TOWARDS DIRECT WASTEWATER REUSE FOR POTABLE AND NON-POTABLE USES: AN URBAN WATER BALANCE, COSTING AND ASSESSMENT OF PERCEPTIONS AT A SOUTH AFRICAN COMMUNITY

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CONTENTS **Page**

DECLARATION 6

ABSTRACT.. 7

ACKNOWLEDGEMENTS 9

LIST OF FIGURES 10

LIST OF TABLES.. 11

LIST OF SYMBOLS 15

CHAPTER 1 INTRODUCTION 16

1.1 Background 16

1.2 Problem statement 17

1.3 Research Aim and Objectives 18

1.4 Research Methodology.. 19

1.4.1 Literature survey of wastewater reuse………….……………..19

1.4.2 Water balance of Hartbeesfontein……….……………………….20

1.4.3 Cost implications…………………………………………………21

1.4.4 Development of a questionnaire………………………………21

1.4.5 Administration and analysis of questionnaires………………..21

1.4.6 Viability study……………………………………………………22

CHAPTER 2 LITERATURE SURVEY 23

2.1 Examples of Water Reclamation around the World....................... 23

2.2 Examples of Water Reclamation in South Africa........................... 28

2.3 The Benefits of Directly Reusing Wastewater for Potable or Non-potable Use 30

2.4 Issues of Concern Regarding Direct Wastewater Reuse for Potable or Non-potable Use 31

2.4.1Health risks……………………………………………………..31

2.4.2 Costs 36

2.4.3 Operational problems when using reclaimed water for irrigation... 38

2.5 Public Views on Water Reclamation for Drinking Purposes 38

2.6 Public Views on Water Reclamation for Irrigation Purposes.......... 39

2.7 Summary 40

CHAPTER 3 WATER BALANCE AND COSTING 42

3.1 Introduction... 42

3.2 The Current Water Consumption, Water Supply and Wastewater Generation Situation... 44

3.3 Replacing a Percentage of the Existing Municipal Water Supply with potable water from the Wastewater Reclamation System. 48

3.4 Replacing a Percentage of the Existing Municipal Water Supply with Non-potable water Supplied from Household Wastewater Reuse Systems for Non-potable Water Uses. 50

3.5 Replacing a Percentage of the Existing Municipal Water Supply with a Percentage of Treated Wastewater Treated for Non-potable Industrial Water Uses. 56

3.6 Cost implications 60

3.7 Cost of Potable Water 61

3.8 Cost of Wastewater Treatment.. 63

3.9 Cost of Direct Wastewater Reuse for Potable Use........................ 64

3.10 Cost of Direct Wastewater Reuse for Non-potable Use 64

3.11 Summary 66

CHAPTER 4 QUESTIONAIRE DEVELOPMENT 68

4.1 Introduction... 68

4.2 Constructs employed in the Questionnaire 68

4.3 Hypothesised Model 70

4.4 Questionnaire 73

CHAPTER 5 DATA CAPTURING AND ANALYSIS 74

5.1 Introduction 74

5.2 Data Capturing 74

5.2.1 Respondents' gender 74

5.2.2 Respondent's ethnic group 75

5.2.3 Respondents' religious group 76

5.2.4 Respondents' age group 77

5.2.5 Respondents' level of education 78

5.2.6 Respondents' garden extent 79

5.2.7 Number of bedrooms in respondents' dwelling 80

5.2.8 Respondents' responses to the direct reuse of treated wastewater for drinking and non-drinking purposes 81

5.3 Position in Mean Score Ranking for Non-drinking Purposes 91

5.4 Position in Mean Score Ranking for Drinking Purposes 94

5.5 Correlations (Non-drinking purposes) 97

5.6 Correlations (Drinking Purposes) 99

5.7 Summary 101

CHAPTER 6 VIABILITY OF WATER RECLAMATION FOR POTABLE AND NON-POTABLE WATER USES IN HARTBEESFONTEIN AND TIGANE 105

6.1 Introduction 105

6.2 Preference of the Community to use Treated Wastewater 105

6.3 Cost Implications if Replacing a Percentage of the Existing Municipal Water Supply with Potable or Non-potable Water from the Wastewater Reclamation System.. 106

6.4 Summary.. 109

CHAPTER 7 CONCLUSION.. 110

7.1 Recommendation for Future Research 112

REFERENCES 114

APPENDIX A 122

APPENDIX B 125

ADDENDUM Ethics Clearance Certificate ………………………..128

DECLARATION

I declare that this research project report is my own unaided work. It is being submitted for the Master of Science in Engineering (Civil Engineering) to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

………………………………………………………………………………

(Signature of Candidate)

……….. day of …………….., ……………

(day) *(month)* *(year)*

ABSTRACT

South Africa is a semi-arid country with an average rainfall of 450 mm per annum. According to the Department of Water Affairs, the total registered water usage in 2013 met the estimated 2025 high water requirement of 17.3 billion m^3/annum. Therefore, the need had arisen to reduce water consumption and increase water supply to ensure the sustainability of our nation's water resources. Many studies show that wastewater reuse or water reclamation is an under-utilized and very viable water conservation concept in South Africa. The reuse of wastewater for direct potable or direct non-potable reuse is a highly debated topic requiring frequent engagement and investigation. Although direct reuse for potable uses is often more contentious than direct reuse for non-potable uses, it is worth investigating for possible future implementation at certain water scares areas. Hence, this study investigated the possibility of the future implementation of direct wastewater reuse at Hartbeesfontein - a selected South African community, for potable or non-potable use. The study incorporated potential users' perceptions, the cost implications of reuse and water saving potential by means of different water balance models.

The survey conducted, measuring the intention of the residents from Hartbeesfontein to accept direct wastewater reuse for potable and non-potable use, revealed the community's overwhelming acceptance (about 70%) of a reuse system should it be implemented in the future. The community's preference for wastewater reuse for non-potable use (75%) was higher than for potable use (67%).

Hypothetically, it would be possible to reuse 85% of the community's daily demand for potable use, if all the wastewater collected at the wastewater treatment plant could be treated. It would then mean that the municipality will only need to provide 15% of the daily water demand.

The option to reuse wastewater for non-potable use (i.e. to supply an industry) could save the community 22% its daily water demand.

In this study, the cost of wastewater treatment for potable use was approximately 350% higher than the cost of potable water supplied by the Midvaal Water Company. The cost of treating wastewater for non-potable use however was approximately 46% less than the cost of potable water supplied by the Midvaal Water Company.

By incorporating the outcomes of the water balance, perceptions of the community and analysis of the different wastewater reuse scenario costs, it was evident from the study that direct wastewater reuse for non-potable industrial application was the most viable water reuse option for Hartbeesfontein.

Keywords: Water balance model, wastewater re-use, potable and non-potable, perception, cost

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LIST OF FIGURES

Figure Page

Figure 3.1: Map of the City of Matlosana (delineated area) in North West Province, South Africa (Google Maps, 2016) 42

Figure 3.2: Map of Hartbeesfontein (Google Maps, 2016) 43

Figure 3.3: Billed water meter readings and amounts for the 2013/2014 financial year for Hartbeesfontein and Tigane (City of Matlosana, 2015) 45

Figure 3.4: Water balance model of current situation............................... 47

Figure 3.5: Water balance if wastewater is directly treated to potable water reuse 48

Figure 3.6 Water balance for greywater reuse installation within a house 51

Figure 3.7: Water balance if a percentage of wastewater is treated for non-potable reuses at an industry 58

Figure 3.8: Water pricing chain (Eberhard, 2003) 60

Figure 4.1: Hypothesised model predicting intended behaviour regarding direct wastewater reuse for potable and non-potable uses (Po *et al*, 2005) 70

Figure 5.1: Values of the correlation coefficient (Saunders et al, 2012) ... 98

LIST OF TABLES

Table Page

Table 1.1: Water reuse terminology (DWA, 2011) 16

Table 2.1: Treated effluent systems at the City of Cape Town (City of Cape Town, 2016) 28

Table 2.2: Examples of major groups of waterborne and water based pathogens (Asano *et al*, 2006) 34

Table 2.3: Recommended maximum concentration of metals in irrigation waters (EPA, 2012) 35

Table 2.4: 2007 production prices of different treatment technologies (Rygaard *et al,* 2011)... 36

Table 3.1: Application of the IWA water balance model to Hartbeesfontein & Tigane 46

Table 3.2: The impact on the System Input Volume from reclaiming different quantities of treated effluent. 50

Table 3.3: Projected 2014 water consumption figures for different consumers (Moedi, 2005).. 53

Table 3.4: Scenarios showing the potential reduction in municipal water supply if middle income residents install greywater reuse systems for toilet flushing. 54

Table 3.5: Scenarios showing the potential reduction in municipal water supply if low income residents install greywater reuse systems for toilet flushing at their homes.. 55

Table 3.6: The potential to reuse wastewater for non-potable purposes in various industrial sectors (Adewumi, 2011).................................. 57

Table 3.7: Scenarios showing the potential reduction in municipal water supply if the identified industry reuses non-potable treated effluent of varied quantities 59

Table 3.8: Water Supply Tariff Structure – City of Matlosana (2015)....... 61

Table 3.9: Typical cost elements of two distinct technologies for wastewater treatment plants (Moshidi *et al*, 2011) 63

Table 4.1: Descriptions of the constructs in the hypothesised model....... 71

Table 4.2: Constructs measuring intention to accept the direct reuse of wastewater for non-drinking purposes and their respective hypotheses (adopted from Adewumi *et al*, 2014) 72

Table 4.3: Constructs measuring intention to accept the direct reuse of wastewater for drinking purposes and their respective hypotheses (adopted from Adewumi *et al*, 2014). 73

Table 5.1: Frequencies pertaining to Respondents' Ethnic Groups (N = 178) 75

Table 5.2: Frequencies and pertaining to Respondents' Religious Groups (N = 178) 76

Table 5.3 Frequencies of Respondents' Age Group (N = 178) 77

Table 5.4: Frequencies pertaining to Respondents' Level of Education (N = 178) 78

Table 5.5: Frequencies pertaining to Respondents' Garden Extent (N = 178) 79

Table 5.6: Frequencies pertaining to Number of Bedrooms in Respondents' Dwellings (N = 178) 80

Table 5.7: Frequencies pertaining to respondents' knowledge of the direct reuse of treated wastewater for drinking purposes (N = 178)........ 81

Table 5.8: Frequencies pertaining to respondents' knowledge of the direct reuse of treated wastewater for non-drinking purposes (N = 178). 82

Table 5.9: Frequencies pertaining to respondents' trust in the authorities to provide treated wastewater for drinking purposes (N = 178)......... 83

Table 5.10 Frequencies pertaining to respondents' trust in the authorities to provide treated wastewater for non-drinking purposes (N = 178) 83

Table 5.11: Frequencies pertaining to respondents' attitude towards treated wastewater for drinking purposes (N = 178) 84

Table 5.12: Frequencies pertaining to Respondents' Attitude towards treated wastewater for non-drinking Purposes (N = 178) 85

Table 5.13: Frequencies pertaining to respondents' perceived control towards treated wastewater reuse for drinking purposes (N = 178) 86

Table 5.14: Frequencies pertaining to respondents' perceived control towards treated wastewater reuse for non-drinking purposes (N = 178) 87

Table 5.15: Frequencies pertaining to respondents' subjective norms towards treated wastewater reuse for drinking purposes (N = 178) 88

Table 5.16: Frequencies pertaining to respondents' subjective norms towards treated wastewater reuse for non-drinking purposes (N = 178) 88

Table 5.17: Frequencies pertaining to respondents' intention to use treated wastewater for drinking purposes (N = 178) 89

Table 5.18: Frequencies pertaining to respondents' intention to use treated wastewater for non-drinking purposes (N = 178)........................... 90

Table 5.19: Means, reliabilities and standard deviation extracted for potential non-drinking respondents 91

Table 5.20: Likert Scale used for statements of questionnaire 92

Table 5.21: Means, reliabilities and standard deviation extracted for potential drinking respondents.. 94

Table 5.22: Likert Scale used for statements of questionnaire 95

Table 5.23: Correlations amongst the constructs predicting the Intention to accept the direct reuse of treated wastewater for non-drinking purposes.. 97

Table 5.24: Correlations amongst the constructs predicting the Intention to accept the direct reuse of treated wastewater for drinking purposes 99

Table 6.1: Summary of questionnaire responses (agreed and strongly agreed responses) 105

Table 6.2: Different water mix ratios to meet daily water demand if existing water supply is augmented by reclaimed wastewater i.e. wastewater treated to potable quality 107

Table 6.3: Different water mix ratios to meet the daily demand of the industry and community if the existing water supply is augmented by reclaiming wastewater i.e. wastewater treated to non-potable quality for industrial use. 108

LIST OF SYMBOLS

Sample size	N
Number of respondents	n
Summated Mean Scores	$\bar{x}$
Reliabilities	α
Correlation	*r*
Significance	p

CHAPTER 1 INTRODUCTION

1.1 Background

South Africa is a semi-arid country with an average rainfall of 450 mm per annum. According to the Department of Water Affairs, the total registered water usage in 2013 met the estimated 2025 high water requirement of 17.3 billion m^3/annum. Therefore, the need has arisen to reduce water consumption and increase water supply to ensure the sustainability of our nation's water resources. During the 17th Conference of the Parties (COP 17) held from 28 November to 9 December 2011 in Durban, it was again emphasized that a significant portion of our nation's surface water resources was fully allocated and that water saving practices should be implemented, because our water security was threatened. Water reuse, although under-utilized, provides a viable alternative to increasing supply capacity to communities. To ensure clarity on all the terminology related to water reuse, Table 1.1 has been employed.

Table 1.1: Water reuse terminology (DWA, 2011)

Water reuse	Utilization of treated or untreated wastewater for a process other than the one that generated it, i.e. it involves a change of user. For instance, the use of municipal wastewater for agricultural irrigation.
Water recycling	Utilization of treated or untreated wastewater for the same process that generated it, i.e. it does not involve a change of user. For instance, recycling the effluents in a pulp and paper mill.
Direct reuse	Re-use of treated or untreated wastewater by directly transferring it from the site where it is produced to a different/separate facility for the next use.
Indirect reuse	Re-use of treated or untreated wastewater after it has been discharged into a natural surface water or groundwater body, from which water is taken for further use.
Reclaimed water	Wastewater that has been treated to a level that is suitable for sustainable and safe re-use.
Wastewater	Water derived from any of a number of uses of water and typically containing residual pollutants associated with the use of the water.
Grey water	Wastewater derived from the domestic and household use of water for washing, laundry, cleaning and food preparation etc. Grey water does not contain faecal matter.

1.2 Problem statement

According to DWA (2011), water reclamation is wastewater that has been treated to a level that is suitable for sustainable and safe re-use. Also, according to Grobicki and Cohen (1999), some of the ways to supplement fresh water resources in South Africa, is through direct reuse of wastewater for agricultural, industrial, domestic, groundwater recharge and potable water uses. Studies undertaken by Adewumi *et al* (2010) shows that wastewater reuse is relatively an untapped concept in South Africa. Where implemented, it is used mainly for sport ground and landscape irrigation, industrial applications and agriculture, mostly at a small scale. Although these are the conventional reuses for wastewater, wastewater can also be reused for drinking purposes. One of the most successful water reclamation plants in the world is situated in Windhoek, Namibia. This plant, the Goreangab water reclamation plant, produces 21,000 m^3/day of potable water for the city of Windhoek and thus satisfied 35% of the 2006 daily potable water requirements of the city (Du Pisani, 2006).

According to Marks (2006) and Asano & Bahari (2010), the densely populated Singapore reuses wastewater for industrial purposes, uses treated wastewater to recharge its' raw water supply and directly reuses wastewater for potable use, also known as "NEWater". With the NEWater initiative, Singapore is changing its' public's perspective towards reclaimed wastewater for drinking purposes. Many other cities across the world (namely, San Diego, Denver, Dublin, San Ramon and Orange County) have designed and proposed water reclamation plants for direct potable reuse, but due to resistance from the public, the proposals were withdrawn (Marks, 2006).

Although water reclamation for drinking purposes is technically possible, it is of no use if the concept is not accepted by the public. Studies done by Dishman *et al* (1989) indicates that educational and psychological obstacles must be overcome before the general public will accept direct reuse of wastewater.

Besides public acceptance, the health risks associated with water reclamation from treated wastewater for drinking purposes is another major concern. Health risks, according to Metcalf & Eddy (2003), include the increasing levels of nonconventional and emerging contaminants. Nonconventional contaminants include: refractory organics, volatile organic compounds, metals and total dissolved solids. Emerging contaminants include: prescription and non-prescription drugs, home care products, veterinary and human antibiotics, sex and steroidal hormones.

The reclamation of wastewater for direct potable use or direct non-potable reuse is a highly debatable topic that needs to be investigated from all possible angles. Although direct reuse for potable uses is often more contentious than direct reuse for non-potable uses, it is worth investigating for possible future implementation at certain water scarce areas. The direct reuse of wastewater for non-potable use will probably be more acceptable than for potable use, but by setting up a water balance to compare the two alternatives, the actual water savings can be determined, potential communities consulted and the most effective reclamation method implemented.

1.3 Research Aim and Objectives

The aim of this research project was to assess the feasibility of direct wastewater reuse for potable uses and direct wastewater reuse for non-potable uses at Hartbeesfontein town, North West Province using an urban water balance, cost analysis, and survey of perceptions.

Specific objectives of this study were:

i. To document, using literature, wastewater reuse for potable and non-potable uses globally and locally.
ii. To undertake a water balance of Hartbeesfontein using different water reuse scenarios.
iii. To develop or amend an existing questionnaire to measure the intention of residents from Hartbeesfontein to accept direct wastewater reuse for potable uses and direct wastewater reuse for non-potable uses.
iv. To administer the above questionnaires at Hartbeesfontein, a selected, water scarce South African community and subsequently, analyze and discuss highlights from the analysis.
v. To investigate the cost implications of direct wastewater reuse for potable uses and direct wastewater reuse for non-potable uses at Hartbeesfontein and to compare these with municipal potable water supply to Hartbeesfontein.
vi. To employ the water balance, perception and cost results to determine the viability of direct wastewater reuse for potable and non-potable uses at Hartbeesfontein.

1.4 Research Methodology

1.4.1 Literature survey of wastewater reuse

An intensive literature study was conducted throughout the entire period of the study to:

- Look at examples of wastewater reclamation around the world and in South Africa.
- Investigate health risks associated with directly reusing wastewater for potable or non-potable uses.

- Investigate the disadvantages of direct wastewater reuse for potable and non-potable uses.
- Investigate public views on wastewater reclamation for drinking purposes and non-drinking uses.

1.4.2 Water balance of Hartbeesfontein

This study was undertaken at Hartbeesfontein, situated in the North West Province, South Africa. To compare different wastewater reuse options and their water saving potential, it was necessary to select a small town with a wastewater treatment plant and metered potable water supply, as well as industrial activities nearby. Hartbeesfontein was considered to be the ideal town, since it is a small town with a newly upgraded wastewater treatment plant and the town is supplied potable water from The City of Matlosana. Data of water usage and volume of wastewater treated where also available. Since Hartbeesfontein is situated in the water scarce North West Province, wastewater reuse or reclamation can be motivated for future implementation.

A water balance of Hartbeesfontein was undertaken based on the Grobicki & Cohen (1999) model. The water balance was used to explore 3 scenarios:

- Replacing a percentage of the existing municipal water supply with potable water from a wastewater reclamation scheme.
- Replacing a percentage of the existing municipal water supply with non-potable water supplied from household wastewater reuse systems for non-potable water uses (e.g. irrigation or toilet flushing).
- Replacing a percentage of the existing municipal water supply with a percentage of treated wastewater treated for non-potable industrial water uses.

1.4.3 Cost implications

The cost implications of direct reuse of wastewater for potable and non-potable purposes within Hartbeesfontein was investigated. The water balance results obtained in ***objective ii*** was used as the basis for investigating the cost implications of direct wastewater reuse for potable and non-potable uses and these were compared to the current cost of potable water supply to the community.

1.4.4 Development of a questionnaire

A questionnaire was developed using the templates provided by Adewumi *et al* (2014) and Ilemobade *et al* (2013) to collect the necessary data to measure perceptions of a segment of the Hartbeesfontein community towards wastewater reclamation. The questionnaire was issued to 178 residents within Hartbeesfontein. The target group included Hartbeesfontein residents who are currently metered for their potable water supplied by the municipality. Many of the residents are retired farmers and have vegetable gardens.

1.4.5 Administration and analysis of questionnaires

A group of ten questionnaire administrators from the Vaal University of Technology went to Hartbeesfontein to administer the questionnaires. Each questionnaire administrator was given a street map of Hartbeesfontein and assigned a specific area to cover. Each questionnaire administrator wore an identification tag and residents were approached and asked to complete the questionnaire. When needed, questionnaire administrators explained difficult or unfamiliar terminology. Each questionnaire administrator was tasked to administer about 20 questionnaires.

1.4.6 Viability study

The outcomes of the water balance, perceptions of the Hartbeesfontein community and cost analysis of the different wastewater reuse scenarios were combined in a rubric to compare different water use options and cost implications at different reuse scenarios and therefore determine the viability of a direct wastewater reuse system for potable or non-potable uses.

CHAPTER 2 LITERATURE SURVEY

WASTEWATER REUSE FOR POTABLE AND NON-POTABLE USES GLOBALLY AND LOCALLY

2.1 Examples of Water Reclamation around the World

In many arid countries around the world, water reclamation has been implemented successfully to supplement potable water supplies e.g. greywater reuse has been implemented in Israel (Friedler, 2008), Jordan (Al-Jayyousi, 2003) and Spain (March *et al*, 2004). Not only arid countries turn towards water reclamation to supplement potable water supplies. According to Lazarova *et al* (2003), Northern European States such as Belgium, France, the UK and Germany have shown growing interest in water reuse, due to increasing population and the longing to implement more environmentally sustainable alternatives towards potable water resources.

A city which has employed water reclamation for drinking purposes is Windhoek, Namibia. After a devastating drought in 1968, the Windhoek Water Reclamation Plant was constructed and commissioned in 1969. In 1990, the city built a new water reclamation plant which treats about 21,000m^3/day and provided for 35% of the 2006 daily potable demand of the city (Du Pisani, 2006).

More recently, Singapore engaged in the direct reuse of wastewater for drinking purposes by means of bottled water. This initiative provides about 1% of the daily potable demand of the city. By introducing the reclaimed water in bottled form, the city of Singapore hopes to change its public's perspective towards reclaimed water for drinking purposes (Marks, 2006).

On Monday, 13 May 2013, Blaney reported that the Big Spring reclamation plant in Texas commenced with the treatment of wastewater up to potable water standards and blending it with treated water from lakes. This plant adds 2 million gallons (7,500 m^3) per day of potable water to the Colorado River Municipal Water District.

In addition to water reclamation for potable purposes, water reclamation for non-potable purposes (e.g. irrigation or industrial usage) has potential to replace a significant quantity of fresh water. According to Asano (2010), the City of Victoria in Spain reclaims 35,000 m^3/day of water for irrigation and stream flow augmentation, up to a standard, that allows for unrestricted irrigation usage. The city also plans to expand this treatment facility to supply reclaimed water to a new industrial park.

Greywater reuse for toilet flushing at the domestic level has been investigated over a wide spectrum of facilities including hotels, multi-storey buildings, residential developments, residential areas and private houses.

March *et al* (2003) investigated the experiences of greywater reuse for toilet flushing at a hotel on the Mallorca Island, Spain. At the time, the seasonal demand for drinking water was not met by the water stored in the reservoir and underground resources, and thus water reuse became an option to solve the problem. At the hotel, a simple treatment system was installed consisting of filtration, sedimentation and disinfection. The greywater from bathtubs and basins within the hotel were collected, treated and then used to flush toilets.

A study undertaken by Ghisi & Ferreira (2007) shows the potential for potable water savings by using rainwater for toilet flushing, clothes washing and cleaning, and reusing greywater for toilet flushing in a multi-storey residential building located in Florianopolis, Brazil. Their study was based on the estimation of water end uses, use of computer simulation and economic analysis. Their study concluded that the percentage of potable water that could be replaced by rainwater was about 16% and when only greywater for toilet flushing is considered, the potential for potable water savings was about 31%. When rainwater and greywater were considered together, the potential for potable water savings was higher (39%). Their economic analysis resulted in a payback time less than 5 years by using either rainwater or greywater separately. Greywater alone was a little bit more cost effective than rainwater. By using rainwater and greywater together, the payback time was longer, but still cost effective.

In another study by Friedler and Hadari (2006), the economic feasibility of on-site greywater reuse in a multi-storey building was performed. Greywater from each flat was collected, treated and pumped to a storage tank at the top of the building, from where it was distributed to the toilet cisterns within each flat. The greywater was sourced from baths, showers and washbasins. The study concluded that for a Membrane Bioreactor (MBR) system to be feasible, the building should be a minimum of four storeys high (16 flats). A cluster of two buildings served by the MBR system became feasible with a payback period of 14 years, while a cluster of 10 buildings could have a payback period of 3 years.

Greywater reuse for toilet flushing and a below-ground garden irrigation system proved to be functional for a small residential development comprising of 107 apartments at the Inkerman D'LUX Development in St Kilda, Merlbourne (Goddard, 2006). A greywater recycling treatment plant was constructed as part of the development for the recycling and UV disinfection of greywater and stormwater. Some issues emerging from the project were regulatory arrangements, public health management issues and the ownership of the recycling scheme which was vested in the Body Corporate. Future developers need to take note of these key issues when planning for a recycling scheme which is to form part of a domestic development.

In 2008, Friedler conducted a study on the water saving potential and the socio-economic feasibility of greywater reuse within the urban sector of Israel. This study hypothetically focused on newly built multi-story residential buildings where the greywater reuse system would be installed during the construction of the building. The reuse and treatment system incorporated a conveyance system and treatment unit. Greywater from each flat would be collected, treated and pumped to a storage tank at the top of the building to a storage tank, from where it would be distributed to the toilet cisterns in each flat. The greywater was sourced from baths, showers and washbasins. The capital costs of the system components were obtained from leading manufacturers and the operation and maintenance costs were obtained from small wastewater treatment works. The study concluded that the Rotating Biological Contactor (RBC)-based reuse system in Israel would become feasible if the building size was seven storeys (26 flats). The survey conducted showed that the public was highly supportive towards the six greywater reuse applications suggested which included: Sidewalk landscaping; public parks irrigation; office toilet flushing; commercial car washing; private garden irrigation and domestic toilet flushing.

Mourad *et al* (2011) investigated potential fresh water savings using greywater for toilet flushing in Syria. Interviews from residents on social acceptance, water consumption and percentage of water use were conducted. An artificial wetland and a commercial bio filter were employed to treat the greywater and an economic analysis was performed. The results showed that by using treated greywater for toilet flushing, about 35% of domestic drinking water was saved. Interviews with the public indicated that about 85% were positive regarding the use of treated greywater. The economic analysis showed that if an artificial wetland should be designed for greywater reuse in new buildings, the payback time for the system would be 7 years. The payback time for commercial bio filter was 52 years and thus unfeasible.

A study done in Melbourne, Australia, by Christova-Boal *et al* (1996), investigated greywater reuse systems connected to privately owned houses. Three houses were retrofitted to reuse greywater for irrigation and toilet flushing. Difficulties were experienced during the installation of these systems such as, insufficient hydraulic head and collection tanks that had to be installed below ground level. The tanks were ventilated and child-proof. To minimize the health risk involved in garden irrigation and toilet flushing, the greywater was filtered and disinfected. Extra-long-lasting chlorine tablets were used and a three-stage filter. The researchers determined that the filters would have to be cleaned every second week. Soil samples were also taken to determine the effect of the treated greywater on the soil. The pH levels of the soil exceeded 8-8.5 and high levels of zinc were found which could damage grass.

Research done by Penn *et al* (2012) was performed at a pilot plant located at the Israel Institute of Technology. Three types of houses were conceptualised to evaluate the influence of onsite greywater reuse on domestic wastewater quality and quantity. Results indicated a reduction in daily household water consumption of 26% when greywater was used for toilet flushing. By using the excess amount of greywater (after toilet flushing) for garden irrigation, the daily household water consumption reduced by 41%. The study also concluded that by reusing light greywater for toilet flushing and irrigation, the reuse did not significantly reduce the daily loads of organic matter and nutrients discharged to the sewer.

Each of the above studies was conducted within a domestic facility, single houses or multi-storey residential buildings. The majority of the studies proved a reduction in domestic water consumption by reusing greywater for toilet flushing and/or irrigation. In most cases, the greywater reuse system proved to be feasible.

2.2 Examples of Water Reclamation in South Africa

To supplement potable water supplies, water reclamation has also been implemented in certain instances in South Africa. The City of Cape Town (2016) reclaims wastewater for irrigation and industrial purposes. The treated effluent is separately piped to different consumers who use it for irrigation or industrial purposes (See Table 2.1).

Table 2.1: Treated effluent systems at the City of Cape Town (City of Cape Town, 2016)

Wastewater treatment plant	Treated effluent capacity (Ml/d)	Km of pipe network	Number of customer meters attached to the treated effluent water network
Potsdam	45.8	111.0	44
Fisantekraal	19.7	0.2	1
Bellville	19.2	12.1	22
Cape Flats	15.8	22.6	3
Athlone	15.0	33.6	58
Macassar	10.9	23.3	17
Kraaifontein	8.9	10.6	24
Scottsdene	8.2	3.1	3
Atlantis	6.3	1.1	2
Mitchells Plain	6.0	1.0	1
Melkbosstrand	2.2	3.8	2
Gordon's Bay	2.0	0	0
Parow	1.9	3.1	5
Total	**161.8**	**222**	**182**

This treated effluent is cheaper than potable water and the City of Cape Town promotes its use in order to conserve water. According to Jimenez and Asano (2008), some of the users of treated effluent from the city's treatment works include Milnerton golf course, Sappi Paper and sports fields in Milnerton and Table View.

Ilemobade *et al* (2009) and Adewumi *et al* (2010) mention that wastewater reuse in South Africa has been implemented at different levels namely household, district, agricultural and industrial. Household wastewater reuse has been implemented in Carnarvon where no sewerage infrastructure exists. In Carnavon, each household collects their greywater in a 50 litre drum via a filter trap and sump. The filtered water is then pumped through a hose and sprinkler to irrigate the gardens.

The Lynedoch Eco-village, Western Cape Province, is an example of district wastewater reuse (Ilemobade *et al*, 2009). This Eco-village has a micro-ecology wastewater treatment plant that treats its wastewater. The treated effluent which is used for irrigation is profitable as a natural organic fertilizer.

According to Jimenez and Asano (2008), one of the largest petroleum and chemical manufacturing industries in South Africa, Sasol, uses large quantities of fresh water. The company therefore has a very complex water system consisting of a high degree reuse and recycling water treatment plant. This advanced treatment technology consists of reverse osmosis and electro-dialysis. Through the recycling and reuse of water at the Sasol water treatment plant, less water is extracted from the Vaal River for industrial processes - therefore promoting water conservation.

According to Ilemobade *et al* (2009), industrial wastewater reuse is also implemented at the Caltex refinery, Nampak Paper, Sappi, Alpha and Lafarge ready-mix, Athlone power station, and Spoornet Truck washing in the City of Cape Town.

The private company, Durban Water Recycling (DWR), was commissioned in May 2001, in Durban (eThekweni Municipality, 2016). The purpose of the DWR is to treat wastewater for industrial use. Currently, the two largest industries that utilise treated water from the DWR are Mondi Paper Mill and Sapref Refinery, owned by Shell and BP. This wastewater reclamation initiative not only conserves Durban’s water resources, but also results in cost savings for the industries since they pay a lower tariff compared to the potable water tariff.

South Africa's first direct potable reuse plant (DPR) was implemented in Beaufort West (Matthews, 2015). It was built in 2010 when the Gamka Dam dried up during a drought. The Gamka Dam is the main water source of the town. The plant became operational in June 2011 and the construction cost was about R24 million, which was funded by the National Treasury. The effluent from a wastewater treatment facility is directly conveyed to the DPR plant, where the wastewater effluent is treated to drinking water standards. This DPR plant involves the process of reverse osmosis, ultra filtration and advanced oxidation to remove pathogens, dissolved salts, dissolved organics and some emerging contaminants, like pesticides, pharmaceuticals and plasticisers.

Another example of wastewater reuse is for toilet flushing at a university academic building and at a university residence (Ilemobade *et al* 2013). At the university academic building (School of Civil and Environmental Engineering, University of the Witwatersrand), greywater from 12 bathroom hand basins where collected, treated, stored and used to flush 2 retrofitted student toilets. At the university residence (Student Town, University of Johannesburg Kingsway Campus) greywater was collected from 2 showers and 2 baths, treated, stored and used to flush 2 retrofitted toilets (Ilemobade *et al* 2013). The payback period achieved for such a system was 17 to 20 years for WITS and UJ respectively, which makes it economically unviable. The perceptions of respondents towards the reuse of greywater for toilet flushing reflected positively overall.

2.3 The Benefits of Directly Reusing Wastewater for Potable or Non-potable Use

Ilemobade *et al* (2009) mention the following benefits/advantages of directly reusing wastewater for potable or non-potable use:

- Water conservation and enhancing green water strategies;

- Meeting growing industrial, agricultural and domestic water demands;
- Alleviate cost of supplying sufficient quantities of potable water to arid areas;
- Greywater use improves the performance of septic tanks in areas without water borne sewerage;
- Greywater use reduces the hydraulic, biological and nutrient load on wastewater treatment works;
- Alternative water source in times of drought due to Climate change or natural drought cycles.

2.4 Issues of Concern Regarding Direct Wastewater Reuse for Potable or Non-potable Use

Some disadvantages/constraints of directly reusing wastewater for potable or non-potable use include (Ilemobade *et al*, 2009):

- Wastewater reuse could initially have some capital expenditure to upgrade the infrastructure and treatment facilities;
- Reused water can pose a health risk in some cases if the water is not treated properly;
- Community perceptions about the risk involved with the reuse of wastewater may discourage the implementation thereof;
- Wastewater reuse will result in less effluent discharged into water bodies like rivers and streams. This may impact negatively on the downstream users, due to reduced surface flow quantities.

2.4.1 Health risks

One of the main concerns regarding wastewater reuse is the risk to health. Inappropriately treated wastewater can be harmful when directly consumed or by eating crops irrigated with treated wastewater (Adewumi *et al*, 2010). Even treated greywater for non-potable uses (e.g. toilet flushing) can be harmful to human life if droplets containing harmful pathogens are indigested (Ilemobade *et al*, 2013).

New technologies and methods make it possible to treat wastewater up to almost any level of quality required. The question remains: "*what constituents must be removed and to what extent must these constituents be removed?*" Constituents present in wastewater are divided into three categories: conventional, non-conventional and emerging.

- *Conventional* constituents include those constituents usually measured at conventional wastewater treatment plants, such as suspended solids, pathogens, nutrients, biodegradable organics, refractory organics, heavy metals and dissolved inorganics.
- *Non-conventional* constituents include constituents that will have to be removed or the levels decreased at an advanced treatment plant in order to produce a higher quality effluent for reuse, such as, refractory organics; volatile organic compounds; surfactants; metals and total dissolved solids.
- *Emerging* constituents refer to those constituents present in small quantities in wastewater, but could have long-term side effects on public health, such as, prescription and non-prescription drugs; home care products; veterinary and human antibiotics; industrial and household products and sex and steroid hormones (Metcalf & Eddy, 2003).

Although a number of constituents can be present in wastewater even in minute concentrations, the quality of the reclaimed wastewater should adhere to the standards stipulated in the potable and non-potable water guidelines of South Africa. When the effluent meets the minimum requirements of the standards, it is safe for human consumption and/or reuse. The microbiological, physical, aesthetic, operational and chemical standards stipulated for potable water in South Africa are available in the SANS 241:2015 manual.

The guidelines for non-potable water are however available in the following South African Water Quality Guidelines (DWAF, 1996):

Volume 2 – Recreational Water Use

Volume 3 – Industrial Water Use

Volume 4 – Agricultural Use: Irrigation

Health risks for wastewater reuse for irrigation purposes are not as stringent as for potable uses, but certain constituents in wastewater pose a risk to soil pollution and crop contamination. Some major concerns to be aware of when reclaiming wastewater for irrigation purposes are:

- Heath risk for people working on crop lands and that will be in contact with reused wastewater
- Health risk for consumers of vegetables irrigated with treated wastewater
- Contamination of groundwater
- Build-up of heavy metals and chemical pollutants
- Excessive growth of algae and vegetation in water supplying canals due to eutrophication (Fatta *et al,* 2005).

The major health risk concerns or diseases deemed to be associated with human consumption of potable water reclaimed from wastewater, are caused by waterborne microorganisms, like enteric pathogens. Enteric pathogens includes enteric bacteria, protozoa and viruses. These enteric pathogens can be spread through the ingestion of contaminated water, from one person to another through human contact or from contaminated surfaces and food. (Asano *et al*, 2006)

Typical waterborne and water based pathogens and the diseases they may cause are shown in Table 2.2.

Table 2.2: Examples of major groups of waterborne and water based pathogens (Asano *et al*, 2006)

Group	Pathogen	Diseases/Symptoms Caused
Bacteria	Salmonella Shigella Escherichia coli	Typhoid and diarrhea Diarrhea Diarrhea
Protozoa	Gardia lamblia Naegleria Enterocytozoon	Chronic Diarrhea Meningoencephalitis Chronic diarrhea and renal disease
Cyanobacteria	Microcystis Anabaena	Diarrhea Liver damage
Helminths	Ascaris lumbricoides Trichuris trichiora Taenia saginata	Ascariasis Whipworm Beef tapeworm
Viruses	Enteroviruses Hepatitis A and E Rotavirus	Meningitis, paralysis, rash, fever, respiratory disease and diarrhea Infectious hepatitis Diarrhea/gastroenteritis

The following parameters and parameter values for reclaimed wastewater quality for restricted irrigation purposes in South Africa were suggested by Adewumi *et al* (2011):

- pH = 6 – 9
- TSS = 10 mg/l
- Turbidity = 5 NTU
- BOD = 10 mg/l
- COD = 30 mg/l
- Total Nitrogen = 10 mg/l
- Total Phosphorus = 2 mg/l
- Faecal Coliform = 0 cfu/100ml

• Total Coliform = 0 cfu/100ml

• Cl_2 residual = 1 mg/l

Recommended maximum concentration of metals in irrigation waters (EPA, 2012) are shown in Table 2.3. Hence, reclaimed water for irrigation purposes should not violate these guidelines.

Table 2.3: Recommended maximum concentration of metals in irrigation waters (EPA, 2012)

Constituent	Maximum Concentrations for Irrigation (mg/L)	Remarks
Aluminum	5.0	Can cause non-productiveness in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity
Arsenic	0.10	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice
Beryllium	0.10	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans
Boron	0.75	Essential to plant growth; sufficient quantities in reclaimed water to correct soil deficiencies. Optimum yields obtained at few-tenths mg/L; toxic to sensitive plants (e.g., citrus) at 1 mg/L. Most grasses are tolerant at 2.0 - 10 mg/L
Cadmium	0.01	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L; conservative limits are recommended
Chromium	0.1	Not generally recognized as an essential element; due to lack of toxicity data, conservative limits are recommended
Cobalt	0.05	Toxic to tomatoes at 0.1 mg/L; tends to be inactivated by neutral and alkaline soils
Copper	0.2	Toxic to a number of plants at 0.1 to 1.0 mg/L
Fluoride	1.0	Inactivated by neutral and alkaline soils
Iron	5.0	Not toxic in aerated soils, but can contribute to soil acidification and loss of phosphorus and molybdenum
Lead	5.0	Can inhibit plant cell growth at very high concentrations
Lithium	2.5	Tolerated by most crops up to 5 mg/L; mobile in soil. Toxic to citrus at low doses—recommended limit is 0.075 mg/L
Manganese	0.2	Toxic to a number of crops at few-tenths to few mg/L in acidic soils
Molybdenum	0.01	Nontoxic to plants; can be toxic to livestock if forage is grown in soils with high molybdenum
Nickel	0.2	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH

Constituent	Maximum Concentrations for Irrigation (mg/L)	Remarks
Tin, Tungsten, and Titanium	-	Excluded by plants; specific tolerance levels unknown
Vanadium	0.1	Toxic to many plants at relatively low concentrations
Zinc	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils

According to Adewumi (2011), restricted irrigation may only be used in areas where public access, including animals, is restricted during or after the application of reclaimed water. The quality of water used for restricted irrigation is typically lower than that used for unrestricted irrigation.

2.4.2 Costs

According to Rygaard *et al* (2011), it is difficult to compare the cost of different wastewater treatment techniques since there are many variables that could be involved in the implementation of the infrastructure. The cost is however, definitely related to the different types of treatment as can be observed in Table 2.4.

Table 2.4: 2007 production prices of different treatment technologies (Rygaard *et al,* 2011)

	Min (US$/m^3)	**Max** (US$/m^3)
Conventional surface water treatment	0.1	2.2
Conventional groundwater treatment	0.2	1.2
Indirect potable reuse	1.3	2.0
On-site non-potable reuse*	1.3	4.2
Reverse Osmosis for seawater treatment	0.9	2.2

* Generic estimates for a Membrane Bio-Reactor system

The cost for direct reuse is not mentioned by Rygaard *et al* (2011). The operational cost at the Windhoek Goreangab reclamation plant in 2002 was

0.77 US$/$m^3$ according to Du Pisani (2006). By applying a 10% inflation per year into account, the production cost at Windhoek in 2007 could have been approximately 1.24 US$/$m^3$. According to Pisani (2006), the 2002 cost was a relatively low rate which was directly linked to the large volume produced each day.

Chen *et al* (2013) reported that tertiary and advanced treatment of wastewater cost about 2.5 Yaun per ton in Beijing. This was equivalent to 0.41 US$/$m^3$. The cost for secondary treatment in Beijing was about 0.08 US$/$m^3$. Comparing the two values, the cost of advanced treatment was still much higher, but not as high as the cost of desalination (0.98 US$/$m^3$) or potable water (1.31 US$/$m^3$) from the South-to-North diversion in Beijing.

Asano (2010) mentioned the Sulaibiya wastewater reclamation and reuse project in Kuwait. The plant delivers potable water at approximately US$0.65 per m^3. At the time, the plant treated 375,000 m^3/day of wastewater and was to be expanded in the future to treat 600,000 m^3/day. The system applies advanced treatment processes, like ultra-filtration and reverses osmosis, to treat mixed reclaimed and brackish water resources for unrestricted irrigation and groundwater recharge.

An economic analysis done by Ilemobade *et al* (2013) as regards a South African greywater reuse system for toilet flushing at a university academic building, indicated that payback time was not achieved within the design life (20 years) of the system. This system was therefore economically unfeasible to justify (Ilemobade *et al*, 2013).

A direct water reclamation plant currently operational in South Africa is the plant situated in Beaufort-West, Northern Cape Province. The plant was implemented during a protracted period of water shortage. According to Swartz *et al* (2014), the total cost (including personnel, energy, chemicals, maintenance, capital and general) to treat wastewater up to potable standards at the Beaufort-West reclamation plant was R16.25/kℓ. This excludes the capital cost of building the treatment plant which came to R24 million in 2010 (Matthews, 2015).

In summary, the costs of water reclamation will differ from community to community. Cost depends on the treatment technologies implemented. From the above information however, it can be deduced that water reclamation for direct potable use is more expensive than direct and indirect reuse for non-potable purposes.

2.4.3 Operational problems when using reclaimed water for irrigation

Carr *et al* (2011) reported a few major problems experienced in the direct use of reclaimed water for irrigation purposes i.e. soil salinity, high chlorine levels and damage to irrigation infrastructure. The high salinity levels typically result in a reduction in crop productivity and farmers typically have to leach their farm lands once a year to reduce the salinity of the soil. High levels of chlorine in the effluent water from treatment plants causes yellowing of the crops. The irrigation pipes get clogged by algae, suspended solids and mineral precipitation, resulting in damage to the infrastructure. Another problem experienced is the high pH levels of reclaimed water. This prevents the effectiveness of pesticides.

2.5 Public Views on Water Reclamation for Drinking Purposes

Public acceptance is one of the key factors in the successful implementation of water reclamation plants. Marks (2006) concluded that public involvement is unavoidable in the whole process of acceptance and the effective management of reclaimed water. Marks (2006) also reported that due to the public’s awareness of the risks involved in reclaimed water for potable use, the implementation of reuse can be challenging.

A study undertaken in Durban, South Africa, by Wilson & Pfaff (2008) indicated that a segment of the residents of Durban showed great concern around the technological competence of water officials, and the operation and maintenance of the infrastructure over time. The power outages experienced and decay of municipal services in some areas contributed to respondents' concern.

Studies done by Dishman *et al* (1989) indicated that educational and psychological obstacles must be overcome before the general public will accept direct reuse of wastewater. This point was also emphasized by Russell & Hampton (2006). According to them, the only way to change the public's perspective on reclaimed water is through education and awareness. These initiatives should emphasize the direct and indirect benefits of reuse to the user.

2.6 Public Views on Water Reclamation for Irrigation Purposes

Carr *et al* (2011) conducted a study in Jordan on a few farmers who were direct users of reclaimed water for irrigation purposes. The interviews conducted showed that the farmers did not have a problem with using reclaimed water to irrigate their crops, but the negative factors they subsequently experienced as a result of using reclaimed water, changed their perceptions. The negative experiences of the farmers who used reclaimed water to irrigate their crops include, lower productivity of crops, clogging of irrigation pipes and the high pH levels in reclaimed water that could lower the effectiveness of pesticides. On the positive side, reclaimed water contains significant amounts of plant nutrients, which fertilize the crops, thus reducing the amount of fertilizer that could be used.

In South Africa, according to a survey done by Adewumi *et al* (2010), 22 % respondents in a survey with a sample size of 17 institutions were concerned about the health risk involved in consuming fruits and vegetables irrigated with non-potable water. This study indicated that treated wastewater involving minimal human contact, like landscape irrigation, would be more acceptable to the public. The intention to accept wastewater reuse was influenced by attitude; the degree of control over the source of water and its application; the knowledge of the advantages of reuse and the trust in the service provider.

Marks (2006) mentioned that caution should be taken by the public before implementing a reuse scheme for irrigation. The community should be well informed and educated before implementing such a scheme. Although they will not consume the water directly, they will work with it and use it to irrigate their crops. They should therefore be made aware of their responsibilities when using reclaimed water for irrigation purposes. When the user is well informed, the scheme will be implemented and executed successfully.

2.7 Summary

Water reclamation for potable use is a relatively untapped concept in South Africa, but since it has been implemented successfully in other countries and in some South African communities, there is potential for reuse to be successfully implemented in more South African communities to supplement fresh and other water resources.

One of the biggest concerns about wastewater reclamation for potable and non-potable applications is the health risk involved. The reclaimed wastewater should therefore adhere to specific standards to assure the quality of the water before it is reused for human consumption or non-potable uses (such as irrigation, toilet flushing or industry).

Other concerns/considerations regarding water reclamation are the cost and operational issues. Wastewater can be treated up to any standard. The higher the quality of reclaimed water required and thus, the more the treatment processes involved, the higher the treatment cost. The reclamation cost for non-potable applications such as irrigation, is often relatively lower than for potable use. Despite this, end-users (e.g. farmers) may need to spend extra money during or after reuse to mitigate the impact of reusing non-potable water (for example, de-clogging of irrigation systems that distribute non-potable reused water.

All of the above need to be communicated to the public or consumers before reuse is implemented. Public acceptance is a key factor in the success of any water reclamation plant for potable or non-potable applications. Potential consumers should therefore be educated and informed about water reclamation processes in order to prevent misconceptions about the quality of the effluent to be produced. Potential consumers also need to understand the water balance in their area and how a sustainability approach to water resources can be vital in sustaining existing water resources. The potential user should also know the direct and indirect benefits of reclaimed wastewater. Farmers that will use it for irrigation purposes should also be aware of the disadvantages of irrigating crops with reclaimed water and on their irrigation systems.

CHAPTER 3 WATER BALANCE AND COSTING

3.1 Introduction

This study was undertaken within Hartbeesfontein, situated within the City of Matlosana, in the North West Province, South Africa (Figures 3.1 and 3.2). The criteria that guided the selection of Hartbeesfontein were:

- A small human settlement where sanitation is provided and/or a wastewater treatment plant is situated in close proximity to potential consumers.
- The number of residents of the settlement should/could be determined.
- The daily water consumption and wastewater production quantities should be estimated with at least one year's data obtained from the local municipality.

Figure 3.1: Map of the City of Matlosana (delineated area) in North West Province, South Africa (Google Maps, 2016)

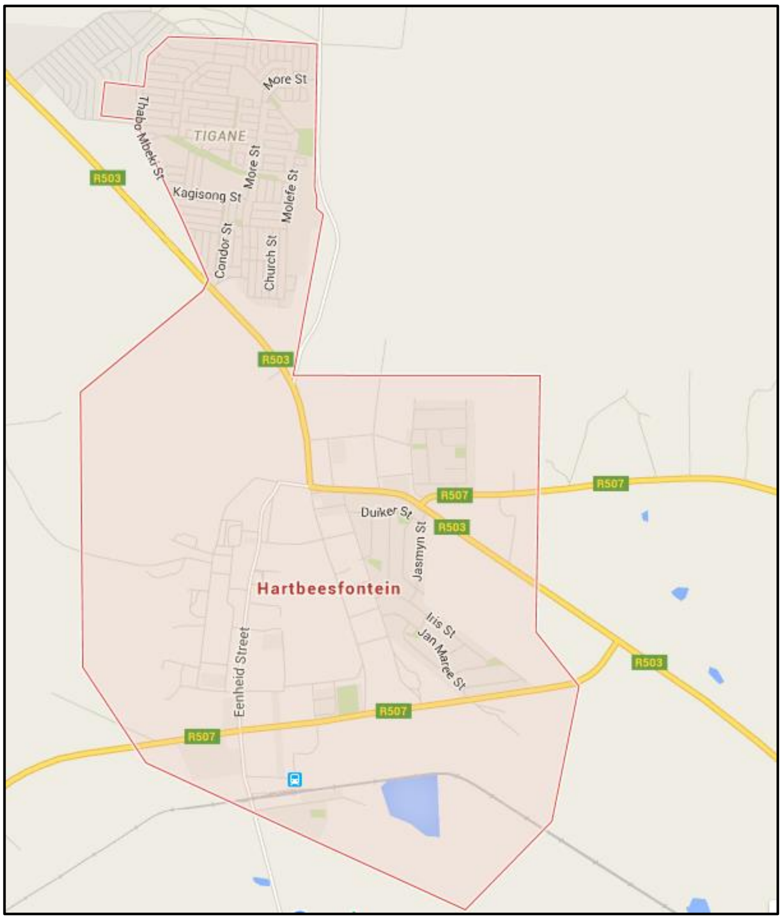

Figure 3.2: Map of Hartbeesfontein (Google Maps, 2016)

A water balance of Hartbeesfontein was undertaken based on the Grobicki & Cohen (1999) model. The water balance for Hartbeesfontein was used to compare 3 scenarios:

- Replacing a percentage of the existing municipal water supply with potable water from a wastewater reclamation scheme.
- Replacing a percentage of the existing municipal water supply with non-potable water supplied from household wastewater reuse systems for non-potable water uses (e.g. irrigation or toilet flushing).
- Replacing a percentage of the existing municipal water supply with a percentage of treated wastewater treated for non-potable industrial water uses.

In this study, the scenario of centrally installing municipal dual systems that will supply potable water for potable uses and reclaimed wastewater for non-potable uses within the community will not be dealt with, since the installation of municipal dual systems in already developed areas, most often results in very high capital expenditure. Ilemobade *et al's* (2009) study recommended that due to the high cost of long distance pipe lines, the optimal economic distance between a wastewater reclamation plant producing non-potable water and non-potable applications, should not be more than 500 metres. In Hartbeesfontein, the wastewater treatment plant is situated more than 500 metres away from the community.

The costing aspects of direct reuse of wastewater for potable and non-potable purposes within Hartbeesfontein were investigated in this study. The water balance models applied in this section were used as the basis for the cost analysis carried out later in this chapter. The costs of the different wastewater treatment options for drinking and non-drinking purposes were then compared to the current situation of the municipal water supply.

3.2 The Current Water Consumption, Water Supply and Wastewater Generation Situation

Hartbeesfontein is supplied potable water by Midvaal Water through the City of Matlosana. Cost of water supplied is recovered by means of metered billing.

Water usage data from The City of Matlosana was sparse and difficult to obtain. Figure 3.3 presents units of water consumed and Rand amounts for the 2013/2014 financial year for Hartbeesfontein and its extension, Tigane (City of Matlosana, Water section, 2015).

2013/2014 WATER STATS HARTBEESFONTEIN		
CATEGORIES OF CONSUMERS	CONSUMED TOTAL UNITS (Kℓ)	TOTAL AMOUNT (R)
WA0501 Domestic	116,127	1,460,204.89
WA0507 Business	302,189	4,584,992.09
WA0510 Government	765	9,052.31
WA0513 School	7,057	74,782.51
WA0514 Nursery	544	5,460.24
WA0515 Church	3,749	61,453.63
WA0517 Hospital	4,830	64,918.50
WA0522 Mine	32,034	218,792.22
WA0533 Municipal	1,402	6,005.60
WA501C Domestic	1,137	14,271.34
WA501D Domestic	1,471	14,164.42
WA501E Domestic	581	6,060.72
WAH001 Indigents	212	496.44
TOTAL	472,098	6,520,654.91
2013/2014	WATER STATS	TIGANE
CATEGORIES OF CONSUMERS	CONSUMED TOTAL UNITS (Kℓ)	TOTAL AMOUNT (R)
WA0501 Domestic	93,713	882,623.33
WA0507 Business	4,450	57,680.55
WA0513 School	17,162	183,685.44
WA0514 Nursery	837	8,504.73
WA0515 Church	4,310	56,703.54
WA501C Domestic	79,599	823,032.89
WA501D Domestic	80,669	753,898.04
WA501E Domestic	152,921	1,479,776.64
WAH00D Indigents	166	100.89
TOTAL	433,827	4,246,006.05

Figure 3.3: Billed water meter readings and amounts for the 2013/2014 financial year for Hartbeesfontein and Tigane (City of Matlosana, 2015)

Total units are given in kilolitres. The total units of water consumed in the 2013/2014 financial year sum was approximately 2 482 kℓ/day. Water consumption within a prominent industry located next to Tigane is estimated at approximately 1 709 kℓ/day. Thus, the total billed water consumption (Hartbeesfontein, Tigane and industry) is estimated to be 4 191 kℓ/day or 4.191 Mℓ/day. Since no data on the system input volume and water losses exists for Hartbeesfontein and Tigane, the standard IWA water balance model (Seago & Mckenzie, 2007) modified by the Department of Water

Affairs (2010) was employed to determine the system input volume for Hartbeesfontein and Tigane as shown in Table 3.1.

Table 3.1: Application of the IWA water balance model to Hartbeesfontein & Tigane

<table>
<tr><td rowspan="4">System Input Volume

6.418 Mℓ/day (100%)</td><td rowspan="2">Authorised Consumption (Billed metered + Billed Unmetered + unbilled metered + Unbilled unmetered)
4.512 Mℓ/day (70.3%)</td><td>Billed Authorised
(Billed metered + Billed Unmetered (flat rate) + Free basic water)

4.191 Mℓ/day* (65.3%)</td><td>Revenue Water (Volume of water for which an income is received. Assumes all billed water is paid for)
4.191 Mℓ/day* (65.3 %)</td></tr>
<tr><td>Unbilled Authorised
0.321 Mℓ/day (5.0%)</td><td rowspan="3">Non-Revenue Water (Volume of Water for which no income is received)

2.227 Mℓ/day (34.7%)</td></tr>
<tr><td rowspan="2">Water Losses (Apparent + Real Losses)

1.906 Mℓ/day (29.7%)</td><td>Apparent or Commercial Loss
0.379 Mℓ/day (5.9%)</td></tr>
<tr><td>Real or Physical Loss
1.527 Mℓ/day (23.8%)</td></tr>
</table>

**Average billed water consumption for Hartbeesfontein and Tigane shown in the above paragraph.*

Since the billed authorised water consumption is the only data available from The City of Matlosana, the other volumes were determined using the percentage distribution as stipulated by the Department of Water Affairs (2010). The different components of the IWA water balance were determined as follows:

- System Input Volume x 65.3% = 4.191 Mℓ/day. Thus the System Input Volume calculates to be 6.418 Mℓ/day. Once the System Input Volume was determined, the other components could be determined using the percentage distribution as given in Table 3.1.
- Authorised Consumption = 6.418 Mℓ/day x 70.3% = 4.512 Mℓ/day
- Water Losses = 6.418 Mℓ/day x 29.7% = 1.906 Mℓ/day
- Unbilled Authorised = 6.418 Mℓ/day x 5.0% = 0.321 Mℓ/day
- Apparent or Commercial Loss = 6.418 Mℓ/day x 5.9% = 0.379 Mℓ/day

- Real of Physical Loss = 6.418 Mℓ/day x 23.8% = 1.527 Mℓ/day
- Revenue Water = 6.418 Mℓ/day x 65.3% = 4.191 Mℓ/day
- Non-Revenue Water = 6.418 Mℓ/day x 34.7% = 2.227 Mℓ/day

The volume of wastewater treated per day fluctuates from month to month due to seasonal and other factors. Therefore, at least a year's sewage flow data is considered reasonable in order to obtain a daily average wastewater generation rate. Readings from July 2014 to June 2015 were obtained from Headstream Water Solutions (2015), for weekly wastewater inflow into the wastewater treatment works servicing Hartbeesfontein. The daily average inflow was 5.934 Mℓ/day (Appendix A).

According to the Guidelines for Human Planning Settlement and Design (CSIR, 2005), the quantity of potable water typically used at domestic level is 600ℓ/day/dwelling for low-income areas and the amount of sewerage flow from low-income areas in developed areas is 500ℓ/day/dwelling. The percentage of sewer generated at household level per day calculates to 500ℓ/600ℓ = 83% of the total potable water used. The remaining 17% of potable water is used for drinking, cooking and gardening.

From the above data, a water balance (adapted from Grobicki & Cohen, 1999) for the current conditions at Hartbeesfontein and Tigane is presented in Figure 3.4:

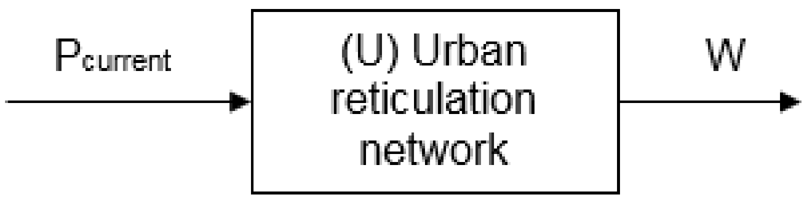

Figure 3.4: Water balance model of current situation

$P_{current}$ = System input volume (i.e. municipal potable water supplied to the community) = 6.418 Mℓ/day

U = Water used within the urban reticulation network that is not discharged into the sewer (e.g. water used for drinking, cooking and gardening). 17% of total potable supply.

W = Wastewater discharged to wastewater treatment facility.

= 6.418 Mℓ/day – 17% of $P_{current}$= 5.327 Mℓ/day.

Based on the above water balance, there is about 5.327 Mℓ of wastewater discharged each day that can potentially be reused for either potable or non-potable purposes. This computes to about 83% of the System Input Volume. In other words, only 83 % of the system input volume supplied to the community can be reused.

3.3 Replacing a Percentage of the Existing Municipal Water Supply with potable water from the Wastewater Reclamation System.

If the water balance shown in Figure 3.4 is directly augmented with water from a reclamation system, the following water balance will result (Figure 3.5):

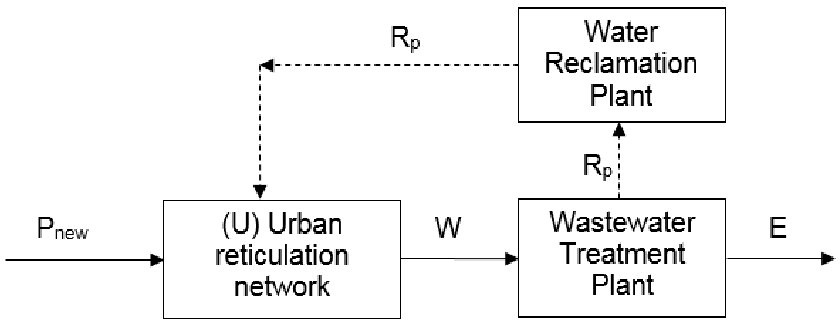

Figure 3.5: Water balance if wastewater is directly treated to potable water reuse

R_p = Reclaimed water (potable water) returned to the urban network

E = Treated effluent from the wastewater treatment plant

P_{new} = System Input Volume (i.e. municipal potable water supplied to the community) after implementing reclamation.

The water balance equations for Figure 3.5 are:

$P_{new} + R_p = U + R_p + E$ ________________ equation (1)

$W = R_p + E$ ____________________________equation (2)

$W \leq 0.83\ P_{current}$ (i.e. 83% of 6.418 Mℓ/d) ______equation (3)

$U = 0.17\ P_{current}$ (i.e. 17% of 6.418 Mℓ/d) ______equation (4)

Practically, water is lost during the water treatment process. The amount of water lost depends on the efficiency of the treatment processes involved. Because these losses are often negligible, the assumption was made that no losses occurred in the water balance model.

- Scenario 1: All treated effluent (83% of $P_{current}$) is reclaimed to potable water quality i.e. $E = 0$ and $R_p = 0.83\ P_{current}$
  Therefore equation (1) becomes $P_{new} = 0.17\ P_{current}$ = 1.091 Mℓ/d

- Scenario 2: Treated effluent amounting to 80% of the system input volume is reclaimed to potable water quality i.e. $E = 0.03\ P_{current}$ and $R_p = 0.80\ P_{current}$
  Therefore, equation (1) becomes $P_{new} = 0.17\ P_{current} + 0.03\ P_{current}$
  i.e. (1.091 + 0.193) Mℓ/d = 1.284 Mℓ/d

- Scenario 3: Treated effluent amounting to 70 % of the System Input Volume is reclaimed to potable water quality i.e. $E = 0.13\ P_{current}$ and $R_p = 0.70\ P_{current}$
  Therefore, equation (1) becomes $P_{new} = 0.17\ P_{current} + 0.13\ P_{current}$
  i.e. (1.091 + 0.834) Mℓ/d = 1.925 Mℓ/d

  Scenarios 4 – 10 follow the same pattern undertaken for Scenarios 1, 2 and 3 and the results are presented in Table 3.2.

Table 3.2: The impact on the System Input Volume from reclaiming different quantities of treated effluent.

	P_{new}	R_p
Scenario 10: No reclamation	6.418	0.000
Scenario 9: Reclaim 10% of System input volume	5.776	0.642
Scenario 8: Reclaim 20% of System input volume	5.134	1.284
Scenario 7: Reclaim 30% of System input volume	4.493	1.925
Scenario 6: Reclaim 40% of System input volume	3.851	2.567
Scenario 5: Reclaim 50% of System input volume	3.209	3.209
Scenario 4: Reclaim 60% of System input volume	2.567	3.851
Scenario 3: Reclaim 70% of System input volume	1.925	4.493
Scenario 2: Reclaim 80% of System input volume	1.284	5.134
Scenario 1: Reclaim 83% of System input volume	1.091	5.327

Referring to the results obtained in Table 3.2., it is theoretically possible to replace the municipal potable water supply with up to 83% of the system input volume i.e. 100% of the treated effluent. The environmental impact of reusing 100% of the treated effluent on downstream catchments (i.e. the Jagers Fontein area and Vaal River) is beyond the scope of this report. The optimum reuse ratio is determined when the above scenarios are input into the cost analysis discussed later in this Chapter.

3.4 Replacing a Percentage of the Existing Municipal Water Supply with Non-potable water Supplied from Household Wastewater Reuse Systems for Non-potable Water Uses.

Although the Ilemobade *et al* (2013) study indicated that the implemented greywater reuse systems were economically unfeasible, this option remains viable to explore in different contexts as Ilemobade *et al* (2013) affirm that the option was mostly attractive to potential beneficiaries. The scenario in this section therefore seeks to determine the total water savings that could be achieved should the community (or a portion thereof) choose to install greywater reuse systems at their properties for non-potable water uses (e.g.

garden irrigation and toilet flushing). Practically, water is lost during the greywater and wastewater treatment processes. The amount of water lost depends on the efficiency of the treatment processes involved. Because these losses are often negligible, the assumption was made that no losses occurred during the treatment processes.

The water balance for a single household can be supplemented by installing a greywater treatment system, as shown in Figure 3.6.

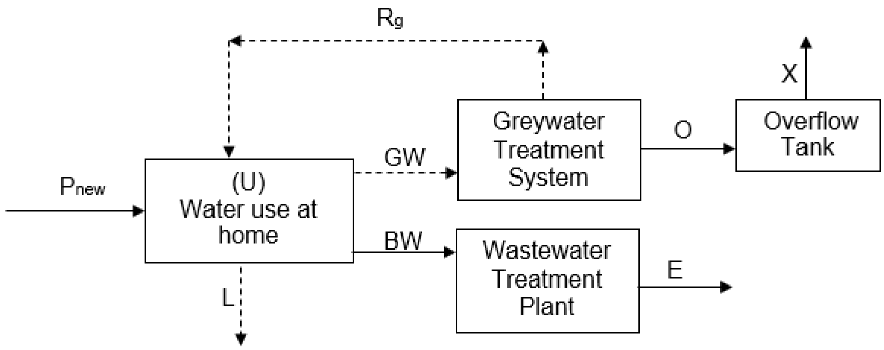

Figure 3.6 Water balance for greywater reuse installation within a house

BW = Blackwater from toilets and the kitchen sink(s);
GW = Greywater from bathtubs, showers, bathroom basins and laundry;
R_g = Treated greywater supplied to the household for non-potable application (e.g. toilet flushing);
O = Treated greywater to overflow tank;
X = Greywater from overflow tank which can be used for non-potable application (e.g. landscape irrigation)

According to Jacobs *et al* (2005), the typical water use breakdown per middle income household in South Africa is:

Drinking, cooking, and gardening	14%
Toilet flushing	37%
Bathtubs, showers and bathroom basins	32%

Laundry	15%
Kitchen	2%

The water balance equations based on Figure 3.6 and the breakdown of water use per middle-income household in South Africa are:

$P_{new} + R_g = U + GW + BW$ ______________________________ (5)

$U = 0.14\ P_{current}$ (i.e. 14% of $P_{current}$) ________________________ (6)

$GW = 0.47\ P_{current}$ (i.e. 32% of $P_{currenct}$ for bathtubs, showers and bathroom basins and 15% of $P_{current}$ for laundry) ____________________ (7)

$E = BW = 0.39\ P_{current}$ (i.e. 37% of $P_{current}$ for toilet flushing and 2% of $P_{current}$ for kitchen sink) ______________________________ (8)

$R_g = 0.37\ P_{current}$ (i.e. 37% of $P_{current}$ for toilet flushing) ___________ (9)

$X = O = 0.10\ P_{current}$ (i.e. 10% of $P_{current}$ – the remainder of GW after deduction for toilet flushing) ____________________________ (10)

If all greywater is reused for toilet flushing (37%) and landscape irrigation (10%), the total potable demand (P_{new}) of the household will be reduced to 53% of the current demand ($P_{current}$).

From Figure 3.6, it can be seen that the installation of a greywater reuse system for toilet flushing alone, may save up to 37% of the total potable water supply for a single middle- income household.

To investigate the impact of this potential water saving of 37% at the household level and relating this to the total water demand of the community, a certain percentage of the community will be used. According to Leverenz and Asano (2011), greywater reuse systems are expensive if retrofitted to existing houses or buildings. It is therefore more economical to install a greywater reuse system during the construction of the house or building. It can therefore be anticipated that residents of a higher income will be the ones that can afford to retrofit a greywater reuse system at their homes for toilet flushing. The first scenario below computes the potential reduction in municipal water supply if middle-income residents install greywater reuse systems for toilet flushing at each home. For the purpose of this study it was decided to use the middle-income group of the community in order to get more realistic results.

The Census done in 2011 estimated a population of about 1 467 for Hartbeesfontein and 17 141 for Tigane resulting in a combined population of 18 608. The population growth rate of South Africa, according to Statistics South Africa (2014), was on average 1.55 % per annum. This projects the combined population in 2014 to be 19 486. Table 3.3 shows the breakdown of low, middle and high income water consumers for Hartbeesfontein and Tigane based on the 2005 Water Services Development Plan of Klerksdorp (Moedi, 2005) and the projected 2014 population.

Table 3.3: Projected 2014 water consumption figures for different consumers (Moedi, 2005)

Area	Consumers	2004	2014	
		Number of persons	Litres per person	Number of persons
Hartbeesfontein	Low income	339	200	608
Hartbeesfontein	Middle income	466	350	836
Hartbeesfontein	High income	42	750	76
Tigane	Yard pipes	7324	60	11 541
Tigane	Low income	3944	93	6 214

According to Table 3.3, the size of the middle class population is 836 persons. According to the WSDP of Klerksdorp (2005), the average number of persons living on a middle class stand is 2.75 (In reality, the value should be 3). From that data the estimated number of middle class stands is 836/2.75 = 304 stands

From Table 3.3 therefore, the estimated 2014 water demand per stand is 350 ℓ/per person/day x 2.75 persons per stand = 962.5 ℓ/stand/day. From the water balance illustrated in Figure 3.6, the total potable water saving per stand due to greywater reuse for toilet flushing alone is 37%. Therefore, the total potable demand per stand is 63% of 962.5 ℓ/stand/day and that calculates to 606.375 ℓ/stand/day.

Table 3.4 shows the potable water savings at municipal level if a varied middle income population install greywater reuse systems for toilet flushing at their houses.

Table 3.4: Scenarios showing the potential reduction in municipal water supply if middle income residents install greywater reuse systems for toilet flushing.

% of middle income homes with a greywater reuse system	Total demand in litres per day	No of middle class homes	Potable water potentially saved (kl) per day	Potential daily reduction of potable water at municipal level (%) *
10	962.5	30	10.689	0.167 %
25	962.5	76	27.066	0.422%
50	962.5	152	54.131	0.843%
75	962.5	228	81.197	1.265%
100	962.5	304	108.262	1.687%

* Determined using the municipal daily demand of 6418 Kℓ.

The results shown in Table 3.4 indicate an insignificant potential reduction (1.687%) in municipal water supply if greywater reuse systems are installed at all middle-income class households for toilet flushing. The reason for this is simply due to the trivial number of middle-income class residents. If such systems could be installed at more households, including low-income class houses, the percentage of water saved could be significant. According to the WSDP of Klerksdorp (2005), the average number of persons living on a low class stand is 5.9. From that data the number of low class stands is:

(6214+608)/5.9 = 1156 stands

From Table 3.3 therefore, the estimated 2014 water demand per stand is 200ℓ/person/day x 5.9 persons per stand in Hartbeesfontein = 1180ℓ/stand/day and 93 ℓ/per person/day x 5.9 persons per stand in Tigane = 548.7 ℓ/stand/day. From the water balance illustrated in Figure 3.6, the total potable water saving per stand due to greywater reuse for toilet flushing is 37%. Therefore, the total potable demand per stand is 63% of 548.7 ℓ/stand/day in Tigane and 63% of 1180 ℓ/stand/day in Hartbeesfontein resulting in 345.681 ℓ/stand/day in Tigane and 743.4 ℓ/stand/day in Hartbeesfontein.

Table 3.5 shows the potable water savings at municipal level if varied proportions of the low income population install greywater reuse systems at their houses.

Table 3.5: Scenarios showing the potential reduction in municipal water supply if low income residents install greywater reuse systems for toilet flushing at their homes.

% of low income homes with greywater reuse system	Total demand in litres per day	No of low class homes	Potable water Potentially saved (kl) per day	Potential daily reduction of potable water at municipal level (%) *
	Tigane + Hbft	*Tigane + Hbft*		
10	548.7 + 1180	105 + 10	25.683	0.400 %
25	548.7 + 1180	263 + 25	64.309	1.002 %
50	548.7 + 1180	526 + 51	129.055	2.011 %
75	548.7 + 1180	789 + 77	193.800	3.020 %
100	548.7 + 1180	1053 + 103	258.749	4.032 %

* Determined using the municipal daily demand of 6418 Kℓ.

The results shown in Table 3.5 indicate an insignificant potential reduction (4.032%) of municipal water demand if greywater reuse systems are installed at all low-income class households. In theory, it would be possible to save 5.718 % of the total system input volume per day if all the low and middle-income class houses install greywater reuse systems for toilet flushing. If low, middle and high-income populations install greywater reuse systems, potential savings would be 6.833 % of the total system input.

In addition to the insignificant potential savings achieved if all or a portion of households in Hartbeesfontein and Tigane install greywater reuse systems for toilet flushing and irrigation, the subject of payback makes these systems unattractive. According to March *et al* (2004) and Ghishi & Ferreira (2007), the payback time for a greywater reuse system is between 8 to 14 years and this will most likely negatively influence home owners decision to invest in such a system.

Municipal centralised dual systems would be a more effective way to reduce the total municipal water demand for the area, but this is too expensive to install over long distances (Ilemobade *et al*, 2009). The installation of a dual system would mean that each household would have two water supply pipes. One pipe supplying potable water and the other pipe supplying non-potable water. Such a system has been successfully implemented at the Lynedoch Eco-Village, South Africa, but according to Ilemobade *et al* (2009), the optimal distance between the wastewater treatment plant and the end users should not be more than 500 m. The wastewater treatment plant near Hartbeesfontein is situated more than 500 m away from the community and therefore a dual system will not be economically feasible.

3.5 Replacing a Percentage of the Existing Municipal Water Supply with a Percentage of Treated Wastewater Treated for Non-potable Industrial Water Uses.

The water quality requirements of the industry located within proximity of the community were not released for this study for confidential reasons. For the sake of this study, it was therefore assumed that the industry would be able to reuse non-potable water. Table 3.6 shows the different industries that may use non-potable water for their respective processes.

Table 3.6: The potential to reuse wastewater for non-potable purposes in various industrial sectors (Adewumi, 2011)

High Potential	Medium Potential	Low Potential
• Pulp and paper • Cotton textile • Glass and steel • Utility power plants	• Slaughterhouse • Dairy • Canning and food processing • Distillery • Wool textile • Photographic processing • Chemical • Fertilizer • Oil refining • Petroleum • Electroplating • Meat processing	• Tanneries and leather finishing • Pesticide • Rubber • Aluminium • Explosives manufacturing • Paint manufacturing

The industry located within proximity of the community uses about 1.709 Mℓ/day of potable water. According to Greyling (2015), eighty five percent (85 %) of the daily potable water used by the industry is discarded as wastewater. If this 85% can be reused for non-potable purposes, it will reduce total water supply to the community by 22% as calculated in Table 3.7.

The water balance shown in Figure 3.7 depicts how the municipal supply can be supplemented by treated wastewater for non-potable industrial reuse.

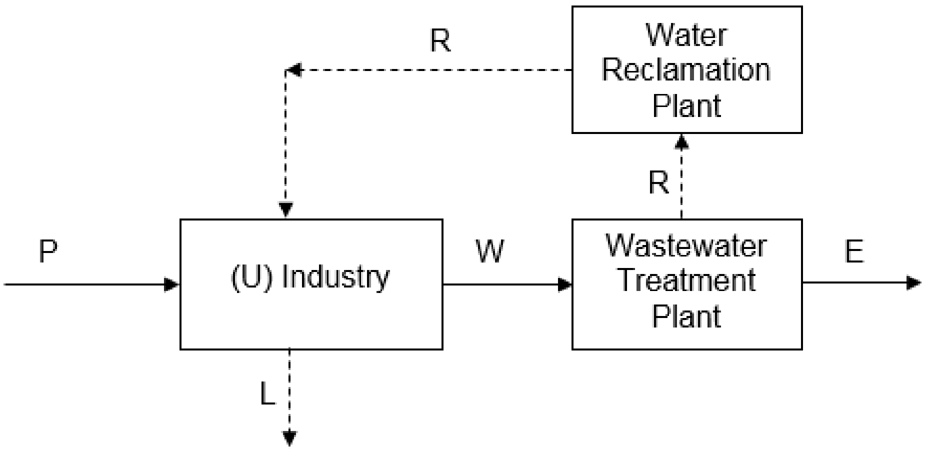

Figure 3.7: Water balance if a percentage of wastewater is treated for non-potable reuses at an industry

R = Reclaimed water (non-potable water) returned to the urban network
E = Effluent from the wastewater treatment plant

The water balance equations for Figure 3.7 are:

P_{new} + R = U + R + E ________________ equation (11)

W = R + E ____________________________equation (12)

W ≤ 0.85 $P_{current}$ (i.e. 85% of 1.709 Mℓ/d) ______equation (13

U = 0.15 $P_{current}$ (i.e. 15% of 1.709 Mℓ/d) ______equation (14)

- Scenario 1: All treated effluent (85% of $P_{current}$) is reclaimed to non-potable water quality i.e. E = 0 and R = 0.85 $P_{current}$
  Therefore equation (11) becomes P_{new} = 0.15 $P_{current}$ = 0.256 Mℓ/d

- Scenario 2: Treated effluent amounting to 80% of the system input volume is reclaimed to non-potable water quality i.e.
  E = 0.05 $P_{current}$ and R = 0.80 $P_{current}$
  Therefore, equation (11) becomes P_{new} = 0.15 $P_{current}$ + 0.05 $P_{current}$
  i.e. (0.256 + 0.085) Mℓ/d = 0.342 Mℓ/d

- Scenario 3: Treated effluent amounting to 70 % of the System Input Volume is reclaimed to non-potable water quality i.e. E = 0.15 $P_{current}$ and R = 0.70 $P_{current}$
  Therefore, equation (11) becomes P_{new} = 0.15 $P_{current}$ + 0.15 $P_{current}$ i.e. (0.256 + 0.256) Mℓ/d = 0.513 Mℓ/d

  Scenarios 4 – 10 follow the same pattern undertaken for Scenarios 1, 2 and 3 and the results are presented in Table 3.7.

Table 3.7: Scenarios showing the potential reduction in municipal water supply if the identified industry reuses non-potable treated effluent of varied quantities

	P_{new}	R
Scenario 10: No reclamation	1.709	0.000
Scenario 9: Reclaim 10% of System input volume	1.538	0.171
Scenario 8: Reclaim 20% of System input volume	1.367	0.342
Scenario 7: Reclaim 30% of System input volume	1.196	0.513
Scenario 6: Reclaim 40% of System input volume	1.025	0.684
Scenario 5: Reclaim 50% of System input volume	0.855	0.855
Scenario 4: Reclaim 60% of System input volume	0.684	1.025
Scenario 3: Reclaim 70% of System input volume	0.513	1.196
Scenario 2: Reclaim 80% of System input volume	0.342	1.367
Scenario 1: Reclaim 85% of System input volume	0.256	1.453

The results obtained in Table 3.7 indicate that industrial reuse for non-potable uses may reduce the municipal water supply by 1.453 Mℓ/day if 85% of the industry's daily water usage is satisfied with non-potable water from a reuse scheme. This would mean that the municipality needs to supply 1.453 Mℓ/day less potable water to the community resulting in a saving potential of about 22% of the total system input volume. This reduction will alleviate the daily water demand substantially and the 22% "extra" water can be employed for other potable water applications.

3.6 Cost implications

Potable water treatment and wastewater treatment are separate and distinct treatment infrastructure. A wastewater reclamation plant, at the minimum, combines the two infrastructures. Therefore, the costs of water reclamation are typically higher than that for either potable water treatment or wastewater treatment. As seen in Figure 3.8, there are many different costs involved in the water provision chain and therefore only the *treatment related* costs were compared in this report.

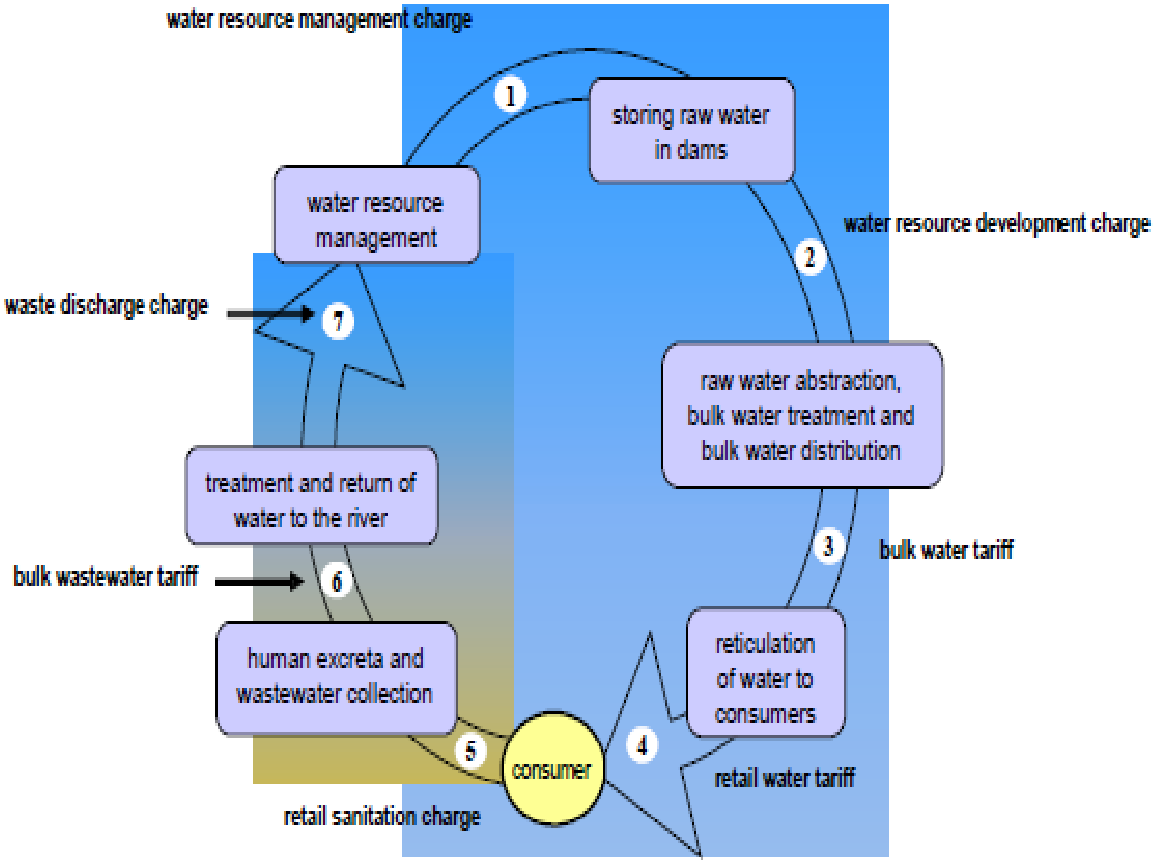

Figure 3.8: Water pricing chain (Eberhard, 2003)

This section estimates the cost of wastewater treatment for direct potable and direct non-potable uses and compare it with the cost of potable water supplied by the Midvaal Water Company. The volume of potable water purchased from the Midvaal Water Company could be reduced by direct wastewater reclamation for potable applications, but the cost of water reclamation could be higher than the cost of potable water from the Midvaal Water Company. The same can also be realised in the direct reuse of wastewater for non-potable applications i.e. if wastewater is reused for non-potable purposes, potable water demand will decrease, resulting in the reduction of potable water purchased from the Midvaal Water Company.

3.7 Cost of Potable Water

According to the 2013 annual report of the Midvaal Water Company, potable water is sold to the City of Matlosana at a rate of R5.74/kℓ excluding vat. The City of Matlosana then sells the potable water to different consumers at a higher rate as shown in Table 3.8.

Table 3.8: Water Supply Tariff Structure – City of Matlosana (2015)

Catagories	Units	Amount (Rand) 2014/2015
Domestic		
Step 1 (0-6kl)	per kl	R 0.00
Step 2 (7-10kl)		R 13.58
Step 3 (11-20kl)		R 16.60
Step 4 (21-50kl)		R 17.15
Step 5 (51-100kl)		R 17.75
Step 6 (101-200kl)		R 18.75
Step 7 (201-300kl)		R 20.30
Step 8 (Excess of 300kl)		R 25.00
Business		
Step 1 (0-10kl)	per kl	R 9.30
Step 2 (11-20kl)		R 14.30
Step 3 (21-30kl)		R14.50
Step 4 (31-50kl)		R 14.65
Step 5 (51-100kl)		R 15.60
Step 6 (101-500kl)		R 16.85
Step 7 (Excess of 500kl)		R 16.90

Catagories	Units	Amount (Rand) 2014/2015
Industry		
Step 1 (0-10kl)	per kl	R 12.40
Step 2 (11-20kl)		R 13.55
Step 3 (21-30kl)		R 13.85
Step 4 (31-50kl)		R 13.90
Step 5 (51-100kl)		R 14.00
Step 6 (101-500kl)		R 14.20
Step 7 (Excess of 500kl)		R 15.00
Government		
Step 1 (0-10kl)	per kl	R 9.95
Step 2 (11-20kl)		R 14.35
Step 3 (21-30kl)		R 14.65
Step 4 (31-50kl)		R 15.00
Step 5 (51-100kl)		R 15.60
Step 6 (101-500kl)		R 16.85
Step 7 (Excess of 500kl)		R 17.15
Schools		
Step 1 (0-10kl)	per kl	R 10.00
Step 2 (11-20kl)		R 10.65
Step 3 (21-30kl)		R 11.25
Step 4 (31-50kl)		R 11.40
Step 5 (51-100kl)		R 11.55
Step 6 (101-500kl)		R 11.85
Step 7 (Excess of 500kl)		R 12.25
Churches		
Step 1 (0-10kl)	per kl	R 9.85
Step 2 (11-20kl)		R 15.40
Step 3 (21-30kl)		R 15.40
Step 4 (31-50kl)		R 15.45
Step 5 (51-100kl)		R 15.60
Step 6 (101-500kl)		R 16.70
Step 7 (Excess of 500kl)		R 16.90
Hospitals and correctional services		
Step 1 (0-10kl)	per kl	R 9.85
Step 2 (11-20kl)		R 14.30
Step 3 (21-30kl)		R 14.50
Step 4 (31-50kl)		R 14.65
Step 5 (51-100kl)		R 14.85
Step 6 (101-500kl)		R 15.05
Step 7 (Excess of 500kl)		R 15.25

3.8 Cost of Wastewater Treatment

Moshidi *et al* (2011) studied the costing of wastewater treatment in South Africa. In their study, Moshidi *et al* (2011), included a typical breakdown of low and high end technology wastewater treatment costs, as shown in Table 3.9. The full operational and maintenance cost elements include maintenance, staffing, electricity and chemicals.

Table 3.9: Typical cost elements of two distinct technologies for wastewater treatment plants (Moshidi *et al*, 2011)

	Description	Low end technology plants		High end technology plants	
		Percentage	Cost (R/kℓ)	Percentage	Cost (R/kℓ)
2011	Maintenance	28%	R 0.200	35%	R 0.639
	Staffing	52%	R 0.366	31%	R 0.559
	Electricity	**11%**	**R 0.076**	**20%**	**R 0.364**
	Chemicals	9%	R 0.067	13%	R 0.240
	Full O&M	100%	R 0.708	100%	R 1.801
	Annual municipal budget per cost centre		R 258,429.976		R 657,485.884

From Table 3.9, it can be seen that there are differences between the different costing components of low end and high end technology wastewater treatment plants. According to Moshidi *et al* (2011), low end technology plants include biofilters and oxidation ponds, while high end technology plants include activated sludge processes and biological nutrient removal processes. According to Pickering (2015), the upgraded wastewater treatment plant at Hartbeesfontein may be regarded as a high end technology plant, since it incorporates an activated sludge process (HYBACS©) and a biological nutrient removal process (SMART©). Hence, the costs shown for high end technology plants will be presumed to be same in the Hartbeesfontein wastewater treatment plant.

3.9 Cost of Direct Wastewater Reuse for Potable Use

Direct water reclamation involves the treatment of effluent from a wastewater treatment plant and then, further treating it to the SANS 241: Class 1 potable standard. Traditional wastewater treatment plants treat wastewater collected from communities and industry up to a standard before discarding it into a water body (such as a river or dam) while traditional water purification plants extract water from a water body and then treat it up to potable standards. Direct water reclamation plants, at the minimum, combine the processes incorporated in the two traditional treatment plants.

A direct water reclamation plant currently operational in South Africa is the plant situated in Beaufort-West, Northern Cape Province. The plant was implemented during a protracted period of water shortage. According to Swartz *et al* (2014), the total cost (including personnel, energy, chemicals, maintenance, capital and general) to treat wastewater up to potable standards at the Beaufort-West reclamation plant was R16.25/kℓ. This excludes the capital cost of building the treatment plant which came to R24 million in 2010 (Matthews, 2015).

3.10 Cost of Direct Wastewater Reuse for Non-potable Use

The current Hartbeesfontein wastewater treatment plant will have to be upgraded to treat the wastewater up to a standard where the effluent can be used for non-potable purposes. As discussed in Section 3.1, the implementation of a centralized (municipal) dual system supplying households with non-potable water was not considered in this report. However, supplying a local industry with wastewater treated up to non-potable standards for industrial application could reduce the total water supply of the community by about 22% as discussed in Section 3.5.

In South Africa, the City of Cape Town and Durban successfully upgraded their wastewater treatment plants to treat effluent up to a specific quality for industrial use. In Cape Town, Caltex refineries and Sappi Paper use treated wastewater (Adewumi, 2011). In Durban, Mondi Paper and Sapref use treated wastewater for industial use (Gisclon *et al*, 2002). In the case of Durban, funding for the wastewater treatment project was provided entirely by the private sector. Loans from Societe Generale, Natexis, the French government, Rand Merchant Bank and the Development Bank of South Africa, provided the necessary funding for the construction of the wastewater treatment plant (Giscon *et al,* 2002).

According to Adewumi (2011), the cost of treating wastewater up to non-potable standards for industrial use is 16% higher than that of ordinary wastewater treatment. The cost of wastewater treatment according to Table 3.9 was R1.801/kℓ for high end technology wastewater treatment plants (processes including activated sludge and biological nutrient removal), based on actual tender prices for South Africa in 2011. Considering a 16% increase in cost as determined by Adewumi (2011) in order to upgrade the plant to produce the expected water quality for non-potable reuse, the cost of non-potable water for industrial use would have been about R2.089/kℓ in 2011. Assuming a 10% inflation rate per year since 2011, the cost in 2015 is estimated at R3.059/kℓ.

Greywater reuse at the household level was also investigated in Section 3.4. The results shown in Table 3.4 indicate an insignificant potential reduction (1.687%) of municipal water demand if greywater reuse systems are installed at all middle-income households and 4.032% saving if greywater reuse systems are installed at all low-income households (Table 3.5). In theory, it would be possible to reduce the total water demand by about 5.719% (Tables 3.4 and 3.5) if the majority (low class and middle class) of the community install greywater systems at their homes.

3.11 Summary

From the different wastewater treatment scenarios applied to specific water balance models, the most significant water reuse saving will be if the wastewater of the community could be treated for reuse as potable water. Hypothetically it would be possible to reuse 83% of the community's daily demand for potable use. It would mean that the municipality will then only need to provide 17% of the daily water demand. The 2014/2015 cost of wastewater reclamation for potable use was however, extremely high (R16.25/kℓ) compared to the cost of potable water (R5.74/kℓ) supplied by Midvaal Water. Although the amount of water saved (i.e. Total System Input Volume) through the reclamation process could be close to 83%, the viability of such a reuse scheme will have to be justified despite its high cost.

Another option is to supplement 85% of the identified industry's daily water demand with treated wastewater for non-potable use. This will reduce the total System Input Volume by about 22%. This option will be less expensive than the latter, since the volume of water treated is less and the water is only treated up to non-potable quality. The 2014/2015 cost of wastewater reclamation for non-potable use was about R3.059/kℓ, which is less than that of the potable water (R5.74/kℓ) supplied by Midvaal Water. Although the amount of water saved through the reclamation could be close to 22%, the viability of such a reuse scheme will have to be justified.

The scenario of greywater reuse systems at household level for non-potable uses at some of the middle-income houses indicates the lowest water saving potential. If more households should decide to implement greywater reuse systems for non-potable use, it would result in more potable water savings. Since the capital expenditure of a greywater reuse system at individual homes is relative high and the payback time about 8 to 14 years, residents may be resistant to implement these systems. This potable water savings option is therefore the least attractive compared to the other scenarios mentioned in this study.

From the above, it is clear that in order to select the best water reclamation option, the costing aspects are insufficient as a guide. To select the most workable option, a more comprehensive study (involving costing, perceptions and water balance (i.e. water saving potential) is undertaken (See chapters 4, 5 and 6).

CHAPTER 4 QUESTIONAIRE DEVELOPMENT

4.1 Introduction

To implement any new concept that will directly affect a community, the residents of the community should buy into the new idea. For this reason, public acceptance is one of the key factors in the successful implementation of wastewater reclamation plants (Marks, 2006).

One of the ways to evaluate the perceptions of a community about the direct reuse of wastewater for drinking and non-drinking purposes is by means of data collection through the use of a questionnaire. A questionnaire, as shown in Appendix B, was developed using the templates provided by Ilemobade *et al* (2013) and Adewumi *et al* (2014) and used to gather the necessary data in order to determine the perceptions of a sample of the community towards wastewater reclamation.

Perceptions of the direct reuse of wastewater for potable and non-potable uses were surveyed using the questionnaire in Hartbeesfontein. The questionnaire was issued to 178 residents within Hartbeesfontein. The target group included residents of Hartbeesfontein who are currently metered for their potable water. Many of the residents are retired farmers and have vegetable gardens. The sampled group consists of residents representing the demographics of South Africa. Different age and gender groups were also targeted.

4.2 Constructs employed in the Questionnaire

An intensive survey was conducted by Po *et al* (2005) in Australia. Their survey was developed to measure the intended behavior of a community towards the reuse of wastewater for different uses. The survey model of Po *et al* (2005) was also adopted by Adewumi et al (2014) in their study on

“*Factors predicting the intention to accept wastewater reuse for non-potable uses amongst domestic and non-domestic respondents*.” The focus of the survey undertaken in this study was to measure the intention of residents from Hartbeesfontein and Tigane to accept the reuse of wastewater for potable and non-potable uses.

According to Ajzen (1991), an individual’s behaviour is determined by the individual’s intention to participate in the behaviour. Intentions are in turn influenced or guided by three main factors or constructs: *attitudes*, *subjective norms* and *perceived behavioural control*. Po *et al* (2005) expanded on Ajzen’s model by adding two constructs namely *trust* and *knowledge*. Based on the 5 constructs in Po *et al*’s (2005) study and their application in Adewumi *et al* (2014), the following constructs will be measured in this study: *Attitudes; Subjective Norms; Preceived Behavioral Control; Knowledge* and *Trust.*

The Hypothesised model predicting intended behaviour regarding direct wastewater reuse for potable and non-potable uses is shown in Figure 4.1.

4.3 Hypothesised Model

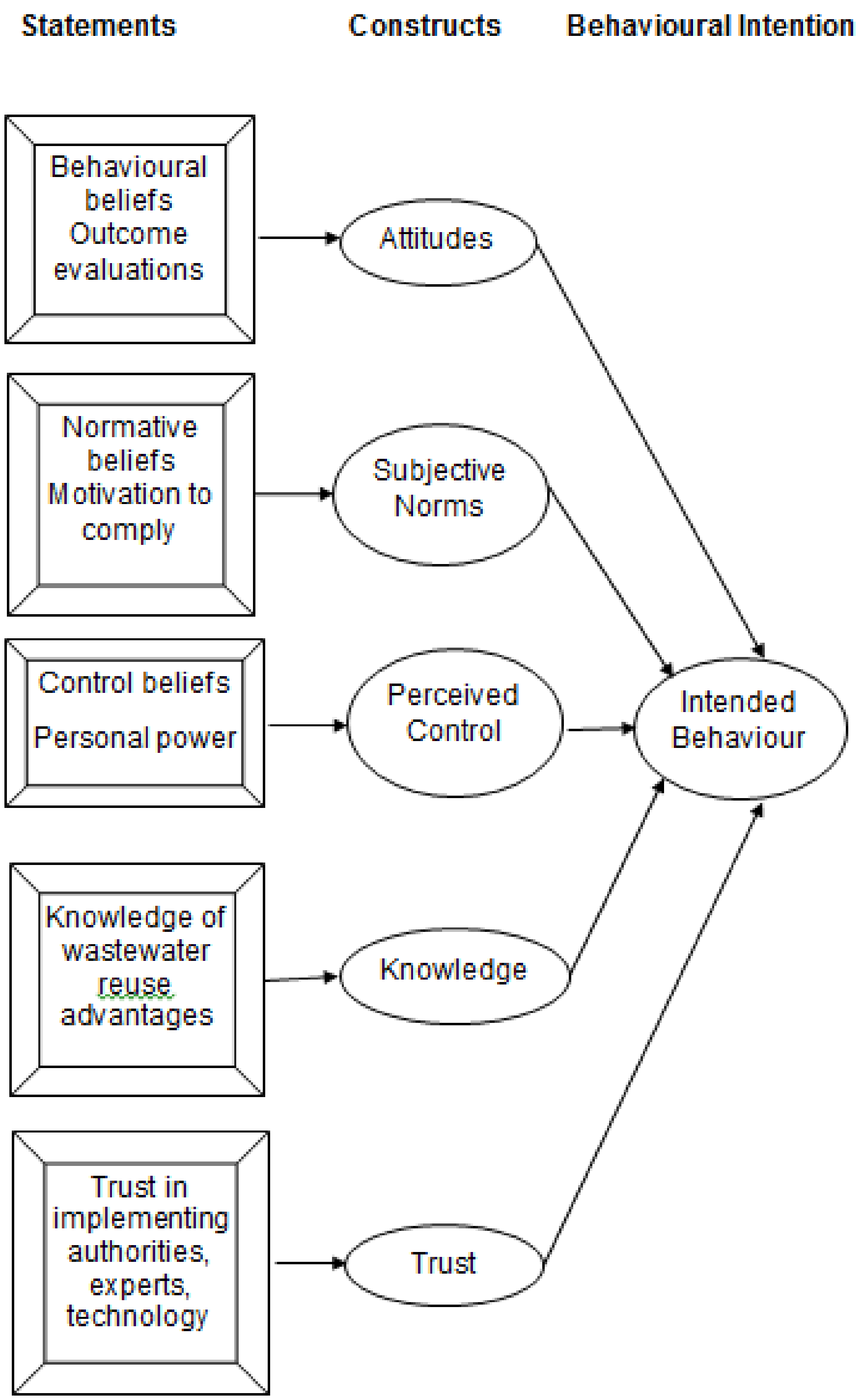

Figure 4.1: Hypothesised model predicting intended behaviour regarding direct wastewater reuse for potable and non-potable uses (Po *et al*, 2005)

Descriptions of the constructs used in the development of the questionnaire are shown in Table 4.1.

Table 4.1: Descriptions of the constructs in the hypothesised model

Construct	Description of Construct
Knowledge	Facts and information acquired through experience or education about the reuse of treated wastewater for non-drinking and drinking purposes.
Trust	The extent to which a person trusts the authorities involved in implementing and managing the reuse of treated wastewater for non-drinking and drinking purposes.
Attitude	The extent to which a person has a negative or positive disposition towards the reuse of treated wastewater for non-drinking and drinking purposes.
Perceived Control	The amount of perceived control over the source of water and its application if wastewater is treated for non-drinking and drinking reuse purposes.
Subjective Norms	The amount of pressure and influence a person feels from other significant people to support or not to support the reuse of treated wastewater for non-drinking and drinking purposes.
Intention	The intention to behave in a way that supports or does not support the reuse of treated wastewater for non-drinking and drinking purposes.

The constructs listed in Table 4.1 are hypothetical and therefore cannot be directly observed, but must instead be concluded from respondents' responses to questions or statements that statistically correlate with the constructs. Table 4.2 shows the different hypothesis for each construct in order to measure the intention of the respondents to accept the reuse of wastewater for non-drinking purposes.

Table 4.2: Constructs measuring intention to accept the direct reuse of wastewater for non-drinking purposes and their respective hypotheses (adopted from Adewumi *et al*, 2014)

Construct	Hypothesis
Knowledge (BKW)	H1: Respondents' knowledge of the advantages of wastewater reuse has a positive effect on intention to accept direct wastewater reuse for non-drinking purposes.
Trust (CTR)	H2: Respondents' trust in the treated wastewater service provider has a positive effect on intention to accept direct wastewater reuse for non-drinking purposes.
Attitude (DATT)	H3: Respondents' positive attitude towards direct wastewater reuse will increase the intention to accept direct wastewater reuse for non-drinking water purposes.
Perceived Control (ECON)	H4: Respondents' perceived control over the source of water and its application has a positive effect on the intention to accept direct wastewater reuse for non-drinking water purposes.
Subjective Norms (FSN)	H5: Higher subjective norms associated with direct wastewater reuse for non-drinking water purposes, has a positive effect on intention to accept direct wastewater reuse.

Table 4.3 shows the different hypothesis for each construct in order to measure the intention of the respondents to accept the reuse of wastewater for drinking purposes.

Table 4.3: Constructs measuring intention to accept the direct reuse of wastewater for drinking purposes and their respective hypotheses (adopted from Adewumi *et al*, 2014).

Construct	Hypothesis
Knowledge (HKW)	H1: Respondents' knowledge of the advantages of wastewater reuse has a positive effect on intention to accept direct wastewater reuse for drinking purposes.
Trust (ITR)	H2: Respondents' trust in the treated wastewater service provider has a positive effect on intention to accept direct wastewater reuse for drinking purposes.
Attitude (JATT)	H3: Respondents' positive attitude towards direct wastewater reuse will increase the intention to accept direct wastewater reuse for drinking water purposes.
Perceived Control (KCON)	H4: Respondents' perceived control over the source of water and its application has a positive effect on the intention to accept direct wastewater reuse for drinking water purposes.
Subjective Norms (LSN)	H5: Higher subjective norms associated with direct wastewater reuse for drinking water purposes, has a positive effect on intention to accept direct wastewater reuse.

4.4 Questionnaire

A questionnaire, as shown in Appendix B, was developed and administered to a random sample of potential domestic potable and non-potable water consumers. The questionnaire was sub-divided into three sections: introduction, demographics of respondents and perceptions.

The introduction stated the aim of the project, which, was to determine perceptions toward the direct reuse of treated municipal wastewater for both drinking and non-drinking purposes. Definitions of terminology were also given for clarification. The second section gathered information about the demographics of the respondents in order to ensure a well-represented target group. The third section comprised statements (developed to test hypotheses H1-H5) aimed at measuring respondents' positive or negative perceptions towards wastewater reuse.

CHAPTER 5 DATA CAPTURING AND ANALYSIS

5.1 Introduction

On the 20th of September 2014, the developed questionnaires were administered at Hartbeesfontein. Each of the nine (9) employed questionnaire administrators was issued with a street map, name tag, clip board, pen and 30 questionnaires, and assigned to a different residential block within the community. Residents were then randomly approached and requested to participate in the survey. The administrators were trained to translate questionnaire statements or questions where necessary and this occurred several times since many of the residents did not understand English. In total, of the 270 administered questionnaires, 178 questionnaires were completed.

5.2 Data Capturing

The demographic characteristics of respondents are discussed below:

5.2.1 Respondents' gender

An analysis of the gender of the respondents indicates that of the 178 respondents, 46.1% (n=82) were male and 53.9% (n=96) were female. The fact that there was only a 7.8% difference in the ratio of males to females likely suggests a gender balance within Hartbeesfontein and thus, a reasonably reliable gender representation in the survey. According to Robinson *et al* (2005), women are more concerned about the use of treated wastewater for drinking purposes than men. Hence, it was beneficial to this study to assess the perception of a reasonable sample of women.

5.2.2 Respondent's ethnic group

The frequencies pertaining to respondents' ethnic groups are illustrated in Table 5.1

Table 5.1: Frequencies pertaining to Respondents' Ethnic Groups (N = 178)

Categories	n	%
Black	142	79.8
Indian/Asian	1	0.6
Coloured	3	1.7
White	30	16.8
Other	2	1.1

The demographic profile presented reflects very closely to the demographic profile of the City of Matlosana, where Hartbeesfonten is located i.e.:81.0 % Black, 14.5% White, 3.5% Coloured and 0.8% Indian/Asian (Census 2011). This implies that the target group was demographically well represented during the survey.

5.2.3 Respondents' religious group

The frequencies pertaining to respondents' religious groups are illustrated in Table 5.2

Table 5.2: Frequencies and pertaining to Respondents' Religious Groups (N = 178)

Categories	n	%
Christian	153	86.0
Islam	3	1.7
Hinduism	1	0.6
No Religion	19	10.6
Other	2	1.1

The frequencies shown in Table 5.2 may be indicative of the fact that the largest religious group in the 2 communities may likely be Christian. According to Wilson and Pfaff (2008), who conducted a study in Durban Christian, Islamic and Hindu religions do not have an issue with the reuse of treated wastewater for drinking purposes. This predominant high number of Christian respondents could therefore respond in a more positive manner towards wastewater reuse since their religious beliefs do not oppose wastewater reuse.

5.2.4 Respondents' age group

The frequencies pertaining to respondents' age groups are illustrated in Table 5.3.

Table 5.3 Frequencies of Respondents' Age Group (N = 178)

Categories	n	%
18-29	86	48.3
30-39	34	19.1
40-49	15	8.4
50-59	17	9.6
60+	25	14.6

The frequencies shown in Table 5.3 are likely indicative of the fact that the community has a predominant young adult population amongst its economically active population. Hence, responses to different statements in the survey may likely, more often, echo their viewpoints than the rest of the adult population.

5.2.5 Respondents' level of education

The frequencies pertaining to respondents' level of education are illustrated in Table 5.4.

Table 5.4: Frequencies pertaining to Respondents' Level of Education (N = 178)

Categories	n	%
Matric or less	132	74.1
Certificate	27	15.2
Diploma	7	3.9
Degree	8	4.5
Postgrad. degree	3	1.7
Other	1	0.6

The frequencies of the sample population shown in Table 5.4 are likely indicative of the fact that the majority of the community may have a level of education at the Matric level or less. This predominant level of education will influence how respondents interpret and respond to questions and statements on wastewater reuse.

5.2.6 Respondents' garden extent

The frequencies pertaining to respondents' garden extent are illustrated in Table 5.5.

Table 5.5: Frequencies pertaining to Respondents' Garden Extent (N = 178)

Categories	n	%
No vegetable garden	101	56.7
Small to medium vegetable garden and lawn	32	18.0
Large vegetable garden and lawn	5	2.8
Vegetable garden only	5	2.8
Lawn only	35	19.7

The frequencies shown in Table 5.5 show that about 43% of respondents have some form of vegetation (vegetable garden and/or lawn) within their properties while about 57% do not. It is therefore likely that those without vegetation may influence the overall responses to the questions and/or statements regarding the reuse of wastewater for watering vegetables and crops.

5.2.7 Number of bedrooms in respondents' dwelling

The frequencies pertaining to number of bedrooms in dwellings are illustrated in Table 5.6.

Table 5.6: Frequencies pertaining to Number of Bedrooms in Respondents' Dwellings (N = 178)

Categories	n	%
1 Bedroom	27	15.2
2 Bedrooms	57	32.0
3 or more bedrooms	94	52.8

The majority of the community may have 3 bedrooms or more since the results from the sample size dictates so.

The National Norms and Standards (2007) as stipulated by the Department of Human Settlements, outline the minimum physical requirements for standalone permanent dwellings. Each house must at least have 40m² of floor space, two bedrooms, a separate bathroom with a toilet, a shower and hand basin, and a combined living area and kitchen. More than 50% of respondents in dwellings with 3 or more bedrooms are anticipated to likely influence respondents' responses to questions and statements on water saving and perceived control over the water source, since they should be responsible for their water bill.

5.2.8 Respondents' responses to the direct reuse of treated wastewater for drinking and non-drinking purposes

a) Respondents' knowledge of direct reuse of treated water for drinking and non-drinking purposes

The frequencies pertaining to respondents' knowledge of the direct reuse of treated wastewater for drinking and non-drinking purposes are illustrated in Table 5.7 and Table 5.8.

Table 5.7: Frequencies pertaining to respondents' knowledge of the direct reuse of treated wastewater for drinking purposes (N = 178)

	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
HKW1: *The direct reuse of treated wastewater for drinking purposes will save scarce freshwater resources.*					
Number (%)	**74(41.6)**	**78(43.8)**	**9(5.0)**	**11(6.2)**	**6(3.4)**
HKW2: *The direct reuse of treated wastewater for drinking purposes will ensure that communities in dry areas have enough water in the future.*					
Number (%)	**72(40.4)**	**74(41.6)**	**14(7.9)**	**12(6.7)**	**6(3.4)**
HKW3: *The direct reuse of treated wastewater for drinking purposes will reduce the amount of wastewater entering our rivers, streams and dams.*					
Number (%)	**66(37.1)**	**73(41.0)**	**13(7.3)**	**15(8.4)**	**11(6.2)**

Table 5.8: Frequencies pertaining to respondents' knowledge of the direct reuse of treated wastewater for non-drinking purposes (N = 178)

	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
BKW1:*The direct reuse of treated wastewater for non-drinking purposes will save scarce freshwater resources*					
Number (%)	**72(40.5)**	**80(44.9)**	**15(8.4)**	**8(4.5)**	**3(1.7)**
BKW2: *The direct reuse of wastewater for non-drinking purposes will ensure that communities in dry areas have enough water in the future.*					
Number (%)	**72(40.5)**	**75(42.2)**	**12(6.7)**	**12(6.7)**	**7(3.9)**
BKW3: *The direct reuse of treated wastewater for non-drinking purposes will reduce the amount of wastewater entering our rivers, streams and dams.*					
Number (%)	**72(40.5)**	**68(38.2)**	**20(11.2)**	**13(7.3)**	**5(2.8)**

The majority of the respondents either agreed or strongly agreed that the direct reuse of treated wastewater for drinking (78.1% to 85.4%) and non-drinking purposes (78.7% to 85.4%) will save scarce freshwater resources, ensure enough water in the future and reduce the amount of wastewater entering our water bodies. This demonstrates that the majority of the respondents have knowledge about the importance of saving water and that water is a precious entity that we need to protect for the future. According to Dishman *et al* (1989), one of the key factors of the public acceptance of direct wastewater reuse for drinking purposes, is the level of education about wastewater reuse. According to Asano *et al* (2010), public awareness of wastewater reclamation plays an important role in implementing water reclamation schemes successfully.

b) Respondents' trust in the authorities to provide treated wastewater for drinking and non-drinking purposes

The frequencies pertaining to respondents' trust in the authorities to provide treated wastewater for drinking and non-drinking purposes are illustrated in Table 5.9 and Table 5.10.

Table 5.9: Frequencies pertaining to respondents' trust in the authorities to provide treated wastewater for drinking purposes (N = 178)

	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
IRT1: *I have confidence that the City of Matlosana will deliver good treated wastewater quality for drinking purposes.*					
Number (%)	**54(30.3)**	**48(26.9)**	**22(12.4)**	**24(13.5)**	**30(16.9)**
IRT2: *I can depend on the City of Matlosana to provide good treated wastewater quality for drinking purposes.*					
Number (%)	**72(40.4)**	**74(41.6)**	**14(7.9)**	**12(6.7)**	**6(3.4)**
IRT3: *I have complete trust in the City of Matlosana to provide me with good treated wastewater quality for drinking purposes.*					
Number (%)	**47(26.4)**	**47(26.4)**	**23(12.8)**	**29(16.3)**	**32(17.9)**

Table 5.10 Frequencies pertaining to respondents' trust in the authorities to provide treated wastewater for non-drinking purposes (N = 178)

	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
CRT1: *I have confidence that the City of Matlosana will deliver good treated wastewater quality for non-drinking purposes.*					
Number (%)	**46(25.8)**	**54(30.3)**	**25(14.0)**	**33(18.5)**	**20(11.2)**
CRT2: *I depend on the City of Matlosana to provide good treated wastewater quality for non- drinking purposes.*					
Number (%)	**43(24.2)**	**54(30.3)**	**26(14.6)**	**38(21.3)**	**17(9.6)**
CRT3: *I have complete trust in the City of Matlosana to provide me with good treated wastewater quality for non-drinking purposes.*					
Number (%)	**39(21.9)**	**51(28.7)**	**25(14.0)**	**43(24.2)**	**20(11.2)**

Between 10.1% and 34.2% of respondents disagreed and strongly disagreed in response to IRT1, IRT2 and IRT3. Between 7.9% and 12.8% of respondents were neutral in their response to the above statements.

For CRT1, CRT2 and CRT3, the disagree and strongly disagree responses were between 29.7% and 35.4% while neutral responses were between 14.0% and 14.6%. In essence therefore, a little lower than 50% of respondents were not completely trusting the City of Matlosana to provide treated effluent of the recommended quality for drinking and non-drinking purposes. This may have a negative impact any wastewater reuse initiatives within the city. According to Ross *et al* (2014) and Po *et al* (2005), trust in water supply authorities plays a major role in the acceptance of a wastewater reuse system.

c) Respondents' attitude towards treated wastewater for drinking and non-drinking purposes

The frequencies pertaining to the respondents' attitude towards treated wastewater for drinking and non-drinking purposes are illustrated in Table 5.11 and Table 5.12.

Table 5.11: Frequencies pertaining to respondents' attitude towards treated wastewater for drinking purposes (N = 178)

	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
JATT1: *I feel the need to save as much water as is possible.*					
Number (%)	**109(61.2)**	**53(29.8)**	**9(5.1)**	**5(2.8)**	**2(1.1)**
JATT2: *I would prefer to use treated wastewater for drinking purposes.*					
Number (%)	**49(27.5)**	**55(30.9)**	**25(14.0)**	**30(16.9)**	**19(10.7)**
JATT3: *I would only use treated wastewater for drinking water purposes in a time of drought.*					
Number (%)	**37(20.8)**	**64(36.0)**	**24(13.4)**	**31(17.4)**	**22(12.4)**

Table 5.12: Frequencies pertaining to Respondents' Attitude towards treated wastewater for non-drinking Purposes (N = 178)

	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
DATT1: *I feel the need to save as much water as is possible.*					
Number (%)	**109(61.2)**	**60(33.7)**	**3(1.7)**	**6(3.4)**	**0(0)**
DATT2: *I prefer to use treated wastewater for non-drinking purposes.*					
Number (%)	**65(36.5)**	**66(37.0)**	**22(12.4)**	**22(12.4)**	**3(1.7)**
DATT3: *I will only use treated wastewater for non-drinking water purposes in a time of drought.*					
Number (%)	**34(19.1)**	**66(37.0)**	**22(12.4)**	**40(22.5)**	**16(9.0)**

From the results obtained in Table 5.11 and Table 5.12, it is evident that more than two thirds of the community have a positive mind-set about the use of treated wastewater for drinking or non-drinking purposes. This outcome positively correlates with respondents' awareness of water conservation from Table 5.7 and Table 5.8. A factor that might have a negative impact on respondents' attitude could be their trust in authorities treating and providing the treated wastewater.

However, despite the positive responses towards reuse in Table 5.11 (JATT1 and JATT2) and Table 5.12 (DATT1 and DATT2), majority (56.1%) of responses to DATT3 and the majority (56.8%) of responses to JATT3 indicate preference to reuse only during a drought. This response could imply that if respondents have a choice to use treated wastewater for drinking purposes they would only use it during desperate times such as was experienced during the 2015 drought.

d) Respondents' perceived control towards treated wastewater reuse for drinking and non-drinking purposes

The frequencies pertaining to respondents' perceived control towards treated wastewater reuse for drinking and non-drinking purposes are illustrated in Table 5.13 and Table 5.14.

Table 5.13: Frequencies pertaining to respondents' perceived control towards treated wastewater reuse for drinking purposes (N = 178)

	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
KCON1: *I have a choice to use treated wastewater for drinking purposes.*					
Number (%)	**69(38.8)**	**60(33.7)**	**14(7.9)**	**15(8.4)**	**20(11.2)**
KCON2: *If I pay for drinking water, I have the right to choose the source of water supply (e.g. surface water, treated wastewater and groundwater).*					
Number (%)	**104(58.4)**	**52(29.2)**	**11(6.2)**	**6(3.4)**	**5(2.8)**
KCON3: *Water experts should have control over the kind of water the community is supplied with.*					
Number (%)	**94(52.8)**	**58(32.6)**	**11(6.2)**	**9(5.0)**	**6(3.4)**

Between 72.5% and 87.6% of respondents agreed and strongly agreed that they had a right to choose the source of their drinking water supply. Blair *et al* (2007) had comparable responses when a similar study was conducted in South East Queensland, Australia, where some respondents indicated that they would source drinking water from elsewhere if they did not like the tap water provided by the authorities. About 85% (n=152) of the respondents agreed and strongly agreed that water experts should have control over the kind of water the community is supplied with. While the responses in the last two sentences may seem contradictory, respondents, while preferring to exercise significant control over the source(s) of their water supply, are willing for competent water personnel to also make that decision on their behalf.

Table 5.14: Frequencies pertaining to respondents' perceived control towards treated wastewater reuse for non-drinking purposes (N = 178)

	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
ECON1: *I have a choice to use treated wastewater for non-drinking purposes.*					
Number (%)	**62(34.8)**	**69(38.8)**	**9(5.1)**	**23(12.9)**	**15(8.4)**
ECON2: *It is my human right to know if fruits or vegetables were irrigated with treated wastewater.*					
Number (%)	**69(38.8)**	**63(35.4)**	**10(5.6)**	**22(12.3)**	**14(7.9)**
ECON3: *Fruits and vegetables irrigated with treated wastewater should be labelled in the supermarket.*					
Number (%)	**69(38.8)**	**52(29.2)**	**14(7.9)**	**26(14.6)**	**17(9.6)**

Approximately 75% (n=134) of the respondents agreed and strongly agreed that they needed to be informed if fruits or vegetables were irrigated with treated wastewater. The respondents felt strongly that they needed to have a choice whether to use or not to use treated wastewater for non-drinking purposes. This result shows that the respondents will not simply accept the use of treated wastewater for non-drinking purposes. They would rather like to make an informed decision.

According to Adewumi *et al* (2014) and Po *et al* (2005), the degree of control that a respondent has over their water supply source will influence their intention to accept reclaimed wastewater for drinking and non-drinking purposes.

e) Respondents' subjective norms towards treated wastewater for non-drinking purposes

The frequencies pertaining to respondents' subjective norms towards treated wastewater reuse for drinking and non-drinking purposes are illustrated in Table 5.15 and Table 5.16.

Table 5.15: Frequencies pertaining to respondents' subjective norms towards treated wastewater reuse for drinking purposes (N = 178)

	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
LSN1: I will use treated wastewater for drinking water purposes if other people in my community are using it.					
Number (%)	**49(27.5)**	**58(32.6)**	**19(10.7)**	**39(21.9)**	**13(7.3)**
LSN2: *I will use treated wastewater for drinking purposes if most people in my community support it.*					
Number (%)	**48(26.9)**	**65(36.5)**	**17(9.6)**	**34(19.1)**	**14(7.9)**
LSN3: *I will use treated wastewater for drinking purposes if the leaders of my community encourage us to do so.*					
Number (%)	**53(29.8)**	**59(33.1)**	**21(11.8)**	**29(16.3)**	**16(9.0)**

Table 5.16: Frequencies pertaining to respondents' subjective norms towards treated wastewater reuse for non-drinking purposes (N = 178)

	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
FSN1: *I will use treated wastewater for non-drinking purposes if other people in my community are using it.*					
Number (%)	**53(29.8)**	**61(34.3)**	**19(10.7)**	**38(21.3)**	**7(3.9)**
FSN2: *I will use treated wastewater for non-drinking purposes if most people in my community support it.*					
Number (%)	**54(30.3)**	**75(42.1)**	**16(9.0)**	**28(15.7)**	**5(2.8)**
FSN3: *I will use treated wastewater for non-drinking purposes if the leaders of my community encourage us to do so.*					
Number (%)	**60(33.7)**	**62(34.8)**	**16(9.0)**	**30(16.9)**	**10(5.6)**

There is a noticeable increase (60.1% for LSN1 to 63.4% for LSN2 and 62.9% for LSN3) from Table 5.15 and also a noticeable increase (64.1% for FSN1 to 72.4% for FSN2 and 68.5% for FSN3) from Table 5.16 in respondents’ willingness to reuse treated wastewater when underscored by the fact that most people in the community accept the initiative and/or when community leaders encourage reuse. According to Po *et al* (2005), subjective norms influence respondents’ intention to reuse treated wastewater for *drinking* purposes and according to Adewumi *et al* (2014), subjective norms influence respondents’ intention to reuse treated wastewater for *non-drinking* purposes.

f) Respondent’s intention to use treated wastewater for drinking and non-drinking purposes

The frequencies pertaining to respondents’ intention to use treated wastewater for drinking and non-drinking purposes are illustrated in Table 5.17 and Table 5.18.

Table 5.17: Frequencies pertaining to respondents’ intention to use treated wastewater for drinking purposes (N = 178)

	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
MINT1: *If provided by the City of Matlosana, I will use treated wastewater for drinking purposes.*					
Number (%)	**48(27.0)**	**70(39.3)**	**15(8.4)**	**22(12.4)**	**23(12.9)**
MINT2: *If provided by the City of Matlosana, I will use treated wastewater for drinking purposes during a time of drought.*					
Number (%)	**42(23.6)**	**75(42.1)**	**12(6.7)**	**31(17.5)**	**18(10.1)**
MINT3: *I intend to use treated wastewater for drinking purposes if the City of Matlosana can ensure it is of good quality.*					
Number (%)	**56(31.5)**	**66(37.0)**	**21(11.9)**	**15(8.4)**	**20(11.2)**

Between 65.7% and 68.5% of the respondents agreed and strongly agreed that they intend to use treated wastewater for drinking purposes if provided and quality assured by the City of Matlosana. Between 19.6% and 27.6% of the respondents disagreed and strongly disagreed – this equates to about one fourth of the community. This negative reaction from the respondents will have a negative impact on the implementation of such a system if direct drinking water reuse is considered.

Table 5.18: Frequencies pertaining to respondents' intention to use treated wastewater for non-drinking purposes (N = 178)

	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
GINT: *If provided by the City of Matlosana, I will use treated wastewater to irrigate my vegetable garden.*					
Number (%)	**56(31.5)**	**72(40.4)**	**22(12.4)**	**19(10.7)**	**9(5.0)**
GINT2: *If provided by the City of Matlosana, I will use treated wastewater to irrigate my lawn.*					
Number (%)	**62(34.8)**	**71(39.9)**	**17(9.6)**	**22(12.3)**	**6(3.4)**
GINT3: *If provided by the City of Matlosana, I intend to use treated wastewater for non-drinking purposes during a time of drought.*					
Number (%)	**50(28.1)**	**78(43.8)**	**20(11.2)**	**21(11.9)**	**9(5.0)**
GINT4: *I intend to use treated wastewater for non-drinking purposes if the City of Matlosana can ensure it is of good quality.*					
Number (%)	**72(40.4)**	**69(38.8)**	**13(7.3)**	**17(9.6)**	**7(3.9)**

In summary, each of the statements measured in Table 5.18 produced greater than 71% of respondents in favour of intending to use treated wastewater for certain non-drinking purposes if the quality provided by the City of Matlosana is satisfactory. This positive response from the respondents will contribute to the success of any possible future plans to reuse wastewater for non-drinking purposes if supplied by the City of Matlosana. Disagreed and strongly disagreed responses were between 13.5% and 16.9% and less, was obtained for drinking purposes.

5.3 Position in Mean Score Ranking for Non-drinking Purposes

Table 5.19 is an illustration of the means, reliabilities and standard deviation associated with each of the five constructs related to the reuse of wastewater for non-drinking purposes.

Table 5.19: Means, reliabilities and standard deviation extracted for potential non-drinking respondents

Constructs	No of items	Relia-bilities α	Recom-mended Value (Saunders *et al*, 2012)	Summated Mean Scores $\bar{x}$	Std De-viation	Position in Mean Score Ranking
DATT (Attitude)	3	0.33	>0.70	2.06	0.67	2
FSN (Subjective Norms)	3	0.84		2.27	1.04	5
ECON (Perceived Control)	3	0.70		2.21	1.03	4
BKW (Know-ledge)	3	0.78		1.89	0.82	1
CTR (Trust)	3	0.91		2.65	1.23	6
GINT (Intention)	4	0.84		2.12	0.92	3

The summated means of the five constructs in Table 5.19 indicates that knowledge ($\bar{x}$ = 1.89) was ranked the highest and trust in the authorities ($\bar{x}$ = 2.65) the lowest.

The average mean score from Table 5.19 for the five subscales = (2,06 + 2.27 + 2.21 + 1.89 + 2.65 + 2.12) / 6 = 2.2, indicating an average scoring between agree and neutral (however, closer to neutral) on the Likert Scale as shown in Table 5.20.

Table 5.20: Likert Scale used for statements of questionnaire

<table>
<tr><td>Statement</td><td>Strongly Agree</td><td>Agree</td><td>Neutral</td><td>Disagree</td><td>Strongly Disagree</td></tr>
<tr><td>Scoring</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>Average Mean</td><td colspan="5">1.5 2.5 3.5 4.5
Average mean score = 2.2</td></tr>
</table>

According to Suanders *et al* (2012), the standard deviation measures how concentrated the data are around the mean; the more concentrated, the smaller the standard deviation. In the current study, the standard deviation for *Attitude* is 0.67 with a mean score of 2.06, which means the data points for *Attitude* are concentrated around the mean (2.06). This result indicates that the majority of respondents agreed to use treated wastewater for non-drinking purposes.

The standard deviation for *Subjective Norms* shows a standard deviation of 1.04 with a mean score of 2.27, which means that the data points are spread across the mean (2.27). The majority (65%) of respondents agreed to use wastewater for non-potable use if promoted by community leaders, but one third either remained neutral or disagreed to this statement.

The standard deviation for *Perceived Control* shows a standard deviation of 1.03 with a mean score of 2.21, which means that the data points are spread across the mean (2.21). The majority (70%) of respondents agreed or strongly agreed to use wastewater for non-potable use if they had a choice to use is, whereas about 30% remained neutral or disagreed to this statement.

The standard deviation for *Knowledge* shows a standard deviation of 0.82 with a mean score of 1.89, which means that the data points are concentrated around the mean (1.82). This result indicates that the majority of respondents strongly agreed and agreed that treated wastewater for non-drinking purposes would save scarce freshwater resources.

The standard deviation for *Trust* shows a standard deviation of 1.23 with a mean score of 2.65, which means that the data points are spread across the mean (2.65). About one third (32%) of respondents disagreed or strongly disagreed to trust authorities to provide communities with treated wastewater for non-potable use, and about 17% remained neutral. The remainder of respondents either agreed or strongly agreed to trust the local authorities to provide them with treated wastewater for non-potable use. This widespread response could impact any wastewater reuse initiative negatively.

The standard deviation for *Intention* shows a standard deviation of 0.92 with a mean score of 2.12, which means that the data points are concentrated around the mean (2.12). This result indicates that the majority of respondents (67%) agreed that they have the intention to use treated wastewater for non-drinking purposes if provided.

Reliability was measured using the Cronbach's alpha coefficient, which is recommended to be above 0.7 (Saunders *et al*, 2012). The Cronbach Alpha result for *Attitude towards treated wastewater for non-drinking purposes* illustrates that the analysis for this construct was not reliable. The Cronbach Alpha results for *Subjective norms, perceived control, knowledge, trust and intention towards treated wastewater for non-drinking purposes* all illustrated that the analysis for these constructs were reliable with their respective results all above 0.7 as indicated in Table 5.19.

5.4 Position in Mean Score Ranking for Drinking Purposes

Table 5.21 is an illustration of the means, reliabilities and standard deviation associated with each of the five constructs related to the reuse of wastewater for drinking purposes.

Table 5.21: Means, reliabilities and standard deviation extracted for potential drinking respondents

Constructs	No of items	Relia-bilities α	Recom-mended Value (Saunders *et al*, 2012)	Summated Mean Scores $\bar{x}$	Standard Deviation	Position in Mean Score Ranking
JATT (Attitude)	3	0.50	>0.70	2.23	0.67	3
LSN (Subjective Norms)	3	0.91		2.45	1.19	5
KCON (Perceived Control)	3	0.37		1.85	0.74	1
HKW (Knowledge)	3	0.88		1.94	0.96	2
ITR (Trust)	3	0.95		2.69	1.37	6
MINT (Intention)	3	0.90		2.41	1.20	4

The summated means of the five constructs in Table 5.21 indicates that perceived control ($\bar{x}$ = 1.85) was ranked highest, and trust in the authorities ($\bar{x}$ =2.69) the lowest.

The average mean score from Table 5.21, for the five subscales = (2.23 + 2.45 + 1.85 + 1.94 + 2.69 + 2.41) / 6 = 2.26, indicating an average scoring between agree and neutral (however, closer to neutral) on the Likert Scale as shown in Table 5.22.

Table 5.22: Likert Scale used for statements of questionnaire

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Scoring	1	2	3	4	5
Average Mean	1.5 2.5 3.5 4.5 Average mean score = 2.26				

In the current study, the standard deviation for *Attitude* is 0.67 with a mean score of 2.23, which means the data points for *Attitude* are concentrated around the mean (2.23). This result indicates that the majority of respondents agreed to use treated wastewater for drinking purposes.

The standard deviation for *Subjective Norms* shows a standard deviation of 1.19 with a mean score of 2.45, which means that the data points are spread across the mean (2.45). The majority (65%) of respondents agreed to use wastewater for potable use if promoted by community leaders, but one third either remained neutral or disagreed to this statement.

The standard deviation for *Perceived Control* shows a standard deviation of 0.74 with a mean score of 1.85, which means that the data points are concentrated around the mean (1.85). The majority (80%) of respondents agreed or strongly agreed that they should have a choice of the source of their drinking supply, especially for drinking purposes.

The standard deviation for *Knowledge* shows a standard deviation of 0.96 with a mean score of 1.94, which means that the data points are concentrated around the mean (1.94). This result indicates that the majority of respondents strongly agreed and agreed that treated wastewater for drinking purposes would save scarce freshwater resources.

The standard deviation for *Trust* shows a standard deviation of 1.37 with a mean score of 2.69, which means that the data points are spread across the mean (2.69). About one third (32%) of respondents disagreed or strongly disagreed to trust authorities to provide communities with treated wastewater for potable use, and about 17% remained neutral. The remainder of respondents either agreed or strongly agreed to trust the local authorities to provide them with treated wastewater for potable use. This widespread response could impact any wastewater reuse initiative negatively.

The standard deviation for *Intention* shows a standard deviation of 1.20 with a mean score of 2.41, which means that the data points are spread across the mean (2.41). This result indicates that the majority of respondents (67%) agreed that they have the intention to use treated wastewater for drinking purposes if provided, but approximately 24% disagreed or strongly disagreed – this equates to almost one third of the community and could have a negative impact on the implementation of such a system.

The Cronbach Alpha results for *Attitude towards wastewater for drinking purposes and perceived control* illustrate that the analysis for these constructs were not reliable. The Cronbach Alpha results for *Subjective norms, knowledge, trust and intention towards treated wastewater for non-drinking purposes* all illustrated that the analysis for these constructs were reliable with their respective results all above 0.7 as indicated in Table 5.21.

5.5 Correlations (Non-drinking purposes)

The Pearson Correlation Coefficient (Saunders *et al* 2012) was used to examine the relationship between the five constructs predicting the intention to accept the direct reuse of treated wastewater for non-drinking purposes (Table 5.23).

Table 5.23: Correlations amongst the constructs predicting the Intention to accept the direct reuse of treated wastewater for non-drinking purposes

Constructs	Knowledge	Trust	Attitude	Perceived Control	Subjective Norms	Intention
Knowledge	1.000	0.166*	0.290**	0.018	0.305**	0.552**
Trust	0.166*	1.000	0.093	-0.132	0.175*	0.402**
Attitude	0.290**	0.093	1.000	0.185*	0.372**	0.385**
Perceived Control	0.018	-0.132	0.185*	1.000	-0.002	0.123
Subjective Norms	0.305**	0.175*	0.372**	-0.002	1.000	0.524**
Intention	0.552**	0.402**	0.385**	0.123	0.524**	1.000

** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

In terms of the relationship between the factors (*Knowledge, Trust, Attitude, Perceived Control, and Subjective Norms*) and the *Intention* to accept the direct reuse of treated wastewater for non-drinking purposes, Pearson correlations showed (see Figure 5.1) positive correlations with the *Intention* factor. There is a statistically significant moderate to strong positive relationship between *Knowledge* and *Intention* (r=0.552; p<0.01); there is a statistically significant moderate to strong positive relationship between *Trust* and *Intention* (r=0.402; p<0.01); there is a statistically significant moderate to strong positive relationship between *Attitude* and *Intention* (*r*=0.385; p<0.01); there is no statistically significant relationship between *Perceived Control* and *Intention* (*r*=0.123; p>0.05); and there is a statistically significant moderate to strong positive relationship between *Subjective Norms* and *Intention* (*r*=0.524; p<0.01). Thus, the higher or more positive the *Knowledge, Trust, Subjective Norms* and *Attitude* of the respondents are towards the direct reuse of wastewater for non-drinking purposes, the more likely their *Intention* to accept it.

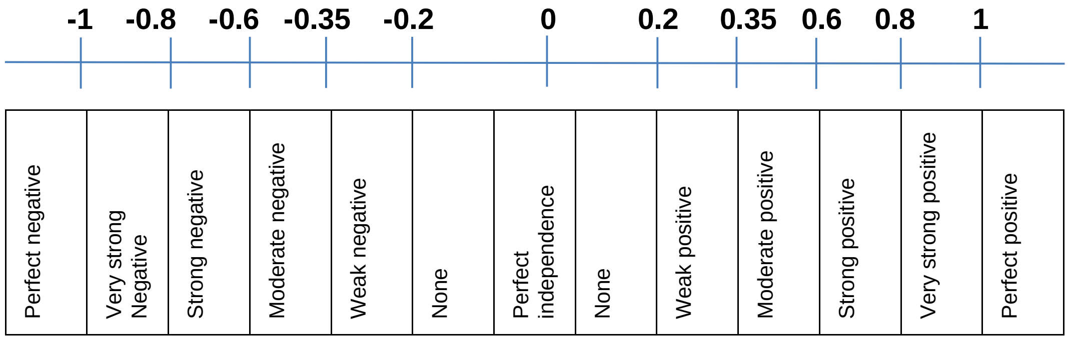

Figure 5.1: Values of the correlation coefficient (Saunders et al, 2012)

Perceived Control is a weak construct that will not influence respondents' intention to reuse wastewater for non-drinking purposes. These findings are consistent with the results of Po *et al* (2005) which reveal that constructs such as *Trust, Attitudes, Subjective Norms, Environmental Obligation* and *Emotion* are positively related to the *Intended Behaviour* and that *Perceived Control* indicates a weak contribution to the Intended Behaviour. A similar study conducted by Adewumi *et al* (2014) in Limpopo, South Africa, also indicated a positive correlation between *Trust, Attitude, Advantages, Subjective Norms* and the *Intention* to accept reuse. In contradiction to this study, Adewumi et al's (2014) results indicated a strong relationship between *Perceived Control* and *Intention* to accept reuse.

5.6 Correlations (Drinking Purposes)

The Pearson Correlation Coefficient (Saunders *et al* 2012) was used to examine the relationship between the five constructs predicting the *Intention* to accept the direct reuse of treated wastewater for drinking purposes. The results are reported in Table 5.24.

Table 5.24: Correlations amongst the constructs predicting the Intention to accept the direct reuse of treated wastewater for drinking purposes

Factors	Know-ledge	Trust	Attitude	Perceived Control	Subjective Norms	Intention
Knowledge	1.000	0.471**	0.539**	0.096	0.436**	0.592**
Trust	0.471**	1.000	0.463**	0.050	0.377**	0.625**
Attitude	0.539**	0.463**	1.000	0.155*	0.522**	0.552**
Perceived Control	0.096	0.050	0.155*	1.000	-0.076	-0.028
Subjective Norms	0.436**	0.377**	0.522**	-0.076	1.000	0.648**
Intention	0.592**	0.625**	0.552**	-0.028	0.648**	1.000

** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

In terms of the relationship between the factors (*Knowledge, Trust, Attitude, Perceived Control, and Subjective Norms*) and the *Intention* to accept the direct reuse of treated wastewater for drinking purposes, Pearson correlations showed positive correlations with the *Intention* factor. There is a statistically significant strong positive relationship between *Knowledge* and *Intention* (*r*=0.592; p<0.01); there is a statistically significant strong positive relationship between *Trust* and *Intention* (*r*=0.625; p<0.01); there is a statistically significant moderate to strong positive relationship between

Attitude and *Intention* (*r*=0.552; p<0.01); there is no statistically significant or a weak negative relationship between *Perceived Control* and *Intention* (*r*=-0.028; p>0.05); and there is a statistically strong positive relationship between *Subjective Norms* and *Intention* (*r*=0.648; p<0.01). Thus the higher or more positive the *Knowledge, Trust, Subjective Norms* and *Attitude* constructs of the respondents are towards the direct reuse of wastewater for drinking purposes, the higher their *Intention* to accept.

The comments made in the last paragraph of section 5.5 (Perceived control being a weak construct that will not influence respondents' *Intention*; consistency between results of this study, Po *et al's* (2005) study and Adewumi *et al's* (2014) study; and contradiction between the results obtained for *Perceived Control* obtained in this study and Adewumi *et al* (2014)) are also echoed in this section.

5.7 Summary

Public acceptance of a direct wastewater reclamation system for drinking and/or non-drinking purposes is crucial for the successful implementation of such a system. One of the aims of this study was to identify the main factors that would influence the public's intention to accept a direct wastewater reclamation system for drinking and/or non-drinking purposes.

The hypotheses of this study for direct wastewater reuse for drinking and non-drinking water applications were:

H1: Respondents' *Knowledge* of the advantages of wastewater reuse has a positive effect on *Intention* to accept direct wastewater reuse.

The results of the correlation analysis proved that the higher or more positive the *Knowledge* construct is, the higher the *Intention* to accept direct wastewater reuse for drinking and non-drinking purposes.

H2: Respondents' *Trust* in the treated wastewater service provider has a positive effect on *Intention* to accept direct wastewater reuse.

The results of the correlation analysis proved that the higher or more positive the *Trust* construct is, the higher the *Intention* to accept direct wastewater reuse for drinking and non-drinking purposes.

H3: Respondents' positive *Attitude* towards direct wastewater reuse will increase the *Intention* to accept direct wastewater reuse.

The results of the correlation analysis proved that the higher or more positive the *Attitude* construct is, the higher the *Intention* to accept direct wastewater reuse for drinking and non-drinking purposes.

H4: Respondents' *Perceived Control* over the source of water and its application has a positive effect on the *Intention* to accept direct wastewater reuse.

The results of the correlation analysis proved that *Perceived Control* is a weak construct that will not influence respondents' *Intention* to accept direct wastewater reuse for drinking and non-drinking purposes.

H5: Higher *Subjective Norms* associated with direct wastewater reuse have a positive effect on *Intention* to accept direct wastewater reuse.

The results of the correlation analysis proved that the higher or more positive the *Subjective Norm* construct is, the higher the *Intention* to accept direct wastewater reuse for drinking and non-drinking purposes.

Respondents from the Hartbeesfontein community were sampled randomly. According to Saunders *et al* (2012), the sample size for Hartbeesfontein was computed to be more than hundred. A total of 178 questionnaires were completed by respondents and this equated to about 1% of the total population.

The results of the summated means for the five non-drinking constructs from Table 5.19, indicate that *Knowledge* ($\bar{x}$ = 1.89) was ranked highest, followed by *Attitude* ($\bar{x}$ = 2.06), *Perceived Control* ($\bar{x}$ = 2.21), *Subjective Norms* ($\bar{x}$ =2.27) and *Trust* in the authorities ($\bar{x}$ = 2.65). This result points decision makers to specific areas where to focus on during public participation when planning a wastewater reuse scheme for non-drinking purposes. Since *Knowledge* measured the highest, decision makers should focus on educating communities on wastewater reuse for non-drinking purposes. The more knowledge the community members gain, the more likely they would be accepting of wastewater reclamation.

The results of the summated means for the five drinking constructs from Table 5.21, indicate that *Perceived Control* ($\bar{x}$ = 1.85) was ranked highest, followed by *Knowledge* ($\bar{x}$ = 1.94), *Attitude* ($\bar{x}$ = 2.23), *Subjective Norms* ($\bar{x}$ = 2.45) and *Trust* in the authorities ($\bar{x}$ =2.69). Having *Perceived Control* over the water source and *Knowledge* about wastewater reuse ranked the two highest, could imply that since respondents were confronted with the idea of drinking treated wastewater, they would be more comfortable if they had the choice to drink it or not. Decision makers should therefore be careful not to implement a wastewater reuse scheme for drinking water without the consent and approval of the community. Education and information about such a non-conventional scheme will be beneficial in convincing communities about water reuse.

Thus the mean score results for both drinking and non-drinking purposes constructs are significant and therefore acceptable.

The results of the correlation analysis done for non-drinking purposes between the constructs (*Knowledge, Trust, Subjective Norms, Attitude* and *Perceived Control)* and *Intention* indicated that the higher or more positive the *Knowledge, Trust, Subjective Norms* and *Attitude* of the respondents were towards the direct reuse of wastewater for non-drinking purposes, the higher their *Intention* to accept it in the future. *Perceived Control* is a weak construct that will not influence respondents' *Intention* to reuse wastewater for non-drinking purposes. This result reinforces the need for public awareness campaigns to gauge and prepare recipients for treated wastewater reuse for non-drinking purposes.

The results of the correlation analysis done for drinking purposes between the constructs *(Knowledge, Trust, Subjective Norms, Attitude* and *Perceived Control*) and *Intention* indicated that the higher or more positive the *Knowledge, Trust, Subjective Norms* and *Attitude* of the respondents were towards the direct reuse of wastewater for drinking purposes, the higher their *Intention* to accept it in the future. *Perceived Control* is a weak construct that will not influence respondents' *Intention* to reuse wastewater for drinking purposes. This result reinforces the need for public awareness campaigns to gauge and prepare recipients for treated wastewater reuse for drinking purposes.

CHAPTER 6 VIABILITY OF WATER RECLAMATION FOR POTABLE AND NON-POTABLE WATER USES IN HARTBEESFONTEIN AND TIGANE

6.1 Introduction

Direct wastewater reuse systems for potable and/or non-potable uses is a relatively under-utilised concept in South Africa and to ensure the successful implementation of such a system, a viability (feasibility) study should be conducted. In this study, the outcomes of the water balance, perceptions of respondents (~ 1% of the community) and typical costs of wastewater treatment technologies will be combined to assess the viability of direct wastewater reuse for potable and non-potable uses.

6.2 Preference of the Community to use Treated Wastewater

To compare the community's preference for wastewater reuse application (i.e. potable or non-potable) and intention, results from similar statements within the administered questionnaire are compared in Table 6.1.

Table 6.1: Summary of questionnaire responses (agreed and strongly agreed responses)

Statement	Responses to Non-drinking Purposes	Responses to Drinking Purposes
I prefer to use treated wastewater for non-drinking (DATT2 - Table 5.10) or drinking (JATT2 – Table 5.16) purposes.	(n = 131) 73.5%	(n = 104) 58.4%
If provided by the City of Matlosana, I intend to use treated wastewater for non-drinking (GINT3 - Table 5.13) or drinking (MINT2 - Table 5.19) purposes during a time of drought.	(n = 128) 71.9%	(n = 117) 65.7%
I intend to use treated wastewater for non-drinking (GINT4 - Table 5.13) or drinking (MINT3 - Table 5.19) purposes if the City of Matlosana can ensure it is of good quality.	(n = 141) 79.2%	(n = 122) 68.5%

From Table 6.1, between 71.9% and 79.2% of respondents generally prefer and intend to reuse wastewater for non-potable uses while between 58.4% and 68.5% of respondents generally prefer and intend to reuse wastewater for drinking purposes.

Both options are therefore investigated in the following sections in order to select the most viable.

6.3 Cost Implications if Replacing a Percentage of the Existing Municipal Water Supply with Potable or Non-potable Water from the Wastewater Reclamation System.

The different water balance scenarios in Chapter 3 were used to determine the cost implications of replacing a percentage of the existing municipal water supply with potable or non-potable water from a wastewater reclamation system.

To determine the cost of replacing a percentage of the existing municipal water supply with potable water from a wastewater reclamation plant, the water balance from Table 3.2 of this report, was used. Different water mix ratios and the results obtained are shown in Table 6.2 and the following, which were employed in the water balance exercise, are noted:

- Calculated daily demand = 6.418 Megalitres (Section 3.2)
- The water balance is based on the calculations undertaken in Section 3.3.

Table 6.2: Different water mix ratios to meet daily water demand if existing water supply is augmented by reclaimed wastewater i.e. wastewater treated to potable quality

	Wastewater to be reclaimed (Cost per Kilolitre = R16.25)		Potable water to be supplied by The Midvaal Water Company (Cost per Kilolitre = R5.74)		Combined Cost per Day
	%	Volume (Megalitre)	%	Volume (Megalitre)	
Potable Water Mix Ratio	No reuse	0	100%	6.418	R 36 839.32
	10%	0.642	90%	5.776	R 43 584.64
	20%	1.284	80%	5.134	R 50 329.96
	30%	1.925	70%	4.493	R 57 075.27
	40%	2.567	60%	3.851	R 63 820.59
	50%	3.209	50%	3.209	R 70 565.91
	60%	3.851	40%	2.567	R 77 311.23
	70%	4.493	30%	1.925	R 84 056.55
	80%	5.134	20%	1.284	R 90 801.86
	83%	5.327	17%	1.091	R 92 825.46

From Table 6.2, it can be seen that the direct reuse of wastewater for potable use is very expensive compared to the water supplied from Midvaal Water.

Since the survey also indicated that this water reclamation option is not the preferred option, it can be assumed that direct wastewater reuse for potable use will not be a viable option for Hartbeesfontein and Tigane.

The second option is direct reuse of wastewater for non-potable industrial uses. To determine the costs, the water balance shown in Table 3.7 was used with different water mix ratios. Results obtained are shown in Table 6.3.

Table 6.3: Different water mix ratios to meet the daily demand of the industry and community if the existing water supply is augmented by reclaiming wastewater i.e. wastewater treated to non-potable quality for industrial use.

	Wastewater to be reclaimed (Cost per Kilolitre = R3.06)		% Potable water to be supplied by The Midvaal Water (Cost per Kilolitre = R5.74)		Combined Cost per Day
	%	Volume (Megalitre)	%	Volume (Megalitre)	
Potable Water Mix Ratio	No reuse	0	100%	6.418	R 36 839.32
	10%	0.172	97.32%	6.246	R 36 378.36
	20%	0.344	94.64%	6.074	R 35 917.40
	30%	0.513	92.01%	5.905	R 35 463.56
	40%	0.684	89.35%	5.734	R 35 004.98
	50%	0.855	86.69%	5.564	R 34 549.26
	60%	1.025	84.02%	5.393	R 34 091.25
	70%	1.196	81.36%	5.222	R 33 633.24
	80%	1.367	78.69%	5.051	R 33 175.22
	85%	1.453	77.37%	4.965	R 32 946.22

It can be seen from Table 6.3 that the combined cost of potable water supplied to the community will decrease as the percentage of reused water supplied to industry increases. Not only will money be saved through this reclamation system, but up to 22%, as mentioned in section 3.5 of this document, of potable water can be saved each day or re-directed elsewhere.

Since the survey also indicated that this water reclamation option is the preferred option, it is concluded that direct wastewater reuse for non-potable industrial use is the more viable option (when perceptions, costs and water savings are compared) for Hartbeesfontein and Tigane.

6.4 Summary

By comparing the outcomes of the water balance, perceptions of the community and costs of the different wastewater reuse scenarios of Hartbeesfontein and Tigane, it is evident that the direct reuse of wastewater for non-potable industrial use is the more viable water reclamation option for the community. From Table 6.2, it can be seen that direct reuse of wastewater for potable use is expensive compared to potable water supplied by Midvaal Water. If 83% of the total water demand is supplied from a water reclamation plant, the daily cost is estimated to R 92 825.46 compared to R 36 839.32 if Midvaal Water supplies the potable water demand, i.e. when no reuse is implemented. The option to reclaim wastewater for potable use is therefore an option if it is the last resort, since the financial implications are about thrice the current cost to supply potable water to the community.

If treated wastewater is supplied to industry, the daily cost is about 9% less than the current situation of potable water supply from Midvaal Water. From Table 6.3, it can be seen that if 85% of the industry's water demand is provided from reused wastewater, the daily cost would be about R 32 946.22 per day. Not only will money be saved through this reclamation system, but up to 22% of potable water can be saved each day (as mentioned in section 3.5 of this document).

CHAPTER 7 CONCLUSION

Wastewater reclamation for potable or non-potable use is still a relatively underdeveloped, yet viable concept in South Africa. Since it has been implemented successfully in other countries and in some South African communities, there is potential for wastewater reuse systems to be successfully implemented in more South African communities to supplement fresh and other water resources. The viability for the implementation of a water reclamation plant at Hartbeesfontein and Tigane was the main focus of this study. In theory, as mentioned above, water reclamation is a viable solution to augment South Africa's limited water resources. However, its applicability needs to be investigated on a case by case basis.

A water balance, perception survey and costing analyses were used to determine the viability for the implementation of a water reclamation system at Hartbeesfontein and Tigane.

A water balance of Hartbeesfontein and Tigane was undertaken based on the model proposed by Grobicki & Cohen (1999). The water balance for Hartbeesfontein was used to compare 3 scenarios:

- Replacing a percentage of the existing municipal water supply with potable water from a wastewater reclamation scheme.
- Replacing a percentage of the existing municipal water supply with non-potable water supplied from household wastewater reuse systems for non-potable water uses (e.g. irrigation or toilet flushing).
- Replacing a percentage of the existing municipal water supply with a percentage of treated wastewater treated for non-potable industrial water uses.

From the different scenarios investigated, the most significant water saving was found to be when the wastewater of the community was reclaimed as potable water. Hypothetically it is possible for 83% of the community's daily demand to be reclaimed from wastewater. It would mean that the municipality will then only need to provide 17% of the daily water demand.

The second option was to replace 85% of the industry's daily water demand with reclaimed wastewater, but for non-potable use. This will reduce the total potable water demand of the community by about 22%.

The surveys conducted determined a fraction (~ 1%) of the community's perception of water reclamation. Since public acceptance plays a major role in the success of any project, it was crucial to determine if the community would accept a water reclamation system for potable and/or non-potable use. Factors that were determined from the literature to influence respondent's decision to accept the direct reuse of wastewater for drinking and or non-drinking purposes were: *Knowledge, Trust, Subjective Norms, Perceived Control and Attitude.*

A questionnaire, as shown in Appendix B, was developed and administered to a random sample of potential domestic water consumers (Sample size = 178). The questionnaire was sub-divided into three sections: Introduction, demographics of respondents and perceptions. From the results of selected statements, it was determined that 67% of respondents will accept the direct reuse of wastewater for potable and 74% for non-potable use.

The costing of direct reuse of wastewater for potable and non-potable purposes within Hartbeesfontein and Tigane was investigated. The water balance previously undertaken was used as the basis for the cost analysis. The cost of the different wastewater reclamation options for drinking and non-drinking purposes was compared to the current situation.

The cost of wastewater reclamation for potable use was approximately 283% higher (R16.25/kℓ) than the cost of potable water supplied by Midvaal Water (R5.74). The cost of wastewater treatment for non-potable industrial use was approximately 53.3% (R3.06) less than that of the cost of potable water supplied by Midvaal Water. The overall water saving potential for this option came to about 22% compared to the 83% potential water saving achieved from direct potable wastewater reclamation.

By comparing the outcomes of the water balance, perceptions of the community and costs of the different wastewater reclamation scenarios of Hartbeesfontein and Tigane, it is evident that the direct wastewater reclamation system for non-potable industrial use is the more viable water reclamation option for the community.

7.1 Recommendation for Future Research

Future research is recommended in the following areas:

- Development of educational programs to educate communities on the reuse potential of wastewater (potable and non-potable applications)
- Identify potential towns or communities where wastewater reclamation plants could be implemented in advance to avoid water shortages during droughts.
- Improving wastewater reclamation plants for irrigation purposes, by reducing the salt and chorine content of effluent water which have a negative impact on the discoloring of crops and clogging of the piping system.
- Updating the water usage data of small towns and communities to effectively manage water supply. Small scale water management should be improved to reduce water losses.
- To investigate the impact of downstream users due to the reduced surface flow quantities if a wastewater reclamation plant should be implemented.
- To conduct a comprehensive financial analysis on the total cost of a wastewater reclamation plant – treatment cost, operational cost and

construction to determine the payback time, versus alternative water supplying i.e. construction of a new dam or supplying water with a piping system from a remote source.

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APPENDIX A

Hartbeesfontein Wastewater Treatment Inflow Readings
(29 July 2014 to 28 May 2015)

Date (2014)	Meter Reading	Inflow per week (Kl)	Ave per day	Average inflow per day in August
29-Jul	390115			
07-Aug	454252	64137	7126.333	
14-Aug	505854	51602	7371.714	
20-Aug	544437	38583	6430.5	
27-Aug	590777	46340	6620	
			Kilolitre	**6887.137**

Date (2014)	Meter Reading	Inflow per week (Kl)	Ave per day	Average inflow per day in September
27-Aug	590777			
03-Sep	630225	39448	5635.4286	
10-Sep	666752	36527	5218.1429	
17-Sep	714206	47454	6779.1429	
25-Sep	753689	39483	5640.4286	
			Kilolitre	**5818.286**

Date (2014)	Meter Reading	Inflow per week (Kl)	Ave per day	Average inflow per day in October
25-Sep	753689			
02-Oct	794921	41232	5890.285714	
09-Oct	836071	41150	5878.571429	
30-Oct	957805	121734	5796.857143	
			Kilolitre	**5855.238**

Date (2014)	Meter Reading	Inflow per week (Kl)	Ave per day	Average inflow per day in November
30-Oct	957805			
03-Nov	980855	23050	5762.5	
			Kilolitre	**5762.500**

Date (2015)	Meter Reading	Inflow per week (Kl)	Ave per day	Average inflow per day in January
08-Jan	415254			
15-Jan	487517	72263	10323.28571	
22-Jan	525658	38141	5448.714286	
29-Jan	567950	42292	6041.714286	
			Kilolitre	**7271.238**

Date (2015)	Meter Reading	Inflow per week (Kl)	Ave per day	Average inflow per day in February
29-Jan	567950			
05-Feb	651508	83558	11936.85714	
19-Feb	675656	24148	1724.857143	
25-Feb	691082	15426	2571	
			Kilolitre	**5410.905**

Date (2015)	Meter Reading	Inflow per week (Kl)	Ave per day	Average inflow per day in March
25-Feb	691082			
05-Mar	729395	38313	4789.125	
12-Mar	772727	43332	6190.285714	
18-Mar	812927	40200	6700	
26-Mar	866302	53375	6671.875	
			Kilolitre	**4890.540**

Date (2015)	Meter Reading	Inflow per week (Kl)	Ave per day	Average inflow per day in April
26-Mar	866302			
08-Apr	949139	82837	6372.076923	
16-Apr	993302	44163	5520.375	
			Kilolitres	**5946.226**

Date (2015)	Meter Reading	Inflow per week (Kl)	Ave per day	Average inflow per day in May
15-May	186522			
21-May	218242	31720	5286.666667	
28-May	259162	40920	5845.714286	
			Kilolitres	**5566.190**

Summary of Inflow per Day

Month/Year	Ave daily inflow (Kl) per month:
June 2014	Power Failure: No results
July 2014	Power Failure: No results
August 2014	6887.137
September 2014	5818.286
October 2014	5855.238
November 2014	5762.5
January 2015	7271.238
February 2015	5410.905
March 2015	4890.54
April 2015	5946.226
May 2015	5566.19
Average daily inflow (kl) over 9 months	**5934.251**

APPENDIX B

AIM: My name is Marelize Beer. I am a Master of Science student at the University of the Witwatersrand. I am requesting you to complete this questionnaire, which is part of my Masters research study. The study I am conducting seeks to determine your perceptions toward the direct reuse of treated municipal wastewater for both drinking and non-drinking purposes. Your responses will be treated as anonymous and confidential.

DEFINITIONS:

- Perceptions – The way in which something is regarded, understood, or interpreted.
- Wastewater – all household waste water i.e. waste water from kitchen sinks, dishwashers, bath tubs, basins, showers, toilets and laundry.
- Treated wastewater – wastewater that has been treated (using technologically advanced processes to remove contaminants) to specified standards.
- Direct reuse – reuse of treated or untreated wastewater by directly transferring it from the site where it is produced to a different/separate facility for the next use.
- Drinking purposes – e.g. drinking, cooking and brushing of teeth.
- Non-drinking purposes – e.g. irrigation, toilet flushing and construction.

In each section below, please place a cross (x) in the most appropriate box or boxes.

SECTION A: Demographic profile

A1	**Gender**	Male	Female				
A2	**Ethnic group**	Black	Indian/Asian	Coloured	White	Other	
A3	**Religious group**	Christian	Islam	Hinduism	No Religion	Other Specify:	
A4	**Age**	18 - 29	30-39	40-49	50-59	60 and over	
A5	**Level of education**	Matric or less	Certificate	Diploma	Degree	Postgraduate degree: e.g. Masters or Doctorate	Other: Specify
A6	**Garden extent**	No vegetable garden	Small to medium vegetable garden and lawn	Large vegetable garden and lawn	Vegetable garden only	Lawn only	
A7	**Number of bedrooms in dwelling**	1 bedroom	2 bedrooms	3 or more bedrooms			

SECTION B: Knowledge of treated wastewater direct reuse for non-drinking purposes

	Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
BKW1	The direct reuse of treated wastewater for non-drinking purposes will save scarce freshwater resources.					
BKW2	The direct reuse of wastewater for non-drinking purposes will ensure that communities in dry areas have enough water in the future.					
BKW3	The direct reuse of treated wastewater for non-drinking purposes will reduce the amount of wastewater entering our rivers, streams and dams.					
	SECTION C: Trust in the authorities to provide treated wastewater for non-drinking purposes	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
CTR1	I have confidence that the City of Matlosana will deliver good treated wastewater quality for non-drinking purposes.					
CTR1	I can depend on the City of Matlosana to provide good treated wastewater quality for non- drinking purposes.					
CTR2	I have complete trust in the City of Matlosana to provide me with good treated wastewater quality for non-drinking purposes.					
	SECTION D: Attitude towards treated wastewater for non-drinking purposes	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
DATT1	I feel the need to save as much water as is possible.					
DATT2	I prefer to use treated wastewater for non-drinking purposes.					
DATT3	I will only use treated wastewater for non-drinking water purposes in a time of drought.					
	SECTION E: Perceived control towards treated wastewater for non-drinking purposes	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
ECON1	I have a choice to use treated wastewater for non-drinking purposes.					
ECON2	It is my human right to know if fruits or vegetables were irrigated with treated wastewater.					
ECON3	Fruits and vegetables irrigated with treated wastewater should be labelled in the supermarket.					
	SECTION F: Subjective Norms towards treated wastewater for non-drinking purposes	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
FSN1	I will use treated wastewater for non-drinking purposes if other people in my community are using it.					
FSN2	I will use treated wastewater for non-drinking purposes if most people in my community support it.					
FSN3	I will use treated wastewater for non-drinking purposes if the leaders of my community encourage us to do so.					
	SECTION G: Intention to use treated wastewater for non-drinking purposes	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
GINT1	If provided by the City of Matlosana, I will use treated wastewater to irrigate my vegetable garden.					
GINT2	If provided by the City of Matlosana, I will use treated wastewater to irrigate my lawn.					
GINT3	If provided by the City of Matlosana, I intend to use treated wastewater for non-drinking purposes during a time of drought.					
GINT4	I intend to use treated wastewater for non-drinking purposes if the City of Matlosana can ensure it is of good quality.					

SECTION H: Knowledge of treated wastewater direct reuse for drinking purposes

	Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
HKW1	The direct reuse of treated wastewater for drinking purposes will save scarce freshwater resources.					
HKW2	The direct reuse of treated wastewater for drinking purposes will ensure that communities in dry areas have enough water in the future.					
HKW3	The direct reuse of treated wastewater for drinking purposes will reduce the amount of wastewater entering our rivers, streams and dams.					
	SECTION I: Trust in the authorities to provide treated wastewater for drinking purposes	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
ITR1	I have confidence that the City of Matlosana will deliver good treated wastewater quality for drinking purposes.					
ITR2	I can depend on the City of Matlosana to provide good treated wastewater quality for drinking purposes.					
ITR3	I have complete trust in the City of Matlosana to provide me with good treated wastewater quality for drinking purposes.					
	SECTION J: Attitude towards treated wastewater for drinking purposes	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
JATT1	I feel the need to save as much water as is possible.					
JATT2	I would prefer to use treated wastewater for drinking purposes.					
JATT3	I would only use treated wastewater for drinking water purposes in a time of drought.					
	SECTION K: Perceived control towards treated wastewater for drinking purposes	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
KCON1	I have a choice to use treated wastewater for drinking purposes.					
KCON2	If I pay for drinking water, I have the right to choose the source of water supply (e.g. surface water, treated wastewater, groundwater).					
KCON3	Water experts should have control over the kind of water the community is supplied with.					
	SECTION L: Subjective Norms towards treated wastewater for drinking purposes	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
LSN1	I will use treated wastewater for drinking purposes water if other people in my community are using it.					
LSN2	I will use treated wastewater for drinking purposes if most people in my community support it.					
LSN3	I will use treated wastewater for drinking purposes if the leaders of my community encourage us to do so.					
	SECTION M: Intention to use treated wastewater for drinking purposes	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
MINT1	If provided by the City of Matlosana, I will use treated wastewater for drinking purposes.					
MINT2	If provided by the City of Matlosana, I will use treated wastewater for drinking purposes during a time of drought.					
MINT3	I intend to use treated wastewater for drinking purposes if the City of Matlosana can ensure it is of good quality.					

Thank you very much. Your participation is appreciated.