywater reuse.

7.6 Specific research needs

7.6.1 Groundwater abstraction

Due to the fact that GAPs were identified early in the project as being notable, a case study was included to strategically assess the situation in one particular case. The Hermanus case study, presented in this report, underlines what was expected based on theoretical analyses. Groundwater users impact significantly on the AADD supplied via the WDS by creating a perceived water saving based on municipal water meter readings. Despite the relatively small sample size the findings are notable, with about 50% lower water use for some property types with GAPs than similar ones without access to groundwater.

A similar study should be undertaken to assess the existing registration data for the City of Cape Town, and the process should be revisited and integrated to present a management scheme for personal groundwater registration and use in municipal areas. The study could follow predominantly the same process followed with the case study investigation. Further analysis of the Cape Town groundwater registration data is of paramount importance to better understand how and why groundwater is used – and how it impacts on the WDS and sewer flow. The GAP yield should be assessed by means of individual metering of use (at point of abstraction). Similar data from other regions in the country could also be obtained and analysed to extend the study to provide countrywide coverage. A GIS-map could be compiled and overlaid on hydro-geological data to assess correlation between GAP occurrence and hydro-geological regions in urban centres of the country on a micro-scale.

It would also be possible to plot the locations of boreholes/well points in GIS format in order to make conclusions regarding location (hydrogeology, topographic and type), occurrence per income area and whether it is scattered or clustered. The municipal water consumption records of the same properties could then be obtained and compared to surrounding houses that do not have boreholes/well points. The municipal water consumption records and other features of these properties could then be obtained and compared to the average of others who do not utilise groundwater.

Theoretical estimates of the abstraction from a borehole/well point is complicated by various factors, including for example significant variation in geology, soil conditions, equipment ratings and the depth of the groundwater table. The only sufficiently accurate method for gaining this knowledge is considered to be direct measurement, by for example the placing of an in-line water meter in the pipe at the point of abstraction. This is one of the crucial aspects needed to learn more about this notable HWS, at least in Cape Town. Also, it would be necessary to extend the scope to assess whether the same trend is valid in other urban centres locally.

The environmental impact of increased personal groundwater use would have to be addressed on a regional basis in addition to the above.

7.6.2 Greywater reuse

In conclusion, a significant research need was identified in this strategic assessment to generate knowledge with regards to greywater reuse – particularly the implications of on-site use without treatment on a large scale (health and epidemic-related issues arise – Barnes, 2006). Greywater re-use is the "easy HWS" to apply at home: it costs practically nothing to divert a downpipe into a garden and the water is available immediately and reliably. The question that remains unanswered is, "Should this use be encouraged or banned, or is there a safe middle way?" Work by Carden et al. (2007a; 2007b), following a WRC-project, and also knowledge of current initiatives by the WRC shows that the need is being addressed to some extent.

However, it seems that a specific need remains to have a combined team of technical and health-oriented researchers tackle the question of on-site reuse without treatment. This idea is as attractive to the engineer as it is unattractive to the health professional. The fact that less than 100 properties in Cape Town were identified during this study where this type of use is in place points to a very low incidence and possibly a low research priority.

REFERENCES

Barnes, J. (2006). Health aspects of the re-use of household wastewater (greywater). Water Sewer & Effluent, 26(2), March, 26-32.

Botha JJ, Anderson JJ, Groenewald DC, Mdibe N, Baiphethi MN, Nhlabatsi NN and Zere TB (2008). On-farm application of in-field rainwater harvesting techniques on small plots in the central region of South Africa – Volume 1 of 2: Main Report. WRC Report TT313/07.

Butler D and Memon FA (2006). Water Demand Management. IWA Publishing, London.

Carden, K, Armitage, N, Winter, K, Sichone, O, Rivett, U and Kahonde, J (2007a). The use and disposal of greywater in non-sewed areas of South Africa: Part 1 – Quantifying the greywater generated and assessing its quality. WaterSA, 33(4), 425-432.

Carden, K, Armitage, N, Sichone, O and Winter, K (2007b). The use and disposal of greywater in the non-sewered areas of South Africa: Part 2 – Greywater management options. WaterSA, 33(4), 433-441.

Christova-Boal, D, Eden RE and McFarlane, S (1996). Investigation into greywater reuse for urban residential properties, Desalination, 106, 391-397.

Conrad, J. (2008). Personal communication on various occasions, June-November 2008, Director: GEOSS Groundwater Specialists, Techno Park, Stellenbosch, South Africa.

CSIR (1983). Guidelines for the provision of engineering services in Residential Townships (Blue Book). Compiled for the Department of Community Development.

Dixon A (2000). Simulation of domestic water re-use systems: Greywater and rainwater in combination. Ph.D thesis, Department of Civil and Environmental Engineering, Imperial College, London.

Ellis, SJP, Van Duuren, FA (1974). Waterverbruik in Pretoria. The Civil Engineer in South Africa, May 1974, 153-163.

Elphinstone C and Van der Linde NJ (1989). Estimating the annual quantity of groundwater abstracted in the Pretoria municipal area and its effect on municipal water consumption, CSIR Project report, Pretoria (also personal communication, 2009)

Eriksson, E, Auffarth, K, Eilersen, A-M, Henze M and Ledin, A (2003). Household chemicals and personal care products as sources for xenobiotic organic compounds in grey wastewater, WaterSA, 29(2), 135-146.

Fraser, L and Weaver, J (2000). Cape flats aquifer: Bulk water for Cape Town now. Contract report submitted to Ninham Shand Consulting Engineers, Stellenbosch.

Garlipp, DKCO (1979). Water Consumption Patterns in Urban Areas. M.Sc. thesis, University of Pretoria, Water Research Group, Department of Chemical Engineering, Pretoria.

Gebhardt, DS (1975). The effects of pressure on domestic water supply including observations on the effect of limited garden-watering restrictions during a period of high demand. WaterSA 1(1), 3-8.

Gilbert, J and Maheepala, S (1997b). Applying the Object-Oriented Paradigm to integrated water resource planning and management. Environmental Software Systems (CSIRO Australia), Vol.2, 343-350.

Gilbert, J and Maheepala, S (1997a). Optimisation based model for integrated water resource planning (Brochure TOPAZ-SUZO Model). Proceedings of the 24th Hydrology and Water Resources Symposium, 24-27 November 1997, Auckland, New Zealand.

GLS (2002). Compilation of a Residential Water Use Model for Rand Water with Elasticity for Price, Erf Area, Income and Pressure, Pilot Study. Compiled by the Rand Afrikaans University Water Research Group (now University of Johannesburg) and GLS Consulting Civil Engineers for Rand Water, August 2002.

GLS (2001). Computer Analysis and Master Planning of Sewerage System, Volume 1. Report by GLS Civil Consulting Engineers, March 2001.

Green, GC (1985). Estimated Irrigation Requirements of Crops in South Africa (Part 1). Department of Agriculture and Water Supply, Soil and Irrigation Research Institute.

Grobicki A and Cohen B (1999). Water reclamation for direct re-use in urban and industrial applications in South Africa and its projected impact upon water demand. South African Water Research Commission, WRC Report KV118/99.

Guillon, A, Kovacs, Y, Roux, C and Sénéchal, C (2008). Rain water reusing for watering purposes: what storage capacity is needed and what are the benefits for the sewer network? Paper 449:1-9, Proceedings of the 11th International Conference on Urban Drainage, Edinburgh International Conference Centre, Edinburgh, Scotland, 31 August to 5 September 2008, IWA Publishing.

Howe, CW and Linaweaver, FP (1967). The impact of price on residential water demand and its relation to system design and price structure. Water Resources Research, 3(1), 13-32.

Hunt, JB, McDevitt, W and Hunt, G (1998). Water Efficiency Manual for Commercial, Industrial and Institutional Facilities. A joint publication of the Division of Pollution Prevention and Environmental Assistance and Division of Water Resources of the North Carolina Department of Environment and Natural Resources, and the Land-of-Sky Regional Council, August 1998.

Husselman, M and Van Zyl, JE (2006). Effect of stand size and income on residential water demand. Journal of the South African Institution of Civil Engineers, 48(3), 12-16.

Jacobs, HE and Van Staden, S (2008). Direct on-site greywater reuse – an illicit or illustrious option? Proceedings of the Water Institute of South Africa Biennial Conference, Sun City, South Africa, 18-22 May 2008. http://www.ewisa.co.za/literature/

Jacobs HE and Haarhoff J (2007). Prioritisation of parameters influencing residential water use and wastewater flow. Journal of Water Supply: Research and Technology – AQUA, 56(8), 495-514.

Jacobs HE, K Fair, L Geustyn, J Daniels, & JA Du Plessis (2007). Analysis of water savings: A Case study during the 2004-2005 water restrictions in Cape Town. Journal of the South African Institution of Civil Engineers, 49(3), 16-26.

Jacobs HE, Geustyn LC, Loubser BF, Van Der Merwe B (2004). Estimating residential water demand in Southern Africa. Journal of the South African Institution of Civil Engineers, 46(4), 2-13.

Jacobs HE and Haarhoff J (2004b). Application of a residential end-use model for estimating cold and hot water demand, wastewater flow and salinity. Water SA, 30(3), pp. 305-316, July 2004.

Jacobs HE and Haarhoff J (2004a). Structure and data requirements of an end-use model or residential water demand and return flow. Water SA, 30(3), 293-304.

Jackson, S, Rodda, N and Salukazana, L (2006). Microbiological assessment of food crops irrigated with domestic water. WaterSA, 32(5), 700- 704.

Johnson, EH (1987). Flow data acquisition and forecasting system for a water distribution network. Laureatus in Technology, Department Civil Engineering, Port Elizabeth Technikon.

Johnson G and Scholes, K (2002). Exploring corporate strategy (Sixth Ed). Pearson Education Limited. Prentice Hall. London.

Khastagir, A and Jayasuriya, N (2009). Impacts of using rainwater tanks on stormwater harvesting and runoff quality. Proceedings of the 8th International Conference of Urban Drainage Modelling and the 2nd International Conference on Rainwater harvesting and management, 7-12 September 2009, University of Tokyo, Japan.

Krishna, PE (2005). The Texas manual on rainwater harvesting. Texas water development board. Third Edition (also listed as: Rainwater Harvesting Potential and Guidelines for Texas).

Krishna, PE (2003). An overview of rainwater harvesting systems and guidelines in the United States.

Kreysig, D (1996). Greywater recycling: treatment techniques and cost savings. World Water and Environmental Engineering, Water Conservation and Recycling, February 1996, 18-19.

Loaiciga, HA and Renehan, S (1997). Municipal water use and water rates driven by severe drought: a case study. Journal of the American Water Resources Association, 33(6):1313-1326.

Lomberg, CR, Rosewarne, PN, Raymer, DA and Devey DG (1996). Research into groundwater abstraction in the Port Elizabeth Municipal area. WRC Report 515/1/97.

Lott, S, Patterson, RA and Petrov, R (1999). On-Site Systems – Soils, Salts and Solutes. Proceedings of the On-site '99 Conference : Making on-site wastewater systems work, 13-15 July 1999, University of New England, Armidale.

McCarton, L. (2009). Rain water harvesting in a domestic situation in Ireland: Design performance and potential. Proceedings of the 8th International Conference of Urban Drainage Modelling and the 2nd International Conference on Rainwater harvesting and management, 7-12 September 2009, University of Tokyo, Japan.

Milne, M (1979). Residential water reuse. Technical Completion Report, California Water Resources Center, Davis Report No.46 September 1979, California Water Resources Center Project UCAL-WRC-W-537.

Saayman, IC and Adams, S (2001). The use of garden boreholes in Cape Town, South Africa: Lessons learnt from Perth, Western Australia. Proceedings of the 2nd WARFSA/WaterNet

Symposium on Integrated Water Resources Management: Theory, Practice, Cases. Cape Town, 30-31 October 2001.

Simpson GC (1990). Research into groundwater abstraction in residential areas. WRC Report 211/1/90 by the CSIR Division of Building Technology.

Tchobanoglous, G and Burton, FL (1991). Wastewater Engineering : Treatment, Disposal and Reuse. Metcalf and Eddy Inc., Third Edition, Published by McGraw-Hill, 1991.

Tennick, FP (2008). Personal communication, Hermanus.

Tennick, FP (2000). Preliminary report on hydrocensus of groundwater resources in the Eastcliff & Northcliff suburbs, Hermanus, Western Cape, South Africa. Compiled by FPT Consulting Services for the Overstrand Municipality, May 2000 (attached to this report as Appendix B).

Thomas (2004). Rainwater harvesting performance indicators (reference incomplete).

Van der Merwe, B and Barbour, E (2000). Literature study on water demand management and water demand forecasting models. A report compiled for Rand Water by Environmental Engineering Services, Windhoek, Namibia, December 2000.

Van Duuren, FA (2008). Personal communication on various occasions between April and September 2008, Pretoria.

Van Zyl HJ, Illemobade, A and Van Zyl, JE (2008). An improved area-based guideline for domestic water demand estimation in South Africa. WaterSA, 34(3), 381-392.

Van Zyl HJ, Van Zyl, JE, Geustyn, LC, Illemobade, A and Buckle, SJ (2007). Benchmarking of water consumption in selected South African cities. South African Water Research Commission Report K5/1525, Pretoria.

Van Zyl, JE and Geustyn LC (2006). Development of a national water consumption archive. Report for WRC Project No. K5/1605, South African Water Research Commission, Pretoria.

Veck, GA and Bill, MR (2000). Estimation of the residential price elasticity of demand for water by means of a contingent evaluation approach. Report to the WRC, Report No. 790/1/00, 2000.

Ward, S, Memon, FA and Butler, D (2008). Rainwater harvesting: model-based design evaluation. Paper 577:1-11, Proceedings of the 11th International Conference on Urban Drainage, Edinburgh

International Conference Centre, Edinburgh, Scotland, 31 August to 5 September 2008, IWA Publishing.

White, I (2009). Rainwater harvesting: modelling issues that influence household consumption. Proceedings of the 8th International Conference of Urban Drainage Modelling and the 2nd International Conference on Rainwater harvesting and management, 7-12 September 2009, University of Tokyo, Japan.

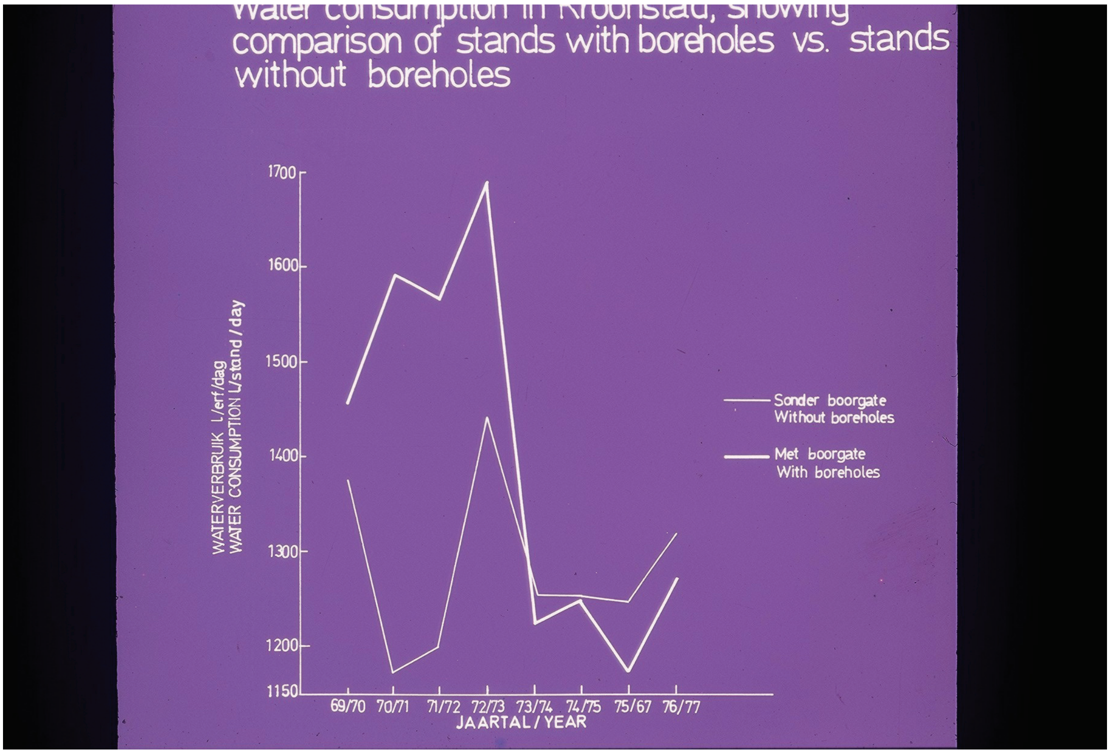
Wikipedia (2008). Information obtained from internet sources: a product suppliers' web site (www.Oasisdesign.com) and an internet encyclopaedia (www.Wikipedia.com), (2008).

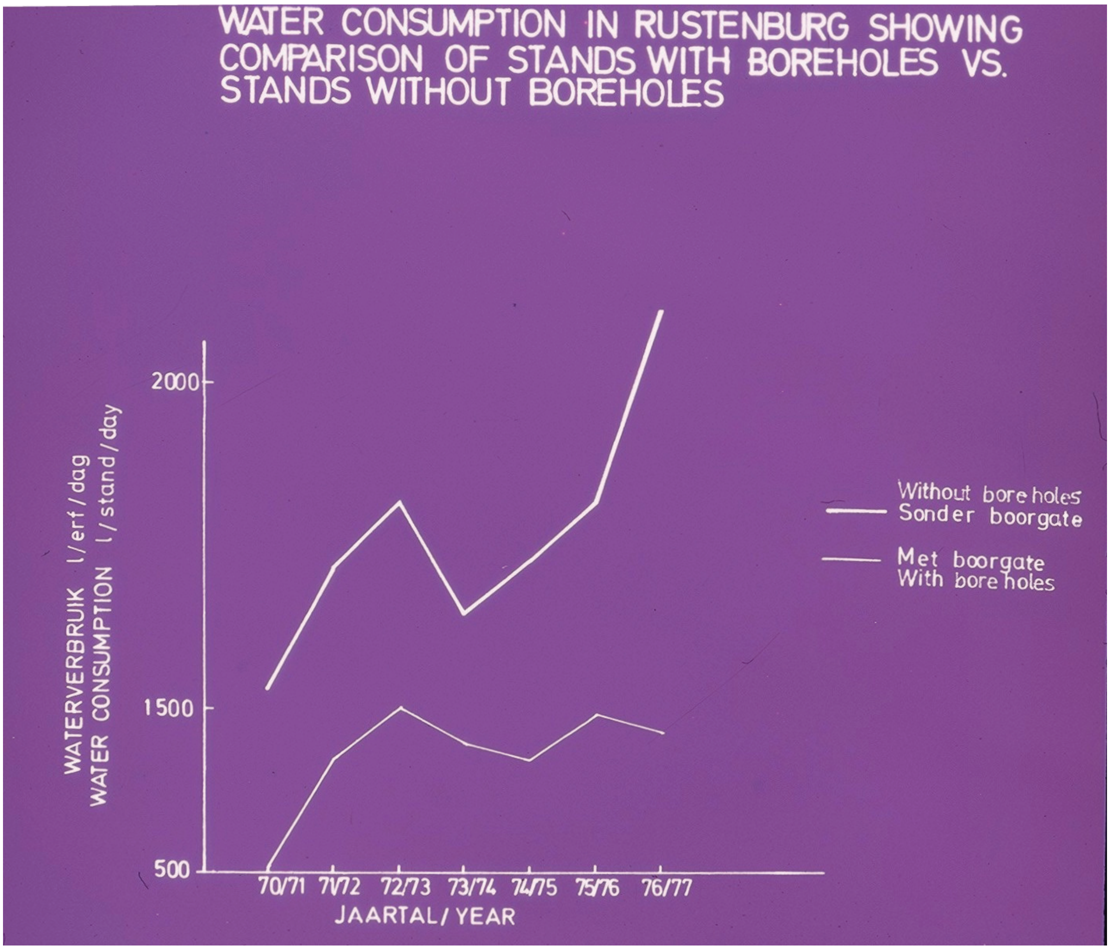
Wurbs, RA (1994). Computer Models for Water Resources Planning and Management, National Study of Water Management During Droughts; Chapter 4: Demand Forecasting and Balancing Supply with Demand. IWR : 94-NDS-7, USA, 1994.

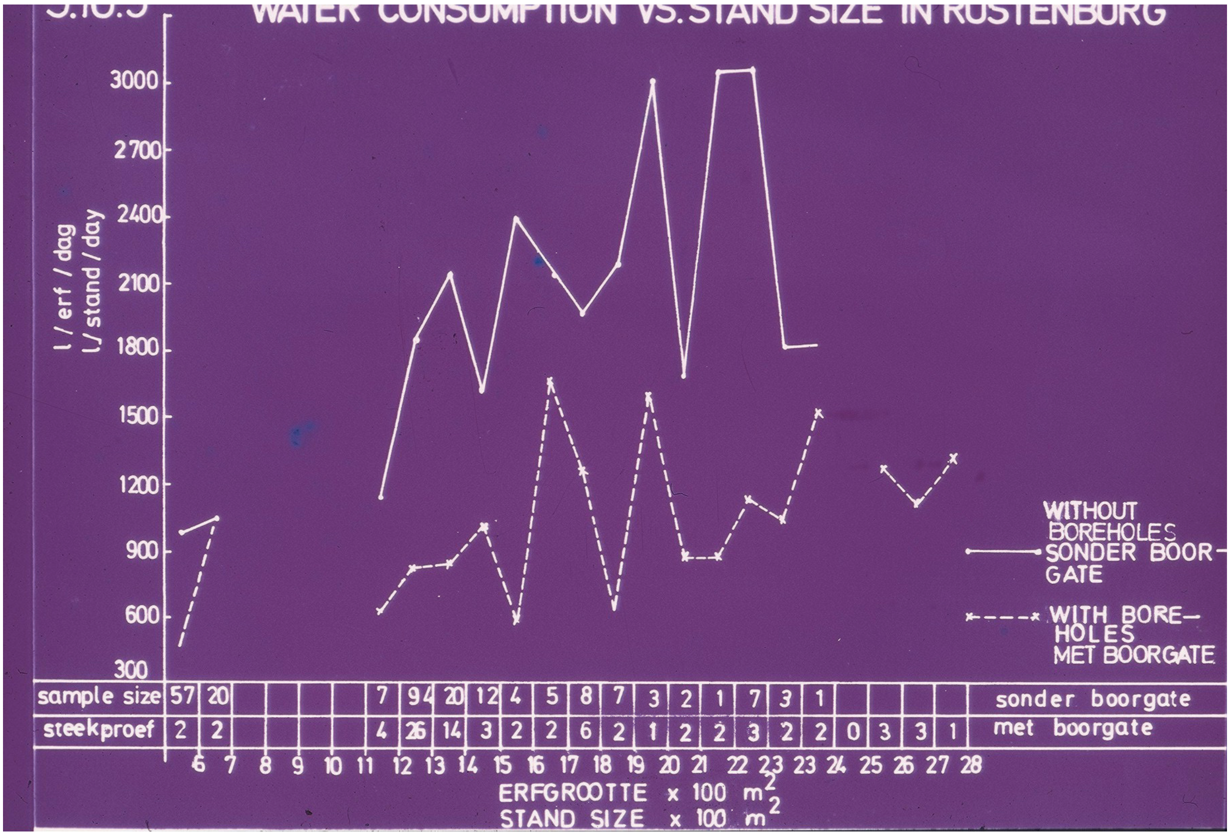
Zeisel, J and Nolde, E (1995). Greywater recycling in urban areas. Proceedings of the 2nd International Symposium on Wastewater Reclamation and Reuse, October 1995, 959-970.

APPENDIX A: Slides of water consumption study (Van Duuren, ±1970)

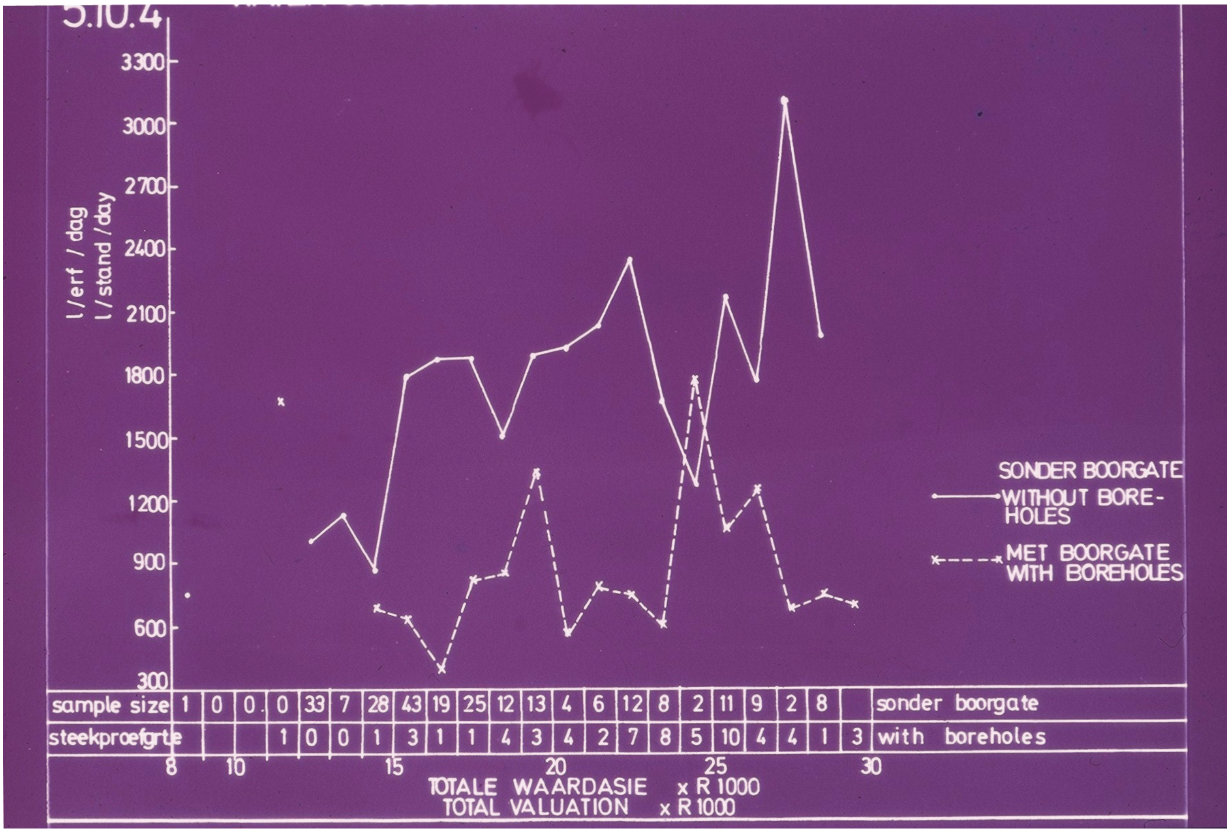
Slides of unpublished research presented in the 1970's (Van Duuren, 2008)







5.10.3
WATER CONSUMPTION VS. STAND SIZE IN RUSTENBURG
l / erf / dag
l / stand / day
WITHOUT BOREHOLES
SONDER BOORGATE
WITH BOREHOLES
MET BOORGATE
sample size
steekproef
sonder boorgate
met boorgate
ERFGROOTTE x 100 m2
STAND SIZE x 100 m2



5.10.4
l /erf / dag
l / stand / day
SONDER BOORGATE
WITHOUT BOREHOLES
MET BOORGATE
WITH BOREHOLES
sample size
steekproefgrte
sonder boorgate
with boreholes
TOTALE WAARDASIE x R 1000
TOTAL VALUATION x R 1000

APPENDIX B: Hermanus hydrocensus report (FPT Consulting, May 2000)

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Preliminary report on hydrocensus of groundwater resources in the Eastcliff & Northcliff suburbs, Hermanus, Western Cape, South Africa

By F P Tennick
May 2000

1. INTRODUCTION

The groundwater resources of the Greater Hermanus Area have not been quantified, neither is current abstraction measured or monitored by any authority. According to the present available records there is a minimum of 220 boreholes/wellpoints identified within the Greater Hermanus Municipal area where abstraction is neither metered nor controlled so that the total withdrawals may already be exceeding the replenishment. (SRK report 1995)
An approach was made to the Hermanus Municipality to set up a groundwater database which could be used to evaluate the quantity and quality of the groundwater resources in the area under the jurisdiction/control of the Greater Hermanus Municipality (GHM).

2. PROPOSAL TO THE HERMANUS MUNICIPALITY

It was proposed that a start be made to gather information and build up a database on the following aspects:

- Number and spatial distribution of abstraction points:
  Record the positions of all wellpoints, boreholes and wells
- Groundwater levels:
  Measure groundwater levels in dedicated boreholes throughout the Greater Hermanus Municipality and compare and contrast how they fluctuate over a period, of say, the wet versus dry months, or over the year. Identify the positions of all boreholes using a GPS. Anecdotal information such as date drilled, depth of hole, depth at which water was struck, daily consumption, etc could be collected during the survey.
- Water Quality
  Determine water quality, i.e. iron and manganese content, chlorides, over a period, wet versus dry months, over the year for the dedicated monitoring holes.
- Abstraction Rate:
  Estimate how much water is being abstracted on an annual basis; initially this would be a rough calculation; maybe it can be metered later. Excessive abstraction could lead to seawater incursion with irreparable damage to the aquifer that cannot be fixed.
- Flow Direction:
  Start modelling groundwater flow within the different aquifers.
- Recharge
  Measure mean annual rainfall within the catchment to determine potential recharge.

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3. OBJECTIVES

- To identify the various geohydrological settings for groundwater occurrence;
- To determine, initially in a small area, like the Eastcliff and Northcliff suburbs; the number of wellpoints, wells or drilled boreholes. To compare these with the existing records;
- To determine how much water is being abstracted from these holes and for which purpose the water is being used;
- To determine the quality of the water being abstracted;
- To identify these abstractions points so that they can be incorporated onto the South African National Groundwater Database (NGDB) for use and interrogation by any interested or affected party (IAP). The following attributes are mandatory for inclusion into the NGDB:
  - Location, farm number or erf number and co-ordinates of a wellpoint/borehole/well etc.,
  - Date of drilling of hole,
  - Name of drilling contractor,
  - Depth of hole,
  - Depth of water strike,
  - Estimated yield of hole,
  - Construction and geology of hole.

4. DEFINITIONS

In the New Water Act 1998, the definition of a borehole "*includes a well, excavation or any artificially constructed or improved underground cavity which can be used for the purpose of—*
(a) intercepting, collecting or storing water in or removing water from an aquifer;
(b) observing and collecting data and information on water in an aquifer; or
(c) recharging an aquifer."
For practical purposes all the wellpoints found in the Hermanus area fall under this definition because they are a*rtificially constructed to intercept, collect and remove water from an aquifer.*

5. METHODS

Initially an attempt was made to conduct a door-to-door survey asking residents to supply information on boreholes or wellpoints that exist on their properties. A questionnaire was prepared (See Appendix I) so that the data gathered could be loaded into a database which is compatible with the information housed in the NGDB.
It soon became apparent that a Mr. John Marriott, who at one time owned a garage in Hermanus and lived at No. 8 Stemmet Street in Eastcliff, had been responsible for siting and drilling many of the early wellpoints. He had started this work as a hobby in 1969 but discontinued around 1990 when he moved to Somerset West. Since then it seems that a Mr. Sutherland and his sons have completed many new wellpoints in the Greater Hermanus area. Mr. Sutherland Senior lives at No. 6, Disa Road in Northcliff but unfortunately has not kept any records of the wellpoints that he has developed over the past 10 years.

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6. RESULTS

Soon after starting the exercise it was also realised that residents were reluctant to divulge information or they were unable to remember or supply the required information on the wellpoint/boreholes on their properties. The main reasons appeared to be:

- ♦ Fear of being identified as having access to groundwater because, under the new Water Act (1998), the National Government "*has the power to regulate the use, flow and control of all water in the Republic*". Some interviewees felt this may result in them having to pay an additional tax or levy for its use. Despite reassurances that under the Act, "*a person may use water in or from a water resource for purposes such as domestic use, domestic gardening….as set out in Schedule 1…*and that divulgence of information would not be prejudicial. Against this background it was clear that obtaining the necessary information was going to be difficult.
- ♦ In many cases no records had been kept of whom or when the wellpoint or borehole had been drilled, at what depth water had been struck or the geology intersected in the hole or the estimated yield of the hole.
- ♦ Apprehension on having equipment dismantled so as to measure water levels in the wellpoint/borehole with a dip meter was also encountered.

Mr. Marriott, however, made his information available when it was explained that it was of value and he would be paid for it. His records, although incomplete, give some indication of where the shallow water aquifers occur and this data is presented in Appendix 2 as an Excel spreadsheet. The main findings can be summarized as follows:

6.1. The suburbs of Eastcliff and Northcliff and parts of Voëlklip have at least 278 wellpoints (of which 11% are dry) and 13 boreholes. Some 7 dug wells are also known to exist in these areas.

6.2. Groundwater occurs basically in two different environments:
- ♦ The larger, shallow, (primary) sand aquifer(s) are those found in and around Eastcliff, the Golf course, Northcliff and portions of Voeklip, where there are many wellpoints tapping this source(s).
- ♦ The smaller, but deeper, (secondary) aquifers, are those located in fractures, fault zones, shears, etc., within the quartzitic sandstones of the Table Mountain Sandstone Group (TMS). An example of this type is found near Mount Pleasant where Borehole SRK2 intersected a major water-bearing feature at a depth of over 200 m.
  The secondary aquifers within the (TMS) formed the main target areas for the investigative work done by groundwater consultants, Steffan Robertson & Kirsten (SRK) and it is in this environment where the higher yielding boreholes are more likely to be found.

6.3. A wellpoint at 30 Musson Street, which taps water from a shallow sand aquifer, had a rest water level, at 10h00 on 13 April 1999, of 2.23m below surface. After pumping the borehole for an hour, during which time it yielded approximately 1000 litres, the water level dropped to 2.38m below surface (a drop of 0.15m). After pumping, the water level rose to its original level (2.23m below surface) within a 4-hour period. This indicated that the wellpoint had recovered in the short-term; therefore, it was recharged and not being over-abstracted. It remained unknown, however, as to where the recharge was coming from or if the pumping of this hole was adversely affecting other wellpoints in the near vicinity and what the long-term affects were likely to be.

6.3.1. The wellpoint has since been used for watering the garden nearly every other day for about an hour over the past 12 months and when the rest water level was again measured on 8 May 2000, it was at a depth of 2.52m below surface. This shows that the water table has dropped by 0.29m over a 12-month period. This indicates that recharge, over the long term, has not kept pace with abstraction which is an ominous sign. Sound groundwater management requires that abstraction be reduced in anticipation that the catchment area receives significant saturation in the forthcoming rainy season(s) for the aquifer to be recharged and replenished to its former status.

6.4. Wellpoints are continuing to be developed and their existence and the information on these abstraction points still remains unknown to the Municipality or the Directorate: Geohydrology, Department of Water Affairs & Forestry (DWAF) who, as custodians of all groundwater information in the Republic, should be kept fully informed of new drillings, particularly under the current legislation.

7. CONCLUSIONS

7.1. Number and spatial distribution of abstraction points:
The suburbs of Eastcliff and Northcliff and parts of Voëlklip have at least 278 wellpoints and 13 boreholes. Some 7 wells are known to exist. There is, therefore, nearly 300 abstraction points, which have been documented between 1969 and 1990. The Municipal records indicate a total of 150 for these areas suggesting that not all abstraction points have been identified, particularly those drilled in the last 10 years.

7.2. Groundwater levels
The average depth of the water table in the shallow sand aquifers in the Eastcliff area is approximately 2.3 m below surface but it has dropped by approximately 0.3 m over the past 12 months.

7.3. Water Quality
Generally the water in the Eastcliff area has a high iron and manganese content giving it a brownish colour. In most instances water is used only for domestic gardening purposes. It would have to be treated for it to become potable and aesthetically acceptable for human consumption.

7.4. Abstraction Rate
Not enough information is available but based on very limited results; it seems that the average abstraction rate for a wellpoint is about 1000 litres/hour. With a lowering of the static water level it appears that abstraction is exceeding the replenishment rate. If this is allowed to go unchecked it could ultimately lead to a local de-watering of the aquifer and enhance seawater incursion into its place

7.5. Groundwater Flow Direction
The groundwater flow direction probably follows the topographic drainage contours but not enough information is available to create flow-nets for the areas under investigation

7.6. Recharge
No further comment can be made on recharge because of insufficient geohydrological information pertaining to the different aquifer(s).

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8. RECOMMENDATIONS

8.1. The acquired information is incomplete and needs to be updated by searching old municipal records.

8.2. The GHM to present an open and transparent attitude concerning the management of the area's groundwater resources with an appeal to groundwater users to take a more active and participative approach to ensure its sustainability into the future.

8.3. The Greater Hermanus Municipality (GHM), through powers vested with the DWAF, needs to acquire the outstanding groundwater information from residents with wellpoints/boreholes/wells in the Eastcliff, Northcliff, Kwaaiwater, Fernkloof and Voëlklip suburbs to complete the survey and publish the results so that they are available to all persons to investigate and interrogate.

8.4. The GHM to increase the area of the hydrocensus survey to include the settlements of Sandbaai, Onrus, Vermont, Hawston and Fisherhaven.

8.5. The GHM, with the assistance of groundwater consultants, to provide a definitive assessment/statement on the quantity and quality of the underground water resources that are available for the future development of the Greater Hermanus area.

9. APPENDICES

9.1. Appendix 1. Questionnaire

9.2. Appendix 2. Excel Spreadsheet summarizing John Marriott's information.

10. REFERENCES

10.1. Steffan Robertson & Kirsten (SRK) 1995.

10.2. Ninham Shand: Greater Hermanus Municipality: Provision of Bulk Water. " A perspective on the availability of water sources in the light of present and future demand". May 1998.

10.3. Greater Hermanus Water Conservation Programme" A model for water demand management" May 1998

F. P. Tennick
Hermanus
8 May 2000

APPENDIX C: Cape Town GAP yields (Matji & Associates, June 2008)

Yield estimation of Cape Town GAPs, 2008 (collaboration with Matji & Associates and CCT)

	Depth	Type	Yield (l/h)
1	275m	B	1000
2	106m	B	300
3	96m	B	3500
4	216m	B	1000
5	60m	B	1000
6	72m	B	2500
7	90m	B	1500
8	80m	B	600
9	70m	B	1000
10	80m	B	2000
11	68m	B	1500
12	22m	B	1000
13	38m	B	1500
14	70m	B	1 800
15	58m	B	2200
16	74m	B	1 800
17	70m	B	2500
18	70m	B	3500
19	95m	B	3000
20	70m	B	1000
21	60m	B	40000
22	70m	B	3000
23	60m	B	30000
24	70m	B	3000
25	48m	B	10000
26	70m	B	15000
27	60m	B	25000
28	109m	B	20000
29	30m	B	2000
30	9m	W	1000
31	78m	B	1000
32	65m	B	3000
33	108m	B	2500
34	72m	B	1000
35	99m	B	1000
36	68m	B	4000
37	110m	B	3500
38	75m	B	2000
39	110m	B	4000
40	140m	B	1000
41	85m	B	3500
42	75m	B	2000
43	12m	W	1500
44	34m	B	600
45	35m	B	2000
46	30m	B	2500
47	22m	B	500
48	36m	B	2000
49	22m	B	600
50	21m	B	2500

	Depth	Type	Yield (l/h)
51	22m	B	2500
52	82m	B	1500
53	80m	B	2000
54	12m	W	1500
55	12m	W	1500
56	42m	B	3200
57	22m	B	1000
58	21m	B	1500
59	18m	W	1000
60	18m	W	1500
61	98m	B	1500
62	80m	B	2500
63	90m	B	2000
64	33m	B	1200
65	33m	B	1500
66	109m	B	3000
67	20m	B	2000
68	18m	W	1800
69	4m	W	800
70	4m	W	800
71	8m	W	1200
72	78m	B	3000
73	80m	B	3500
74	8m	W	600
75	90m	B	2800
76	110m	B	3000
77	105m	B	300
78	165m	B	1000
79	105m	B	3500
80	100m	B	3500
81	90m	B	600
82	38m	B	1500
83	24m	B	1500
84	78m	B	3000
85	9m	W	2000
86	9m	W	1200
87	9m	W	900
88	60m	B	6000
89	212m	B	400
90	70m	B	1500
91	70m	B	2500
92	110m	W	2000
93	212m	B	10000
94	72m	B	2000
95	33m	B	1500
96	100m	B	4000
97	72m	B	3500
98	40m	B	1500
99	24m	B	800
100	21m	B	1200

	Depth	Type	Yield (l/h)
101	18m	B	800
102	18m	B	800
103	18m	W	800
104	18m	B	800
105	60m	B	400
106	70m	B	1200
107	109m	B	6000
108	70m	B	3000
109	60m	B	20000
110	110m	B	1 500
111	80m	B	5000
112	18m	W	1000
113	21m	B	1200
114	70m	B	3000
115	26m	B	1500
116	89m	B	2500
117	105m	B	1200
118	26m	B	1500
119	9m	W	1000
120	60m	B	1500
121	18m	W	1200
122	22m	B	400
123	60m	B	500
124	55m	B	3000
125	15m	W	900
126	60m	B	2000
127	21m	W	1800
128	28m	W	1900
129	80m	B	200
130	9m	W	100
131	7m	W	500
132	42m	B	1000
133	60m	B	3500
134	72m	B	2000
135	60m	B	3500
136	9m	W	8000
137	60m	B	500
138	70m	B	3000
139	16m	W	800
140	65m	B	2000

APPENDIX D: Hermanus GAP case-study data set – filtering

LEGEND
Good, Usable Data
Street Number Required
Non-usable Data
Other (non-domestic)
Different Town/Suburb

No.	Code	Date	Street Name	Suburb	Owner/Occupier (at the time)	Erf No.
1	1	10-Mar-69	Stemmet Street 8	Eastcliff	Marriott J	1094
2	2	01-May-69	Mitchell Street	Eastcliff	Derry	1104
3	3	05-Aug-69	Robin Lane	Northcliff	Visser	5328
4	4	19-Sep-69	c/o Mitchell Str & Stemmet Str	Eastcliff	van Heerden	1096
5	5	Oct-69	Luyt Street 40	Eastcliff	Thorn	1107
6	7	31-Dec-74	Mitchell Street	Eastcliff	Blake	5359
7	8	20-Jan-75	McFarlane Street	Eastcliff	Erwee, Piet	1035
8	13	21-Oct-74	Steenbok Street	Northcliff	du Plessis	4712
9	14	26-Nov-74	Albertyn Street 30	Northcliff	van Wyk	4885
10	15	24-Nov-74	Main Road	Eastcliff	Ketterham W	1190
11	16	28-Nov-74	Robin Lane	Northcliff	van der Vyfer	4630
12	19	03-Nov-69	Albertyn Street	Northcliff	Arnott A	4680
13	20	05-Nov-69	Steenbok Street	Northcliff	Viljoen	4713
14	21	07-Nov-69	Steenbok Street	Northcliff	du Plooy	4716
15	22	11-Nov-69	Flora Avenue	Northcliff	Mayer	4434
16	23	27-Nov-69	Harmony Lane	Northcliff	Riggely	4589
17	24	05-Mar-74	Luyt Street	Eastcliff	Fluit	1109
18	25	05-Dec-69	Luyt Street	Eastcliff	Smart	1088
19	30	??	Luyt Street	Eastcliff	Smart	1088
20	31	??	Luyt Street	Eastcliff	Seuve	1092
21	32	??	Harmony Lane	Northcliff	Rigg	4590
22	33	??	Luyt Street	Eastcliff	Lumsden	1091
23	35	??	Mitchell Street	Eastcliff	Roseselaar	1105
24	36	??	Flora Street	Northcliff	Palmer	4473
25	37	??	Robin Lane	Northcliff	Cronje	4631
26	38	??	Flora Street	Northcliff	Hodgson	4471
27	42	??	Impala Street	Northcliff	du Toit, Neil	4460/4661
28	43	??	Talana Street	Northcliff	White	4463
29	44	??	Robin Lane	Northcliff	Delport Visser	5328
30	46	??	Luyt Street	Eastclliff	Edgar Jones	1087
31	47	??	Luyt Street	Eastclliff	Flint	1109
32	48	??	Luyt Street	Eastcliff	Wardlow	1102
33	56	??	Harmony Lane	Northcliff	Warmenhoven	4561
34	62	??	McFarlane Street	Eastcliff	Wainwright, Roy	1033
35	68	06-May-75	Luyt Street 53	Eastcliff	Waring	1058
36	75		Bird Lane 21	Northcliff	Featherstone-Smith	
37	86	22-Jan-76	c/o Duiker Street & Bird Lane	Northcliff	Peppler	
38	87	22-Jan-76	Duiker Street 41	Northcliff	Lappies	
39	92	03-Mar-76	Fourie Street 23	Northcliff	Freese, Mr	
40	95	03-May-76	Disa Avenue 10	Northcliff	Streicher	
41	96	30-Oct-76	Duiker Street 52	Northcliff	Ravenscroft	
42	98	02-Feb-79	Flora Avenue 14	Northcliff	Derry, Mrs	
43	99	02-Feb-79	Musson Street 55	Eastcliff	Marnham, Brig.	
44	100	15-May-79	Impala Street 20	Northcliff	Brooks, Mr	
45	101	15-May-79	Albertyn Street 42	Northcliff	de Waal, Mrs	
46	102	21-Jan-80	Musson Street 30	Eastcliff	Filmer, G	
47	103	21-Jan-80	Disa Avenue 5	Northcliff	London, Mr	
48	105	28-Jan-80	Musson Street 25	Eastcliff	Michelle, Miss	
49	106	28-Jan-80	Musson Street 27	Eastcliff	Bush, Miss	
50	107	28-Jan-80	Musson Street 41	Eastcliff	Klein, Mr	
51	108	28-Jan-80	Musson Street 32	Eastcliff	Windwad, Mrs	
52	109	28-Jan-80	Musson Street 51	Eastcliff	Smales, Mr	
53	110	28-Jan-80	Musson Street 49	Eastcliff	Tate, Dr	
54	114	10-Feb-80	Musson Street 23	Eastcliff	Blades, Mr	
55	117	19-Feb-80	Fourie Street 26	Northcliff	Groenwald, Bill	
56	118	19-Feb-80	Acacia Street 12	Northcliff	Wessels	
57	119	19-Feb-80	McFarlane Street 33	Eastcliff	Deveneux	
58	121	26-Feb-80	Moffat Street 36	Eastcliff	Bensiluque, Mr	
59	125	16-Mar-80	McFarlane Street 37	Eastcliff	Abbot, Mr	

No.	Code	Date	Street Name	Suburb	Owner/Occupier (at the time)	Erf No.
60	127	10-Apr-80	Dirkie Uys Street 5	Northcliff	Groenwald, Jan	
61	129	15-Apr-80	Mossie Lane 17	Northcliff	Glover, Mr	
62	131	18-Sep-81	Bird Lane 27	Northcliff	Willemse	
63	132	21-Sep-81	Bird Lane 26	Northcliff	Kritzinger	
64	133	24-Sep-81	Fourie Street 33	Northcliff	van Rooyen, A	
65	134	28-Sep-81	Dolphin Street 27	Northcliff	Lawrence	
66	139	13-Oct-81	Albertyn Street 45	Northcliff	Grundlingh	
67	140	19-Oct-81	Fourie Street 29	Northcliff	Hoffman, Thys	
68	142	03-Nov-81	Acacia Street 6	Northcliff	Dunman, Peter	
69	149	01-Dec-81	Impala Street 4	Northcliff	Wynants, Mr	
70	151	07-Dec-81	Dolphin Street 33	Northcliff	Bester, Mr	
71	152	15-Dec-81	Dolphin Street 35	Northcliff	Combrinck, Mrs	
72	153	15-Dec-81	Main Road 346	Northcliff	Humphries, Mr	
73	154	05-Jan-82	Eighth Street 254	Voelklip	Ballard, Mrs	
74	156	19-Jan-82	Mountain Drive 46	Northcliff	Morton, Mr	
75	157	19-Jan-82	Albertyn Street 40	Northcliff	Beckingham, Mrs	
76	158	02-Feb-82	Steenbok Street 5	Northcliff	Uys, L	
77	159	02-Feb-82	Talana Street 5	Northcliff	Botha, Mr	
78	160	18-Jan-82	Mountain Drive 46	Northcliff	Morton, Mr (see ref no.156)	
79	161	09-Feb-82	Luyt Street 38	Eastcliff	Cluver	
80	162	09-Feb-82	Flora Avenue 12	Northcliff	Asplurg, Mr	
81	163	09-Feb-82	Talana Street 5	Northcliff	Botha, Mrs (see ref no.159)	
82	164	16-Feb-82	Duiker Street 20	Northcliff	Coetzer	
83	168	06-Apr-82	Hill Street 11	Eastcliff	Arkcoll, David	
84	171	06-May-82	Stemmet Street 8	Eastcliff	Brown (see ref no.1)	
85	174	06-Aug-82	Albertyn Street 55	Northcliff	Lotter	
86	179	29-Oct-82	Luyt Street 31	Eastcliff	Buchanan	
87	182	09-Nov-82	Impala Street 21	Northcliff	Thiart	
88	184	09-Nov-82	Bird Lane 29	Northcliff	Willemse	
89	185	15-Nov-82	Robin Lane 29	Northcliff	Thorpe	
90	186	15-Nov-82	Bird Lane 42	Northcliff	Visser	
91	189	29-Nov-82	Impala Street 4	Northcliff	Wynants, Mr	
92	192	13-Jan-83	Robin Lane 21	Northcliff	Tyson	
93	194	13-Jan-83	Musson Street 25	Eastcliff	Michelle, Ms (See ref no. 105)	
94	196	20-Jan-83	Robin Lane 18	Northcliff	de Weevdt, AF	
95	198	17-Mar-83	Duiker Street 42	Northcliff	Bourgat	
96	199	07-Nov-83	Duiker Street 42	Northcliff	Bourgat (See ref. No. 198 above)	
97	201	07-Nov-83	Musson Street 56	Eastcliff	Gage, Mr	
98	202	07-Nov-83	Fourie Street 28	Northcliff	Smit, A	
99	203	14-Nov-83	Mountain Drive 18	Northcliff	Smithers	
100	204	14-Nov-83	Harmony Lane 25	Northcliff	Hodge	
101	206	21-Nov-83	Steenbok Street 5	Northcliff	Rodgers (see ref. No. 91)	
102	207	21-Nov-83	Mossie Lane 27	Northcliff	Wessels	
103	209	05-Dec-83	Fourie Street 28	Northcliff	Smit, A	
104	210	12-Dec-83	Bird Lane 42	Northcliff	Visser (see ref.no. 186)	
105	212	12-Dec-83	Robin Lane 20	Northcliff	Kuhn	
106	213	20-Dec-83	Steenbok Street 9	Northcliff	Cooke, Capt.	
107	217	05-Jan-84	Musson Street 51	Eastcliff	Musgrove	
108	219	12-Jan-84	Dolphin Street 27	Northcliff	Lawrence (see ref. No. 134)	
109	222	02-Feb-84	Impala Street 13	Northcliff	Heynes	
110	223	10-Sep-84	Steenbok Street 1	Northcliff	Young	
111	224	10-Sep-84	Impala Street 17	Northcliff	Roets	
112	225	10-Sep-84	Musson Street 58	Eastcliff	de Villiers, CH	
113	228	26-Jul-84	Hill Street 11	Eastcliff	Arkcoll, D (see ref no.168)	
114	232	18-Nov-84	Duiker Street 21	Northcliff	Els	
115	233	18-Nov-84	Musson Street 54	Eastcliff	Pettigrew, S Mrs	
116	234	19-Nov-84	Albertyn Street 39	Northcliff	Woodvine	
117	236	02-Dec-84	Albertyn Street 30	Northcliff	van der Nest	
118	240	10-Dec-84	Stemmet Street 8	Eastcliff	Brown (see ref no. 1 & 171)	
119	242	10-Apr-85	Musson Street 54	Eastcliff	Pettigrew, S Mrs (see ref no. 233)	
120	247	04-Feb-85	Musson Street 55	Eastcliff	Marnham, Brig.(see ref no. 99)	
121	249	08-May-85	Musson Street	Eastcliff	Michelle	
122	250	25-Mar-85	Duiker Street 26	Northcliff	Huddlestone	
123	254	26-Nov-85	Stemmet Street 8	Eastcliff	Brown (see ref no.1 & 171 & 240)	

No.	Code	Date	Street Name	Suburb	Owner/Occupier (at the time)	Erf No.
124	258	22-Oct-85	Musson Street 28	Eastcliff	Schilz, R	
125	260	20-Nov-85	Albertyn Street 61	Northcliff	Kritzinger	
126	263	02-Dec-85	Nichol Street 3	Eastcliff	Dugmore, John	
127	267	02-Dec-85	Eighth Street 254	Voelklip	Ballard, Mrs (see ref no. 154)	
128	271	29-Dec-85	Eighth Street 104	Voelklip	Rousseau, Olden	
129	275	27-Nov-85	Stemmet Street 8	Eastcliff	Brown, B (see ref no.1 & 171 & 240 & 254)	
130	277	13-Jan-86	Musson Street 15	Eastcliff	United Church house	
131	278	15-Dec-85	Bird Lane 29	Northcliff	Sardinha	
132	281	02-Feb-86	Musson Street 51	Eastcliff	Musgrove (see ref no. 217)	
133	283	02-Feb-86	Musson Street 41	Eastcliff	Klein (see ref no. 107)	
134	286	04-Apr-86	Albertyn Street 34	Northcliff	Dugmore	
135	287	04-May-86	Fir Avenue 14	Northcliff	Terblanche	
136	293	24-Mar-86	Impala Street 4	Northcliff	Wjinard	
137	295	12-Aug-86	Fourie Street 30	Northcliff	Visser [cf. Ref no. 210 & 186	
138	298	04-Sep-86	Musson Street 48	Eastcliff	Brown	
139	303	17-Nov-86	Mitchell Street 56	Eastcliff	Giloway	
140	305	16-Mar-87	Albertyn Street 28	Northcliff	Souter	
141	306	18-Jan-87	Musson Street 51	Eastcliff	Musgrove (see ref no. 217 & 281)	
142	312	10-Apr-87	East Street 7	Westcliff	Maree, Piet	
143	313	28-Oct-87	Musson Street 55	Eastcliff	Altona de Klerk (see ref no. 99)	
144	316	02-Nov-87	Duiker Street 30	Northcliff	Vosloo (ex van Wyk) (see ref no. 14,111, 272)	
145	317	19-Jan-88	Mossie Lane 8	Northcliff	de Wet, Dr.	
146	319	01-Feb-88	Impala Street 12	Northcliff	Malherbe	
147	322	29-Dec-87	Protea Street 17	Onrust	de Klerk,	
148	325	26-Oct-87	Duiker Street 20	Northcliff	Haman (see ref no. 164)	
149	329	23-Feb-88	Harmony Lane 25	Northcliff	Hodge	
150	333	24-Aug-88	Mitchell Street 59	Eastcliff	Miller, (see ref no. 35)	
151	334	27-Jun-88	Mitchell Street 61	Eastcliff	Carter	
152	336	10-Jun-88	Dolphin Street 37	Northcliff	Mitchell, Rev.	
153	337	27-Jul-88	Sixth Street 248	Voelklip	Winkler	
154	338	26-Jul-88	Mitchell Street 59	Eastcliff	Miller (see ref no. 35 & 333)	
155	340	06-Sep-88	Moffat Street 16	Eastcliff	Upton, Mr	
156	341	04-Aug-88	Mitchell Street 71	Eastcliff	Carter (see ref no.334)	
157	342	23-Sep-88	Fir Avenue 14	Northcliff	Terblanche (see ref no.287)	
158	344	11-Oct-88	Luyt Street 11	Eastcliff	Loubser, Danie	
159	348	22-Nov-88	Mitchell Street 63	Eastcliff	Buchanan (see ref no. 292)	
160	350	28-Nov-88	Bird Lane 21	Northcliff	van Zyl, ex Feathersone-Smith (see ref no.76)	
161	353	10-Jan-89	Duiker Street 29	Northcliff	Bell	
162	354	16-Jan-89	Moffat Street 24	Eastcliff	Lloyd, A	
163	355	17-Jan-89	Luyt Street 50	Eastcliff	Rea	
164	357	23-Jan-89	Main Road 29	Northcliff	Mathewson	
165	358	23-Jan-89	Disa Avenue 4	Northcliff	Forder	
166	359	23-Jan-89	Disa Avenue 12	Northcliff	Streicher	
167	360	24-Jan-89	Disa Avenue 11	Northcliff	Kuhn	
168	364	13-Feb-89	Flora Avenue 14	Northcliff	Ackermann (ex Derry)	
169	34	??	Impala Street ??	Northcliff	van Zyl	4530?
170	45	??	??	Northcliff	Beuderman	5518
171	51	??	Mitchell Street	Eastcliff	Bacher	
172	59	??	??	??	Pettit	1642
173	61	??	Bird Lane	Northcliff	Haupt	1614?
174	93	04-Mar-76	5th Avenue	Voelklip	Orchard, Prof.	
175	112	10-Feb-80	Albertyn Street	Northcliff	Basson, Chris	
176	113	10-Feb-80	Moffat Street	Eastcliff	Syfret, Piet	
177	115	10-Feb-80	Duiker Street	Northcliff	Frylik	
178	116	10-Feb-80	Mitchell Street	Eastcliff	Gillespie, J	
179	120	26-Feb-80	Robin Lane/Main Road	Northcliff	Tynes, Dr	
180	122	03-Mar-80	Flora Avenue	Northcliff	Dornbrack	
181	124	16-Mar-80	Moffat Street 17	Eastcliff	Patterson, Mr	
182	126	16-Mar-80	Nichol Street	Eastcliff	Moreland, Mr	
183	130	15-Apr-80	Mitchell Street	Eastcliff	Hodgson	
184	135	28-Sep-81	Albertyn Street	Northcliff	Tynes, Mr (Senior)	
185	136	08-Oct-81	Bird Lane	Northcliff	du Toit, A	
186	137	13-Oct-81	Albertyn Street	Northcliff	Bester	
187	138	13-Oct-81	Robin Lane	Northcliff	le Roux	

No.	Code	Date	Street Name	Suburb	Owner/Occupier (at the time)	Erf No.
188	143	10-Nov-81	McFarlane Street	Eastcliff	Haylett, Ms	
189	144	10-Nov-81	Luyt Street	Eastcliff	de Villiers, Ms	
190	145	16-Nov-81	Impala Street	Northcliff	Warhoven, Luis	
191	146	16-Nov-81	Contour Street	Kwaaiwater	Servunier, Mrs	
192	147	16-Nov-81	McFarlane Street	Eastcliff	Erwee, Piet	
193	148	16-Nov-81	McFarlane Street	Eastcliff	Robinson, Mr	
194	150	01-Dec-81	Duiker Street	Northcliff	Stergianous	
195	155	05-Jan-82	Fourth Street	Voelklip	Carse, Tommy	
196	165	16-Mar-82	Fairways Avenue	Eastcliff	Nock	
197	166	27-Mar-82	Dolphin Street	Northcliff	Evenes, Paul	
198	167	06-Apr-82	Dolphin Street	Northcliff	Rennie	
199	169	16-Apr-82	Albertyn Street	Northcliff	Ferreira	
200	170	27-Apr-82	Main Road	Northcliff	Serfontein	
201	175	12-Oct-82	Main Road 22	Northcliff	Ras	
202	176	05-Dec-82	Bird Lane	Northcliff	Peroplev	
203	177	05-Dec-82	Talana Street	Northcliff	Noahayle	
204	178	26-Oct-82	Main Road 22	Northcliff	Ras (see ref no. 175)	
205	180	29-Oct-82	Albertyn Street	Northcliff	Humphries, Mr	
206	181	02-Nov-82	Luyt Street	Eastcliff	Smart, Mrs	
207	183	09-Nov-82	Bird Lane	Northcliff	Thorpe	
208	188	29-Nov-82	Albertyn Street/Mountain Drive??	Northcliff	Rens	
209	191	13-Jan-83	Impala Street	Northcliff	Hough	
210	193	13-Jan-83	Main Road	Onrust	Badenhorst	
211	195	20-Jan-83	Main Road	Onrust	Badenhorst (see ref. No. 193)	
212	197	17-Mar-83	Disa Avenue 1	Northcliff	Beyers	
213	200	07-Nov-83	Luyt Street	Eastcliff	Mr Bekker, Mrs Bindeman	
214	205	14-Nov-83	Mitchell Street	Eastcliff	Reid	
215	208	17-Mar-83	Disa Avenue 1	Northcliff	Ross (see ref. No. 197 [ex Beyers])	
216	211	12-Dec-83	Albertyn Street	Northcliff	Day, L	
217	214	20-Dec-83	McFarlane Street	Eastcliff	Roodt, Mrs	
218	215	06-Mar-84	Albertyn Street	Northcliff	Brink	
219	216	06-Mar-84	Albertyn Street	Northcliff	van der Merwe	
220	218	05-Jan-84	Duiker Street	Northcliff	Frylink (see ref. No. 115)	
221	220	02-Feb-84	McFarlane Street	Eastcliff	Waring (see ref no. 68)	
222	221	02-Feb-84	Robin Lane	Northcliff	Day, L (see ref no. 211)	
223	227	03-Jul-84	Steenbok Street	Northcliff	Viljoen	
224	230	10-Jul-84	Main Road 22	Northcliff	Ras (see ref no. 178)	
225	231	19-Nov-84	Robin Lane	Northcliff	Roetz	
226	237	02-Nov-84	Luyt Street	Eastcliff	Wadlow	
227	238	10-Dec-84	Impala Street	Northcliff	Kingwell	
228	239	10-Dec-84	Eighth Street	Voelklip	Boulard	
229	243	10-Dec-85	Eigth Street	Voelklip	Boulard (see ref no.239)	
230	244	25-Mar-85	Mitchell Street	Eastcliff	Aberhanson	
231	245	24-Apr-85	Eighth Street	Voelklip	Lange	
232	246	25-Mar-85	Fairways Avenue	Eastcliff	Knock (see ref no.165)	
233	248	17-Jan-85	Talana Street	Northcliff	Holhagele	
234	252	08-May-85	Sixth Street	Voelklip	Joubert	
235	255	14-Oct-85	Main Road	Northcliff	Tynes, Dr	
236	256	05-Oct-85	Luyt Street	Eastcliff	Commerel, Dr	
237	257	05-Oct-85	Eighth Street	Voelklip	Orchard (see ref no. 251 & 93)	
238	259	22-Oct-85	Acacia Street	Northcliff	de Kock (see ref no. 226)	
239	261	20-Nov-85	Impala Street	Northcliff	de Kock, Dr	
240	264	02-Dec-85	Dolphin Street	Northcliff	Porter, Dave	
241	268	29-Dec-85	Robin Lane	Northcliff	Day, L (see ref no. 211 & 221)	
242	270	29-Dec-85	Robin Lane	Northcliff	Day, L (see ref no. 268, 221, 211)	
243	273	29-Dec-85	Fourie Street	Northcliff	Grundlingh	
244	279	19-Jan-86	Robin Lane	Northcliff	Day, L (see ref no. 211, 221, 268)	
245	282	02-Feb-86	Robin Avenue 41	Northcliff	Peens	
246	284	11-Feb-86	Steenbok Street	Northcliff	du Plooy (see ref no.21)	
247	285	11-Feb-86	Steenbok Street	Northcliff	du Plessis (see ref no. 13)	
248	288	04-May-86	Robin Lane	Northcliff	Delport Visser (see ref no.	
249	289	04-May-86	Albertyn Street	Northcliff	Lotter (see ref no.	
250	290	04-May-86	McFarlane Street	Eastcliff	Roots	
251	291	04-May-86	Steenbok Street	Northcliff	Rodgers	

No.	Code	Date	Street Name	Suburb	Owner/Occupier (at the time)	Erf No.
252	292	26-Feb-86	Luyt Street	Eastcliff	Buchanan (see ref no.	
253	310	19-Oct-87	Mossie Lane	Northcliff	Geldenhuis	
254	311	19-Oct-87	Fir Avenue	Northcliff	Jordaan, Leon Dr.	
255	314	26-Oct-87	Mossie Lane	Northcliff	Geldenhuis (see ref no. 310)	
256	315	02-Nov-87	Arc Street	Kwaaiwater	Jordaan, L	
257	320	21-Dec-87	Fir Avenue	Northcliff	Senivucci	
258	321	04-Jan-88	Duiker Street	Northcliff	van Wyk (see ref no. 316)	
259	324	09-Nov-87	Fir Avenue	Northcliff	Ferness, Dr.	
260	326	22-Feb-88	Mimosa Road	Northcliff	Harmse	
261	327	22-Feb-88	Musson Street	Eastcliff	Knight	
262	335	26-Jun-88	Westcliff Road	Westcliff	Bouwker	
263	343	23-Sep-88	Luyt Street	Eastcliff	Stewart, ex Lausdon (see ref no.33)	
264	361	30-Jan-89	Albertyn Street	Northcliff	le Roux	
265	373	17-Jan-90	Main Road	??	van Dyk	
266	6	Oct-69	??	??	Seeligen	5510
267	9	20-Jan-75	Robin Street	??	Football Club	4531
268	10	05-Jan-75	??	Northcliff	van der Vyfer	
269	11	31-Jan-75	??	Voelklip	Roussouw P E	
270	12	??	??	??	Hawston Development	
271	17	31-Dec-74	??	??	Schilder	
272	18	30-Dec-74	??	??	Luyt	
273	26	10-Dec-69	??	??	Patterson	
274	27	04-Dec-69	??	??	Ritter S	
275	28	03-Dec-69	??	??	Basson	
276	29	06-Dec-69	??	??	Wood	
277	39	??	Main Road	Eastcliff	Groenwald, Nick	5474
278	40	??	??	??	Tines	
279	41	??	??	??	Langehoven	
280	49	??	??	??	Cook	
281	50	??	??	??	Mulligan, Dr	
282	52	??	??	??	Hoffmeyer R	
283	53	??	??	??	van Breda	
284	54	??	??	??	Louw, George	
285	55	??	??	??	van Zyl	
286	57	??	??	??	Simpson	
287	58	??	??	??	Butler	
288	60	??	??	??	Vaughan-Jones	
289	63	20-Feb-75	??	??	van Zyl	
290	64	20-Feb-75	??	??	Brown, Bruno	
291	65	26-Feb-75	??	??	Syfret	
292	66	10-Jan-75	??	??	Tuck, George	
293	67	04-May-75	??	??	Lubbe, Ben	
294	69	27-Oct-75	??	??	Sanon	
295	70	28-Oct-75	??	??	Mathew	
296	71	29-Oct-75	??	??	Veich	
297	72	23-Nov-75	??	??	Vester	
298	73	24-Nov-75	??	??	Richards	
299	74	26-Nov-75	??	??	Franlash	
300	76	04-Dec-75	??	??	Laubscher	
301	77	06-Dec-75	??	??	de Kock	
302	78	08-Dec-75	??	??	Slabbert, Mrs	
303	79	23-Dec-75	??	??	Bezuidenhout	
304	80	02-Aug-75	??	??	de Villiers, George	
305	81	05-Jan-76	??	Voelklip	Roussouw	
306	82	06-Jan-76	??	Northcliff	Kingwell	
307	83	12-Jan-76	??	Northcliff	Streicher	
308	84	19-Jan-76	??	Northcliff	Wessels	
309	85	19-Jan-76	??	??	Gourum, Mrs	
310	88	09-Jan-76	??	??	Belanrd	
311	89	01-Mar-76	??	??	Wessels	
312	90	01-Mar-76	??	??	Ferriera	
313	91	01-Mar-76	??	??	Rodgers	
314	94	17-May-76	??	??	Meyer, Jack	
315	97	03-Jun-76	??	??	Groenwald, Nick	

No.	Code	Date	Street Name	Suburb	Owner/Occupier (at the time)	Erf No.
316	104	26-Jan-80	??	??	Armstrong, Syd	
317	111	28-Jan-80	Dirkie Uys Street 30	Sandbaai	van Wyk	
318	123	06-Mar-80	Moffat Street 15	Eastcliff	United Church	
319	128	10-Apr-80	Mossie Lane 3	Northcliff	Cooke, Lt SAP	
320	141	03-Nov-81	??	??	du Toit, Saul	
321	172	06-May-82	Musson Street	Eastcliff	Hermanus N.G. Kerk,	
322	173	06-Oct-82	Main Road	Northcliff	N.G. Kerk, Dr Oosterhuizen	
323	187	15-Nov-82	??	Sandbaai	Tredoux, B	
324	190	29-Nov-82	??	Westcliff	Samson, Lee	
325	226	18-Jun-84	c/o Hermanus Datsun	??	de Kock	
326	229	11-Aug-84	??	Kuilsriver	Taverner, Ean	
327	235	25-Nov-84	??	Churchaven	Slingsbi	
328	241	25-Mar-85	Main Road	Northcliff	N.G. Kerk (see ref no. 173)	
329	251	21-Apr-85	Pinewood	??	Orchard	
330	253	20-Nov-85	??	Northcliff	Bowling Club	
331	262	20-Nov-85	??	Somerset West	Orchard Blue Crane (see ref no. 251 & 93)	
332	265	02-Dec-85	??	Northcliff	Bowling Club	
333	266	02-Dec-85	??	Somerset West	Orchard Blue Crane (see ref no. 251 & 93)	
334	269	29-Dec-85	Rooikrans	Voelklip	van Wyk	
335	272	29-Dec-85	Rooikrans	Voelklip	van Wyk (see ref no. 269)	
336	274	27-Nov-85	??	West Coast	Chamanais	
337	276	06-Jan-86	Darling Road	??	Mitchell	
338	280	24-Jan-86	Steyn Rust	Somerset West		
339	294	01-Aug-86	??	Northcliff	du Toit, SAP house	
340	296	12-Aug-86	Behind Bowling Club	Northcliff	du Plooy (see ref no.21 & 284 ?)	
341	297	01-Aug-86	??	??	Kraaifontein Timbers	
342	299	10-Jul-86	Rotary Way Farm	Mt. Pleasant	Myburgh, Nico	
343	300	10-Nov-86	??	Northcliff	Sutherland, SAP house	
344	301	10-Nov-86	??	Northcliff	Fouche, SAP house	
345	302	10-Nov-86	Rotary Way Farm	Mt. Pleasant	Myburgh, Nico [see ref no. 299]	
346	304	22-Feb-87	??	Northcliff	du Toit, Niel	
347	307	22-Jan-87	Rotary Way Farm	Mt. Pleasant	Myburgh, Nico [see ref no. 299]	
348	308	27-Mar-87	??	Voelklip	Nagle, Mrs {new house}	
349	309	18-Aug-87	Disa Street 24	Onrus	Dollman, Mrs	
350	318	18-Jan-88	??	Sandbaai	Booysen	
351	323	15-Dec-97	de Bos camp	??	Bosko	
352	328	01-Feb-88	??	??	Thorpe	
353	330	18-Feb-88	Adam Tas	??	Peters	
354	331	18-Jan-88	??	Sandbaai	Hen Boisen	
355	332	02-Feb-88	Prince Albert Road	Villiersdorp	Dekker	
356	339	08-Sep-88		Rooi Els	Lindsey, Bill	
357	345	21-Oct-88	??	Grabouw	Triangle Farms	
358	346	08-Nov-88	??	Voelklip	Kleyn, Terry	
359	347	16-Nov-88	??	??	Kraaifontein Timbers	
360	349	22-Nov-88	??	??	le Grange, ex du Plooy (see ref no.296)	
361	351	30-Nov-88	??	??	Kraaifontein Timbers	
362	352	15-Dec-88	Niewoudt Street 10	De Aar	du Plessis, R	
363	356	15-Jan-89	Van Riebeeck Street	Kuilsriver	Lotz	
364	362	13-Feb-89	??	??	Thorpe (see ref no. 328)	
365	363	13-Feb-89	??	Northcliff	du Toit Isaac, SAP house 66	
366	365	10-Apr-89	??	??	Stoddard	
367	366	18-May-89	??	??	Goose, Jannie	
368	367	30-Jun-89	Dirkie Uys Street	Sandbaai	Landman	
369	368	05-Jul-89	??	??	Stoddard	
370	369	08-Jul-89	??	??	Schneider	
371	370	01-Aug-89	Duncan Street 37	Sea Point	Field, Nicky	
372	371	10-Aug-89	c/o Rolo Motors	??	Buchner, Willie	
373	372	04-Oct-89	??	??	Stops, Mrs	
374	374	??	??	??	Gaynor	
375	375	??	??	??	Pettigrew	
376	376	??	??	??	Stoddard	
377	377	30-Mar-90	??	??	van Niekerk	
378	378	05-Mar-90	??	Stanford	McCarthy	

APPENDIX E: Hermanus GAP case-study – final data set

No.	Code	Street Address	Suburb	Owner/Occupier	Erf No.	AADD (kl/day)	Erf Size (m^2)
1	259	Acacia Avenue 4	Northcliff	de Kock	4528	0.430	763
2	142	Acacia Avenue 6	Northcliff	Dunman, Peter	4529	0.149	763
3	118	Acacia Avenue 12	Northcliff	Wessels	4536	0.222	763
4	236	Albertyn Street 30	Northcliff	van der Nest	4885	0.549	669
5	286	Albertyn Street 34	Northcliff	Dugmore	4513	0.172	763
6	112	Albertyn Street 36	Northcliff	Basson, Chris	4514	0.602	763
7	361	Albertyn Street 38	Northcliff	le Roux	4517	0.401	763
8	234	Albertyn Street 39	Northcliff	Woodvine	4507	0.237	833
9	157	Albertyn Street 40	Northcliff	Beckingham, Mrs	4518	0.515	763
10	101	Albertyn Street 42	Northcliff	de Waal, Mrs	4521	0.270	763
11	139	Albertyn Street 45	Northcliff	Grundlingh	4504	0.441	833
12	289	Albertyn Street 55	Northcliff	Lotter	4656	1.599	833
13	215	Albertyn Street 59	Northcliff	Brink	4658	0.384	833
14	260	Albertyn Street 61	Northcliff	Kritzinger	4659	1.234	1016
15	135	Albertyn Street 63	Northcliff	Tynes, Mr (Senior)	4679	0.515	807
16	315	Arc Street 14A	Kwaaiwater	Jordaan, L Dr	6318	0.866	2091
17	86	Bird Lane 12	Northcliff	Peppler	4539	0.270	821
18	350	Bird Lane 21	Northcliff	van Zyl	4537	1.268	752
19	132	Bird Lane 26	Northcliff	Kritzinger	4593	0.376	822
20	131	Bird Lane 27	Northcliff	Willemse	4618	0.851	1506
21	278	Bird Lane 29	Northcliff	Sardinha	4617	0.184	763
22	282	Bird Lane 41	Northcliff	Peens	4704	1.305	770
23	210	Bird Lane 42	Northcliff	Visser	4706	0.332	770
24	127	Dirkie Uys Street 5	Northcliff	Groenwald, Jan	748	1.213	595
25	358	Disa Avenue 4	Northcliff	Forder	4619	0.516	763
26	360	Disa Avenue 11	Northcliff	Kuhn	4632	0.608	763
27	359	Disa Avenue 12	Northcliff	Streicher	4611	0.695	763
28	42	Dolphin Street 10	Northcliff	du Toit, Neil	4660	0.350	1330
29	219	Dolphin Street 27	Northcliff	Lawrence	4682	0.752	752
30	151	Dolphin Street 33	Northcliff	Bester, Mr	4687	0.215	732
31	152	Dolphin Street 35	Northcliff	Combrinck, Mrs	4690	0.414	752
32	336	Dolphin Street 37	Northcliff	Mitchell, Rev.	4749	1.371	942
33	264	Dolphin Street 39	Northcliff	Porter, Dave	4748	1.381	807
34	325	Duiker Street 20	Northcliff	Haman	4429	0.338	1041
35	232	Duiker Street 21	Northcliff	Els	4433	0.550	752
36	353	Duiker Street 29	Northcliff	Bell	4509	0.343	881
37	316	Duiker Street 30	Northcliff	Vosloo	5370	0.343	1571
38	87	Duiker Street 41	Northcliff	Lappies	4531	0.259	763
39	199	Duiker Street 42	Northcliff	Bourgat	4886	0.451	669
40	312	East Street 7	Westcliff	Maree, Piet	180	0.636	1053
41	271	Eighth Street 104	Voelklip	Rousseau, Olden	2451	0.734	917
42	267	Eighth Street 254	Voelklip	Ballard, Mrs	5668	0.822	916
43	22	Flora Avenue 7	Northcliff	Mayer	4434	0.403	787
44	162	Flora Avenue 12	Northcliff	Asplurg, Mr	4473	0.553	763
45	364	Flora Avenue 14	Northcliff		4470	0.409	763
46	122	Flora Avenue 16	Northcliff	Dornbrack	4469	0.455	763
47	92	Fourie Street 23	Northcliff	Freese, Mr	6027	0.286	1104
48	117	Fourie Street 26	Northcliff	Groenwald, Bill	4499	0.193	832
49	209	Fourie Street 28	Northcliff	Smit, A	4498	1.049	833
50	140	Fourie Street 29	Northcliff	Hoffman, Thys	4475	0.264	798
51	295	Fourie Street 30	Northcliff	Visser	4497	0.213	833
52	56	Harmony Avenue 3	Northcliff	Warmenhoven	4561	0.708	722
53	32	Harmony Avenue 17	Northcliff	Rigg	4590	0.654	859
54	23	Harmony Avenue 19	Northcliff	Riggely	4589	0.362	859
55	329	Harmony Avenue 25	Northcliff	Hodge	4586	0.422	859
56	228	Hill Street 11	Eastcliff	Arkcoll, David	1082	1.076	720
57	238	Impala Street 9	Northcliff	Kingwell	4665	0.796	870

No.	Code	Street Address	Suburb	Owner/Occupier	Erf No.	AADD (kl/day)	Erf Size (m^2)
58	319	Impala Street 12	Northcliff	Malherbe	4467	0.523	844
59	222	Impala Street 13	Northcliff	Heynes	4651	0.681	807
60	224	Impala Street 17	Northcliff	Roets	4622	0.200	938
61	100	Impala Street 20	Northcliff	Brooks, Mr	4523	0.754	807
62	182	Impala Street 21	Northcliff	Thiart	4620	1.242	825
63	344	Luyt Street 11	Eastcliff	Loubser, Danie	928	0.470	694
64	31	Luyt Street 25	Eastcliff	Seuve	1092	0.284	892
65	181	Luyt Street 29	Eastcliff	Smart, Mrs	7552	0.872	627
66	161	Luyt Street 38	Eastcliff	Cluver	7598	0.349	868
67	47	Luyt Street 42	Eastcliff	Flint	1109	0.471	892
68	355	Luyt Street 50	Eastcliff	Rea	1116	1.439	892
69	68	Luyt Street 53	Eastcliff	Waring	1058	0.480	465
70	230	Main Road 22	Westcliff	Ras	456	0.864	773
71	15	Main Road 207	Eastcliff	Ketterham W	1190	0.238	892
72	30	McFarlane Street 6	Eastcliff	Smart	1088	0.234	781
73	143	McFarlane Street 17	Eastcliff	Haylett, Ms	1013	0.753	892
74	147	McFarlane Street 19	Eastcliff	Wainwright, Roy	1033	0.877	892
75	119	McFarlane Street 33	Eastcliff	Deveneux	1046	0.747	892
76	125	McFarlane Street 37	Eastcliff	Abbot, Mr	1049	0.504	892
77	205	Mitchell Street 57	Eastcliff	Reid	1104	0.488	892
78	338	Mitchell Street 59	Eastcliff	Miller	1105	0.341	892
79	334	Mitchell Street 61	Eastcliff	Carter	1106	0.668	892
80	348	Mitchell Street 63	Eastcliff	Buchanan	1108	0.722	892
81	341	Mitchell Street 71	Eastcliff	Carter	5359	0.414	1784
82	340	Moffat Street 16	Eastcliff	Upton, Mr	958	0.518	574
83	354	Moffat Street 24	Eastcliff	Lloyd, A	980	1.074	689
84	121	Moffat Street 36	Eastcliff	Bensiluque, Mr	992	0.613	685
85	317	Mossie Lane 8	Northcliff	de Wet, Dr.	4558	0.168	714
86	129	Mossie Lane 17	Northcliff	Glover, Mr	4595	0.141	833
87	207	Mossie Lane 27	Northcliff	Wessels	4604	0.300	822
88	203	Mountain Drive 18	Northcliff	Smithers	6884	0.608	762
89	19	Mountain Drive 40	Northcliff	Arnott A	4680	1.052	807
90	160	Mountain Drive 46	Northcliff	Morton, Mr	4685	1.008	854
91	277	Musson Street 15	Eastcliff	United Church House	5446	0.738	693
92	114	Musson Street 23	Eastcliff	Blades, Mr	981	0.311	689
93	249	Musson Street 25	Eastcliff	Michelle, Ms	982	0.681	808
94	106	Musson Street 27	Eastcliff	Bush, Miss	985	0.409	694
95	102	Musson Street 30	Eastcliff	Filmer, G	1000	0.872	746
96	298	Musson Street 48	Eastcliff	Brown	1037	0.420	892
97	242	Musson Street 54	Eastcliff	Pettigrew, S Mrs	1043	0.371	892
98	313	Musson Street 55	Eastcliff	Altona de Klerk	1022	2.406	1338
99	327	Musson Street 56	Eastcliff	Gage, Mr	1045	0.308	892
100	191	Robin Lane 15	Northcliff	Hough	4652	0.227	807
101	288	Robin Lane 17	Northcliff	Delport Visser	8025	0.346	818
102	44	Robin Lane 19	Northcliff	Delport Visser	5328	0.276	763
103	212	Robin Lane 20	Northcliff	Kuhn	4631	0.476	763
104	192	Robin Lane 21	Northcliff	Tyson	4645	0.246	763
105	185	Robin Lane 29	Northcliff	Thorpe	4637	0.591	1079
106	252	Sixth Street 308	Voelklip	Joubert	6099	0.830	990
107	223	Steenbok Street 1	Northcliff	Young	4691	0.869	1102
108	206	Steenbok Street 5	Northcliff	Rodgers	4693	0.499	729
109	213	Steenbok Street 9	Northcliff	Cooke, Capt.	4697	0.736	729
110	285	Steenbok Street 23	Northcliff	du Plessis	4712	1.087	729
111	20	Steenbok Street 25	Northcliff	Viljoen	4713	0.717	729
112	284	Steenbok Street 27	Northcliff	du Plooy	4716	0.698	729
113	163	Talana Road 5	Northcliff	Botha, Mrs	4456	0.311	798
114	43	Talana Road 11	Northcliff	White	4463	0.673	798