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MSc Dissertation

Quantifying the potential for potable water savings in the Liesbeek River catchment

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Abstract

The security of South Africa's water resources has been identified as a major issue affecting the country's potential for socio-economic expansion. With the realisation that current water management interventions require significant improvement, there has been growing interest in finding more effective approaches to water management.

This dissertation aims to quantify the potential potable water savings that could be achieved through the implementation of selected sustainable water management interventions in the Liesbeek River catchment, Cape Town.

The current water use model was constructed in the form of a water balance, using data collected from the catchment. The water balance results showed that the Liesbeek River catchment used in the region of 6105 Mℓ of potable water over a one year period between May 2010 and April 2011; this amounted to approximately 2% of Cape Town's total water demand of 326 000 Mℓ/yr. The domestic sector was responsible for the bulk of the water demand, accounting for 55% of the catchment's total water requirement. The remaining 45% of the water demand was spread evenly between the non-domestic sectors found within the catchment.

Once the water demand for the catchment had been established for the reference year, selected water saving interventions were then incorporated into the model; the results were then compared to the reference year to assess the potential water savings that may be achieved in the catchment.

The selection process for the water saving interventions included in the model was based on the availability of data for the Liesbeek River catchment. The model incorporated the following interventions:

i) Using water efficient devices

ii) Reducing on-site leakage

iii) Rainwater harvesting

iv) Greywater harvesting.

The adoption of water efficient devices has the greatest potential impact on reducing water demand in the catchment. If all properties in the catchment were to install devices that used water in a more efficient manner, the catchment's water use could drop by as much as 30%, potentially saving in the region of 1849 Mℓ/yr. The implementation of water efficient devices has the greatest impact on the domestic sector, potentially reducing water use by approximately 41% which could amount to a water savings 1386 Mℓ/yr. The potential savings achieved through the installation of water efficient devices is significantly lower for the non-domestic sector. Potential water savings range from 13% for community facilities, to 23% for educational institutions, with commercial properties potentially saving 16% and hospitals 12%. Although not as effective as in the domestic sector, water efficient devices could still save 463 Mℓ/yr in the non-domestic sector, 7.5% of the catchment's total water demand.

The quantity of water lost as a result of on-site leakage in the catchment amounts to 66 Mℓ/yr. This is approximately 2% of the catchment's total water demand, a large proportion of which could be saved through more effective water management.

The use of alternative water sources in the Liesbeek River catchment shows significant promise. The implementation of rainwater harvesting systems could collect up to 892 Mℓ of rainwater annually, augmenting 15% of the catchment's total water demand. Rainwater harvesting has the greatest impact on the domestic land use category, potentially providing up to 22% of the total water demand for the domestic sector. The rainwater harvesting contribution to the commercial land use category is significantly lower, with rainwater potentially providing 10% of the annual water demand. Community facilities, education and hospitals all have relatively low rainwater contributions with 6%, 3% and 0.6% of their respective total water demands potentially being supplied by rainwater harvesting. Greywater harvesting could potentially provide 390 Mℓ/yr, nearly 6.5% of the catchment's total water demand. Domestic properties account for the bulk of the yield with 339 Mℓ/yr; approximately 5.5% of the catchment's total water demand. Commercial properties have the next highest yield with 22 Mℓ/yr, less than one tenth of the domestic greywater yield. The community and education land use categories could potentially use 9 Mℓ/yr and 20 Mℓ/yr of greywater respectively, together making up roughly 0.5% of the catchment's total water demand.

Although the selected water-saving interventions could have a significant individual impact on the current water use scenario in the Liesbeek River catchment, it is unlikely that all of the interventions could be implemented at full scale throughout the catchment simultaneously. In order to understand the combined impact of all of these interventions, a final composite scenario was developed to illustrate the combined impact of the water saving interventions in the catchment.

The results from the composite scenario show that the total water demand could be reduced by 37%. The water supply portfolio for the catchment would then consist of 3885 Mℓ/yr of municipal supply, 346 Mℓ/yr of rainwater, and 55 Mℓ/yr of greywater; 91%, 8%, and 1% of the catchment's total water demand respectively. The production of wastewater from within the catchment could be reduced by approximately 36%, or 1904 Mℓ/yr.

This dissertation has successfully shown the significant impact that water saving interventions could have in the Liesbeek River catchment. By applying the findings of the Liesbeek River catchment case study to other catchments with a largely residential development profile similar water savings can be anticipated.

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1. Introduction

The security of South Africa's water resources has been identified as a major threat to the country's future development (Scholes, 2001; Turpie et al., 2008; Blignaut and van Heerden, 2009). Average annual rainfall levels falling well below the global average, increasing urbanisation and the need to provide basic services to all citizens contribute to the water supply challenges (DWA, 2013a). This is being further exacerbated by the wasteful and inefficient management and use of water, particularly in urban environments (*ibid.*).

Current water management interventions focus on expanding the water supply portfolio, largely through the construction of new dams (DWA, 2013a). This approach may have been successful when significant potential remained for the development of new dams; however, most of the economically viable dam sites across the country have now been fully developed and utilised (*ibid.*).

With the realisation that current water management interventions require significant improvement, there has been growing interest in finding more effective and sustainable water management approaches (Brown *et al.*, 2007; Taylor, 2010). A more sustainable approach to urban water management is to move away from conventional, reductionist water management interventions and towards the promotion of a more complex, interdisciplinary approach to water management that better delivers environmental, economic, and social sustainability (Brown *et al.*, 2007). The 'sustainable water management' paradigm incorporates a number of different water management approaches such as: Sustainable Urban Water Management (SUWM), Integrated Urban Water Management (IUWM), Total Water Cycle Management (TWCM), and Water Sensitive Urban Design (WSUD) (Wong and Eadie, 2000; Brown *et al.*, 2007; Maheepala and Blackmore, 2008; Water by Design, 2010). These alternative water management approaches try to improve the efficiency of water-use by considering the entire water cycle as an interconnected and integrated system.

Although the sustainable water management paradigm provides a useful platform for relieving pressures on existing water resources, in South Africa there has been very little practical implementation of these approaches outside of isolated individual projects. This problem is not limited to South Africa; in Australia Brown (2005) noted that although urban water policies are beginning to reflect an understanding of sustainable water management, this rhetoric has not resulted in effective implementation of these approaches. Farrelly and Brown (2008) note that one of the most significant barriers affecting the implementation of sustainable water management interventions is the institutional inertia associated with shifting water management practice from conventional thinking, towards a more integrated, holistic approach. A positive perception of approaches to sustainable water management is required to overcome inertia within institutions dealing with water management. It is important to gather reliable information to illustrate the benefits of implementing more sustainable water-management and so convince the authorities responsible of their viability.

The use of case studies to illustrate the practical, measurable benefit of more sustainable water management is one method that can be used to help promote the development of these approaches in South Africa. However, international case studies, although useful, originate mainly from first world countries such as The United Kingdom, Australia, and Singapore. The climatic, socio-economic, political and institutional contexts of these countries are mostly different to South Africa's and the factors that enable the implementation of these sustainable water management approaches may not apply to the South African context.

In order to develop information relevant to the South African context this dissertation uses a case study to illustrate the potential impact of using more sustainable water management on an existing urban catchment. The case study utilises a selection of modelling tools to quantify the potential potable water savings that could be achieved through the implementation of various sustainable water management interventions. The catchment selected as the case study for the project was the Liesbeek River catchment in Cape Town. This catchment was selected for the convenience of its location and its size – which provided a significantly large sample of 6000 properties whilst still maintaining a manageable project scope – as well as containing a range of residential developments, including lower-middle to very high income households. This dissertation aims to answer the following research question:

To what extent could the water savings achieved through the implementation of sustainable water management interventions be achieved in the Liesbeek River catchment?

In addressing this research question, this dissertation demonstrates that substantial potable water savings can be achieved through a more holistic approach to water management in the Liesbeek River catchment. The scope and limitations of the dissertation include the following:

i) The dissertation primarily focused on the management of water from a quantitative perspective; water quality aspects have not been included in the modelling process.

ii) The Liesbeek River catchment did not include informal settlements which would have added considerable complexities and challenges with regard to water management. It would have been difficult to model the benefits of these interventions in such areas given that the majority of sustainable water management interventions generally apply to the formal urban context.

iii) The modelling process included only those sustainable water management interventions for which there was sufficient data. They included: rainwater harvesting, greywater harvesting, the use of water efficient devices, and the management of on-site leakage.

iv) The economic aspects relating to the installation, operation and maintenance of sustainable water management technologies and interventions were not considered in this research. An economic investigation would require data collection and analysis which could not be completed in the available timeframe.

This report consists of six chapters. Chapter 2 provides a literature review of the water scarcity issues in South Africa, and the potential interventions that can be used reduce urban water use requirements. Chapter 3 provides an introduction to the case study area and a basic summary of the research approach used. A detailed description of the modelling requirements and processes followed is provided in Chapter 4. This is followed by an analysis and discussion of the modelling results in Chapter 5. The sixth and final chapter presents a brief summary of the findings of the dissertation and provides recommendations for further research.

2. Literature review

In order to appreciate the impact that alternative urban water management approaches can have with regard to saving water, it is necessary to understand the causes of the water resources problem in South Africa, and evaluate the options available to reduce the impacts of these issues. This chapter serves to provide a brief overview of South Africa's water resources challenges, and the various sustainable urban water management approaches and interventions available to overcome these challenges.

2.1 Water scarcity in South Africa

Water forms the basis for all ecosystem processes and is part of an unchanging hydrological cycle that is instrumental to sustaining life (Serageldin, 2000). Water provides the basis for social and economic development (Martinez Austria and van Hofwegen, 2006; UN Water, 2009; DWA, 2013a). Despite its renewable nature, the availability of fresh water has become one of the most concerning issues of the new millennium (UNEP, 1999). Issues such as water shortages, loss of biodiversity, and pollution of the hydrosphere are just some of the prominent challenges that require urgent attention (Glasby, 2002).

Water scarcity issues are becoming increasingly important to South Africa's future. The availability of fresh water is to become one of the country's single greatest and most urgent development constraint (Scholes, 2001; Turpie et al., 2008; Blignaut and van Heerden, 2009). South Africa is largely classified as semi-arid country with an average annual rainfall of approximately 450 mm/year; well below the global average of 860 mm/year (DWAF, 2004). The country is ranked the 30th driest in the world, with less water per capita than countries with obvious water scarcity issues such as Botswana and Namibia (DWA, 2013a).

2.2 The urban water cycle

The country's climate is not the only water resources challenge; water scarcity issues are also affected by the way water is collected, distributed, used and disposed of. This is particularly important for the country's urban areas which account for 18% of the total water demand; the highest demand with the exception of the agricultural sector (DWA, 2013a).

Urban development and its associated water related infrastructure significantly alter the natural landscape as well as its hydrological regime (Warburton *et al.*, 2012). Water supply, wastewater and stormwater networks manage the flow of water within the urban built form in an urban water cycle (Wong, 2006a), as illustrated in Figure 2-1. Potable water is imported, sometimes from a different catchment system, and used. The wastewater generated is then removed as efficiently as possible, treated in some cases, and discharged back into the environment (Speers, 2008). Meanwhile, stormwater systems collect and remove runoff from urban areas as quickly and efficiently as possible, discharging it into downstream waterways (Wong and Eadie, 2000). It must be noted that this urban cycle only applies to formal urban development and the situation is frequently significantly different within informal settlements where there is often little in the way of formal infrastructure.

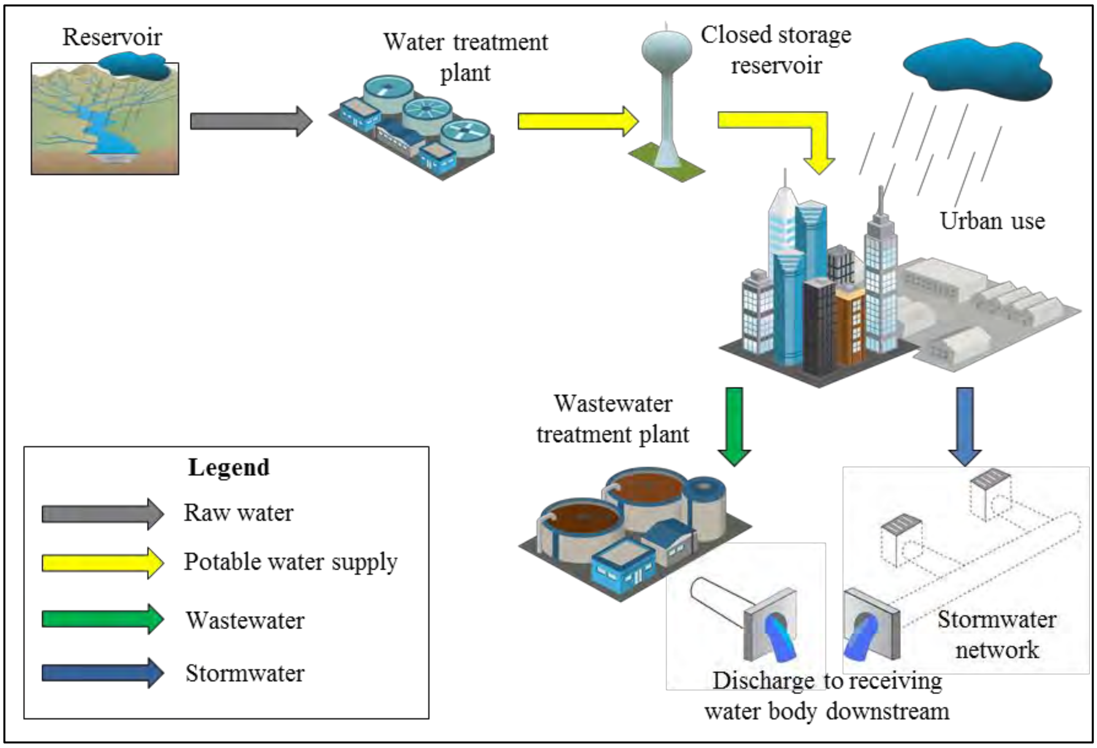

Figure 2-1: The urban water cycle for a typical South African city
(adapted from Wong, 2006a)

2.3 Water resource challenges in South Africa

There are a number of water resource challenges associated with the way that water is managed and used in South Africa. The first challenge relates to the collection and storage of water from natural catchments. South Africa's water management interventions have largely focused on the construction of new dams to satisfy the increasing water demand (DWA, 2013a). This approach may have made sense when significant potential remained for expansion; however most of the economically viable dam sites across the country have been fully developed and utilised (*ibid.*). With more than two thirds of the country's mean annual runoff already collected in dams, there is limited scope for the development of new dam sites.

It is clear from Figure 2-1 that in a conventional urban water management system the movement of water through an urban area is linear in nature; water is extracted from the natural environment and passes through the urban system and is discharged downstream back into the environment. These water infrastructure networks are highly functional and well concealed; potable water is readily available in seemingly endless quantities with its disposal requiring little effort (Dreiseitl, 2001). This pattern of water use is highly convenient for the user, however it presents little incentive or opportunity to reduce wastage through lower water use or re-use of wastewater.

The structure of urban environments plays a significant role in the way water is managed, used and disposed of. Water-related infrastructure forms a vital component of a cities ‘metabolism’ and the structure of these networks determines the way these vital resource-flows move through an urban system. South Africa’s urban areas are characterised by low density urban sprawl (SACN, 2004), interspersed with high density settlements, both formal and informal. Sprawling urban areas require larger infrastructure networks in comparison to more dense settlements. The water services infrastructure has to cover greater distances to reach water users, resulting in increased capital investment and higher operation and maintenance costs. In addition to this, the more extensive networks are less efficient than the smaller, denser networks as there is a greater propensity for water loss through leaks and pipe breakages.

The nature of any urban environment goes beyond its physical form; the social, economic, political, and institutional structure of urban areas play a major role in influencing the way they function. The historical development of South Africa’s cities has produced a multitude of social and economic development challenges that still resonate in South Africa today (Parnell, 2005). Social and economic inequality is prominent in South Africa, which is ranked as one of the most unequal in the world. One of the commonly used inequality indicators is the GINI index; the index measures the variation in distribution of income within an economy from a perfectly equal distribution. An index of 0 represents perfect equality, and an index of 100 represents total inequality (Stats SA, 2008). According to The World Bank (2014) the most recent information for South Africa (2009) shows a GINI index of 63, the highest of all available data.

In addition to the problems associated with social and economic inequality, South Africa is a rapidly urbanising country (DHS, 2010). The World Bank (2014b) estimates that the country is experiencing an urban population growth of 2% per year, with 62% of the country’s population already residing in urban areas (The World Bank, 2014c). The growing urban populations have placed increased pressure on urban infrastructure, particularly within existing townships and informal settlements (SACN, 2011). The result has been the development of severe service delivery backlogs, the eradication of which has become an important objective of Government (DWA, 2013a).

The pollution and degradation of waterways as a result of poor water management practice also has implications for the security of water resources (Haluzan, 2010). Of the 223 river ecosystem types found in South Africa, 60% are threatened – a quarter of which are critically endangered (DWA, 2013a). If South Africa is to maximise the use of the limited available water resources, it is imperative that the negative impacts of water pollution and environmental degradation are reduced. The pollution or degradation of waterways limits the availability of clean water sources suitable for collection and use. The additional costs required to treat polluted water to an acceptable standard often make it economically unfeasible to exploit these water sources (DWA, 2013b), placing additional pressure on existing water sources.

The environmental impacts associated with wastewater vary, depending on the level of treatment before discharge. Even the discharge of low concentrations of chemical constituents in wastewater can lead to significant alterations in the nutrient balances in a water body (Muga and Mihelcic, 2008). The integrity of many of South Africa's waterways has been compromised by the discharge of untreated or poorly treated wastewater. In South Africa many wastewater treatment plants (WWTPs) do not conform to the desired quality standards aspired to by the Department of Water Affairs' Green Drop program (DWA, 2011). Figure 2-2 illustrates the performance of South Africa's 821 WWTPs; nearly 40% of which are in a critical condition. This statistic has major implications for natural waterway health downstream of these sites (DWA, 2011).

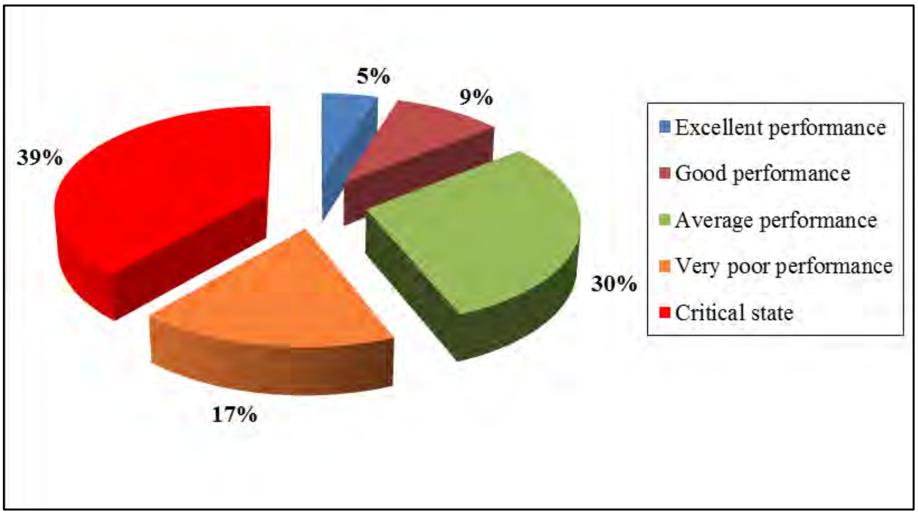

Figure 2-2: Wastewater treatment plant performance in South Africa (DWA, 2011)

The pollution and degradation of waterways is not limited to poor wastewater management; current stormwater management practices also cause significant environmental degradation (Wild *et al.*, 2002). Urban development replaces natural vegetation and soils with impervious surfaces (USGS, 2013). The result is reduced infiltration and evapotranspiration, leading to increased surface runoff and high intensity flows which cause physical damage to downstream waterways (MBRC, 2002). Stormwater also impacts on the quality of downstream waterways caused by the collection of point source pollutants found within the urbanised catchments (Wong and Eadie, 2000; Wild et al., 2002).

2.4 Sustainable water management approaches

With the realisation that current water management interventions are unsustainable in the long term, there has been growing interest in finding more effective, alternative water management approaches (Brown *et al.*, 2007; Taylor, 2010). There are a number of approaches that have aimed to improve the sustainability of water management. Most of these approaches adopt very similar philosophical methods but vary in the scale or extent of their application.

Sustainable Urban Water Management (SUWM) is a term used to describe sustainable water management in its broadest sense (Brown *et al.*, 2007). SUWM views the water cycle as an interconnected and integrated system that needs to be managed in a way that caters for both human and environmental needs. The approach promotes an interdisciplinary approach to water management that takes into account the environmental, social, cultural, political and institutional complexities of the urban context (Brown *et al.*, 2007).

SUWM encompasses many other water management approaches, such as Water Sensitive Urban Design (WSUD), Total Water Cycle Management (TWCM), and Integrated Urban Water Management (IUWM) (*ibid.*).These water management approaches follow a similar philosophical approach to SUWM, but may differ in the scale or scope of their application.

2.4.1 Total Water Cycle Management (TWCM)

Total Water Cycle Management (TWCM) is an approach that promotes sustainable urban water management through holistic management of all components of the water cycle (Queensland Government, 2014). TWCM "*recognises that our water services – including water supply, sewerage and stormwater management – are interrelated and linked to the well-being of our catchments and receiving waterway environments (including surface and sub-surface). It involves making the most appropriate use of water from all stages of the water cycle that best deliver social, ecological and economic sustainability*." (Brown *et al.*, 2007:13). In addition to the interdependence of the different components of the water cycle, TWCM also recognises the importance of integrating infrastructure and land use planning into water management approaches (Water by Design, 2010).

2.4.2 Integrated Urban Water Management (IUWM)

Integrated Urban Water Management (IUWM) is an approach that promotes the coordinated management of water supply, wastewater and stormwater in order to reduce negative environmental impacts and promote their contribution to the economy and society (Maheepala and Blackmore, 2008). Much like TWCM, IUWM aims to consider the entire urban water system through a single coherent framework (Srinivas, 2009; Zhou *et al.*, 2009). The approach recognises the need for holistic management which considers the urban water cycle and its relation to natural ecosystems (Global Water Partnership, 2011).

2.4.3 Water Sensitive Urban Design (WSUD)

Water Sensitive Urban Design (WSUD) is a multi-disciplinary approach to urban water management that aims to consider the environmental, social and economic consequences of water management infrastructure holistically (Wong and Eadie, 2000). The Australian

Government's National Water Initiative defines WSUD as "*the integration of urban planning with the management, protection and conservation of the urban water cycle that ensures that urban water management is sensitive to natural hydrological and ecological processes.*" (COAG, 2004).

Much like TWCM and IUWM, WSUD promotes the holistic management of all components of the urban water system and stresses the importance of an integrated approach to water management (McAlister, 2007). WSUD differs from the other approaches in that it places special emphasis on the integration of water cycle management within the built form through planning and design; the aim being to minimise the impact of the built environment on the sustainability of water resources (QDIP, 2009). The approach aims to consider the environment in conjunction with infrastructure, design and management at the earliest possible stage of the decision making process (McAlister, 2007).

2.4.4 Integrated Water Resources Management (IWRM)

Integrated Water Resources Management (IWRM) is defined as a "*process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*" (Global Water Partnership, 2000:1). IWRM adopts a very similar approach to IUWM The primary difference between the two definitions is their scale of application; IWRM is aimed at a broad, river basin level, while IUWM focuses specifically on urban catchments (Maheepala, 2010).

2.4.5 Water Conservation and Demand Management (WC and DM)

Water Conservation (WC) and Water Demand Management (WDM) are two approaches that are closely linked to improving the sustainability of water resources. Water conservation refers to "*the minimisation of water loss or waste, the care and protection of water resources, and the efficient and effective use of water*" (DWAF, 2004a:4). Water demand management refers to any action or process that promotes the more efficient and sustainable use of water resources (Deverill, 2001; Savenije and Van Der Zaag, 2002). The definition for WDM adopted by the South African Department of Water Affairs expands the scope of the definition to incorporate a range of issues such as social development, social equity, political acceptability and economic efficiency (DWAF, 2004a). The two approaches differ in that WC engages with the broader principles and objectives of sustainable resource use, whereas WDM focuses on the operational interventions available to achieve more sustainable water supply.

2.4.6 Sustainable Drainage Systems (SuDS)

Sustainable drainage systems (SuDS) are an alternative stormwater management approach that use a sequence of management practices and technologies designed to manage surface water in a more sustainable manner (Armitage *et al.*, 2012). Conventional stormwater approaches cause significant environmental degradation, firstly through physical damage as a result of high intensity flows, and secondly by discharging pollutants into receiving waterways (Wild *et al.*, 2002). Conventional stormwater systems also deprive urban environments of the ecological and aesthetic benefits of stormwater (Water by Design, 2009).

Sustainable Drainage Systems (SuDS) strive to address the impacts of urbanisation by aiming to replicate pre-development runoff patterns (Woods-Ballard *et al.*, 2007a). The objectives of SuDS are essentially to minimise the negative impacts of urban development on the quantity and quality of stormwater runoff, whilst simultaneously maximising the ecological and amenity opportunities (Woods-Ballard *et al.*, 2007b). Much like the other sustainable water management approaches, SuDS promotes integrated and holistic water management thinking.

2.4.7 Low Impact Development (LID)

The approach of Low Impact development (LID) is the American equivalent of SuDS. New Zealand also has a SuDS/LID equivalent known as Low Impact Urban Design and Development (LIUDD) which is based on the same approach (van Roon *et al.*, 2006). LID is a design process that aims to recreate predevelopment hydrological regimes in an urban environment. The approach incorporates environmental concerns into urban development and planning processes in order to minimise the negative impact that developments have on the ecology and the environment (Davis, 2005). The principles of LID advocate the source control of stormwater runoff through alternative stormwater management techniques so as to eliminate the need for the conventional centralised stormwater management systems (US EPA, 2000). The LID discourse places significance on the design of urban systems, advocating careful site design in the planning phases to minimise disturbance to the natural environment (Dietz, 2007).

2.5 The objectives of sustainable water management

Although the different sustainable water management approaches may vary slightly in their definition and scope, their objectives are essentially the same. Figure 2-3 illustrates how sustainable water management interventions aim to improve the urban water cycle; the broad objectives of these interventions include:

i) Reducing potable water demands

ii) Increasing the use of alternative water sources such as wastewater, stormwater, and groundwater to help relieve pressures on existing water supply infrastructure

iii) Increasing infiltration to help recharge groundwater stores and attenuate stormwater flows

iv) Reducing wastewater discharge and lowering stormwater flows to help reduce environmental degradation of downstream waterways.

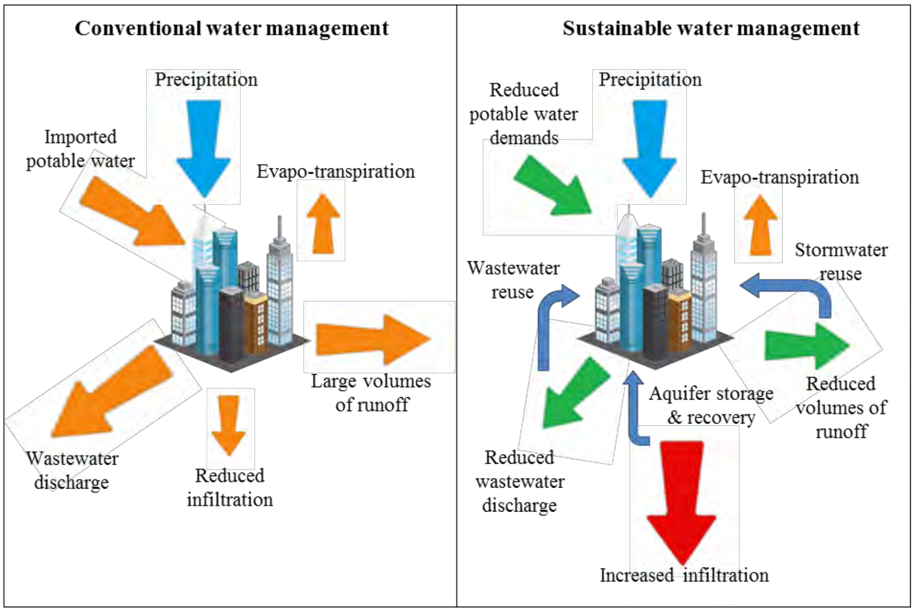

Figure 2-3: Impact of sustainable water supply interventions on the urban water cycle (Adapted from Hoban *et al.*, 2006)

The three streams of the water cycle, namely potable water, stormwater, and wastewater, are intricately linked and require integrated and coordinated management (Wong, 2006b). The ultimate goal for any sustainable water management approach would be the simultaneous and holistic management of all three streams to achieve the desired economic, environmental, and social benefits. Figure 2-4 illustrates some of the linkages between the different streams of the urban water cycle.

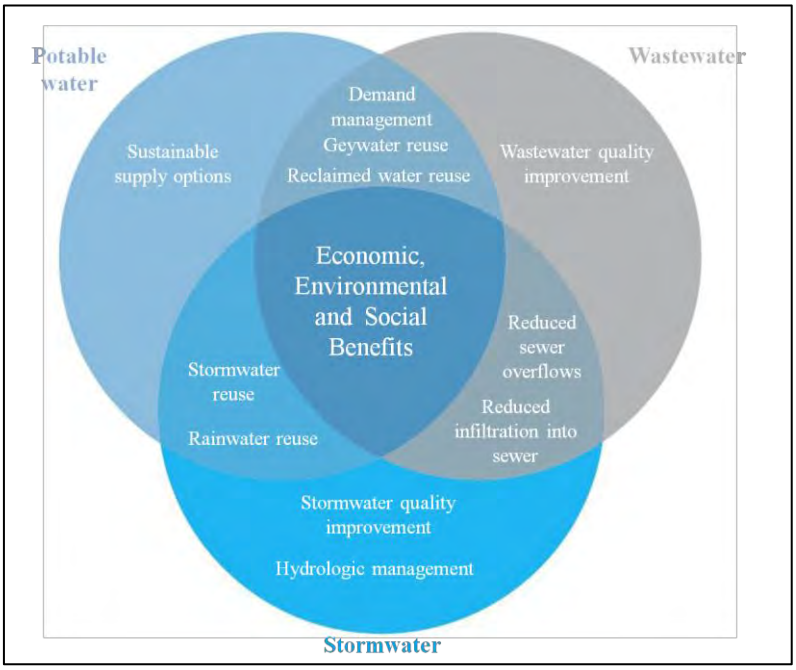

Figure 2-4: Linkages between the three streams of the water cycle (Hoban *et al.*, 2006)

2.6 Interventions to improve potable water savings

Interventions to improve potable water savings aim to save water by: reducing the demand for potable water, reducing water losses as a result of system inefficiencies, and/or diversifying the water supply portfolio to include a range of alternative water supply options. Improvements to the supply of water cover all aspects of water management, from its capture and storage at the catchment level, to its distribution to the user (CoCT, 2007). However, improvements to the demand for water focus on reducing water use at the point of use, either through technological innovation, or induced changes in user behaviour (*ibid.*). The mechanisms include four basic approaches (Flack, 1981; Still *et al.*, 2008):

i) **Structural methods** refer to physical infrastructure interventions that improve the efficiency of the distribution system. Water savings devices which reduce the quantities of water required to perform a specific function are a good example of structural methods. The use of pressure-reducing valves to reduce pressures, and thus leakage rates in the distribution system, is another example of a structural intervention.

ii) **Operational methods** refer to the operational interventions aimed at improving efficiencies within the distribution system. Examples of operational methods include leak detection and repair programs, as well as proactive operation and maintenance of the distribution system.

iii) **Economic methods** include the use of pricing incentives to influence user behaviour.

iv) **Socio-political methods** refer to the education and awareness campaigns as well as laws and regulations that act as 'push factors' which move users towards a water efficient state.

There is a close relationship between the structural, operational, economic, and socio-political aspects of water management. Many water savings interventions encompass more than one of the above listed methods. Pressure reduction, for example, is a structural intervention that relies on the effective operation of the scheme, as well as the careful consideration of its impact on revenue to ensure it achieves its objectives.

In order to gain an appreciation of the numerous strategies used to develop more sustainable water management, The City of Cape Town's '*Long term water conservation and demand management intervention'* (CoCT, 2007) report was used as a guideline. The report summarises the different structural, operational, economic, and socio-political methods under three broad categories:

i) **Reducing non-revenue water** refers to water that does not yield any revenue either as a result of being lost to system leakage, billing or metering errors, or non-payment by users. Interventions focusing on reducing non-revenue water are generally concerned with the effective management of the water distribution network, the billing system used to collect revenue, and the interventions used to reduce the levels of non-payment by users.

ii) **Reducing water wastage at the point of use** applies to interventions that influence user behaviour; regulation, user awareness, education campaigns, informative billing and incentive schemes, all of which play a role in helping to develop a more water-efficient user base.

iii) **Reducing the demand for existing potable water supplies** involves sourcing alternative water supply options – where appropriate – to supplement existing water supplies and create a more diverse and resilient set of water supply interventions. In order to meet growing water supply needs, alternative water supply options and improved water use efficiency will need to undergo significant development to reduce the demand on South Africa's water resources (DWAF, 2004b).

Figure 2-5 illustrates the three broad sustainable water management objectives and the various interventions available under each of these objectives.

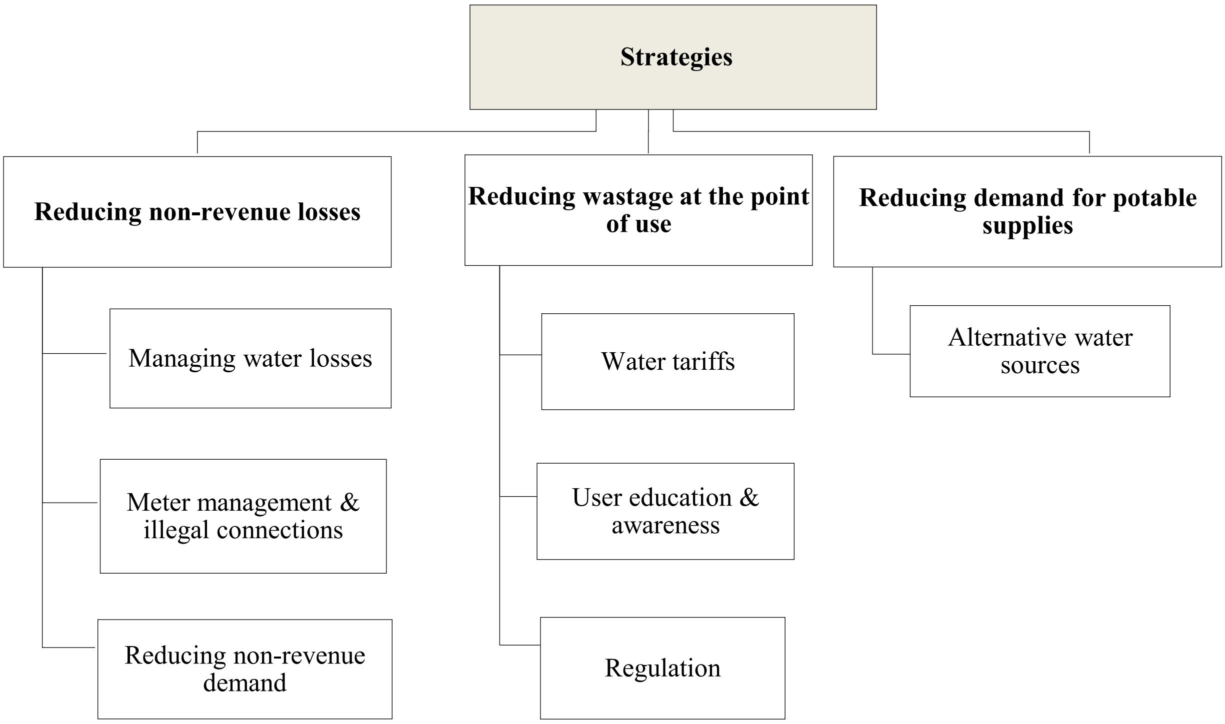

Figure 2-5: Interventions available to improve the efficiency of water use (CoCT, 2007)

2.6.1 Managing water losses

Every water distribution network experiences water losses as a result of leakages and breakages. Reducing the quantity of water lost from the distribution system is an important water savings intervention.

The first step to reducing water losses in a water distribution system is through the effective and proactive operation and maintenance (O&M) of the water related infrastructure.

O&M interventions in South Africa tend to be reactive, where network failures govern maintenance activity (CoCT, 2007). This approach has costly consequences as infrastructure ages and surpasses its design life, leading to poor performance of the system as a whole. This issue is so prominent on a global scale that it is anticipated that the rehabilitation of reticulation systems will present one of the greatest civil engineering challenges for cities around the world (*ibid.*). A comprehensive O&M intervention, which incorporates proactive network rehabilitation, provides a solid basis for tackling the challenge of aging infrastructure helping to significantly reduce reticulation losses and the frequency of pipe bursts. Along with network rehabilitation interventions, preventative maintenance provides an opportunity to prolong the lifespan of existing infrastructure and improve system performance with regard to service delivery and water losses (*ibid.*).

Any effective operation and maintenance plan should incorporate leak control initiatives to reduce system losses. Leakage initiatives can be categorised into two groups: passive leak control and active leak control measures (DWAF, 2004c). Active measures involve leak detection and repair programs as well as pressure-reduction schemes. Passive leak control measures involve the use of asset management plans or infrastructure replacement initiatives to reduce the likelihood of water losses from aging or poorly maintained infrastructure.

Leak management consists of two primary activities, leakage monitoring and leakage control. Leakage monitoring involves the placement of flowrate meters at strategic locations on the reticulation system; each meter measuring flows into a particular sector of the network with a defined boundary, known as a District Meter Area (DMA). The strategic placement of the flowrate meters allows the division the distribution system into a number of DMAs with the least practicable number of meters to continuously monitor night flows and locate pipe bursts and leakages (Pilcher *et al.*, 2007). Leak-monitoring initiatives can be conducted as a routine check of the reticulation system or in response to higher than normal flow measurements from a DMA. The information gathered from the leakage monitoring of the DMAs is then used to prioritise repair initiatives. Repair initiatives focus on identifying the specific location of the leak and performing the necessary repairs. A range of methods are available to pinpoint leakage points, the most common relying on acoustic sensors to pick up on noise generated by leaking pipes.

Pressure management is a useful approach for limiting water losses from leaks or breakages in a distribution system. Water losses as a result of leaks are closely linked with the pressure in the distribution system; higher pressures in a distribution system result in higher leakage flowrates out of pipes (Van Zyl *et al.*, 2003). Water reticulation networks are required to provide water at a specified minimum pressure during periods of high demand. During periods of low demand, particularly at night, the water pressures in the distribution system are significantly higher. These high pressures result in an increased volume of water loss as well as a higher incidence of pipe bursts (Mckenzie *et al.*, 2002). Pressure management aims to lower the water pressures during periods of low demand through the use of pressure reducing valves. The benefits of adopting pressure management can be significant; the Khayelitsha Pressure Management Project in Cape Town provides a useful

South African example of the benefits of adopting pressure management. Initial estimates of water saved by the project amounting to 22 000 Mℓ/yr; nearly 40% of the area's total water demand (Mckenzie *et al.*, 2004).

2.6.2 Meter management and unauthorised connections

It is estimated that up to 6.5% of non-revenue water in South Africa can be attributed to apparent losses (Mckenzie *et al*., 2012). As this suggests, apparent losses refer to water that appears to have been lost through leakage but is actually 'lost' as a result of meter errors, billing errors, and unauthorised use.

No water meter is completely accurate; guidelines provided by the South African Bureau of Standards (SANS 1529) give the expected accuracy of meters over a range of flowrates. Naturally over time the accuracy of a water meter deteriorates, this is particularly acute at low flowrates where meter accuracy is lowest (Van Zyl, 2011). Accurate metering is important and it is essential for effective cost recovery as well as most planning, operation and maintenance functions (CoCT, 2007). Managing apparent losses due to meter under-registration involves the replacement of inaccurate meters through a meter management and replacement program. In large cities, where distribution networks could have hundreds of thousands of water meters, identifying which meters require replacement is challenging. One solution involves the use of GIS-based software to identify anomalies in measured data that could point to faulty metering. Another approach involves the investigation of suspected meter errors that emerge from the billing cycle.

Illegal connections to the water network are another source of non-revenue water (CoCT, 2007). Although there is a need to eliminate these illegal connections, disconnecting users can be a sensitive issue as very often the users are not currently serviced by the municipality (*ibid.*). It is vital that appropriate policies and procedures are formulated to manage the disconnection process.

2.6.3 Reducing non-revenue demand

Non-revenue demand refers to water that is metered and billed but that has not been paid for by the user. Non-revenue demand is most prolific in poor urban areas and water management interventions need to pay particular attention to the need to develop a more effective billing system in these areas (CoCT, 2007). Easy payment schemes or the writing off of arrears would help to create a more functional billing system and improve cost recovery (*ibid.*). Debt management interventions could also help users manage excessive debt such as the reduction of their water demand to an affordable level in order to avoid problems of debt – and thus one excuse for the non-payment of their water bills – in the future.

An alternative approach involves the use of interventions centred on reducing on-site water leakage in low income areas. Initiatives focused around leak detection and repair at a neighbourhood scale could have a significant impact on reducing water losses, as well and lowering individual user bills (CoCT, 2007).

2.6.4 Water tariffs

The long term sustainability of any water supply scheme is governed by its financial viability. Aside from the cost recovery aspects, pricing also plays an important role in reducing water use (Olmstead and Stavins, 2006; Blignaut and van Heerden, 2009; Dziegielewski, 2011). The challenge is to use pricing incentives to ensure adequate cost recovery while still limiting the use of water.

There are several innovative interventions relating to billing and tariff structures that could have an impact on reducing water use. One of the methods of controlling water use utilises pricing incentives in the form of rising block tariffs. Rising block tariffs involve the use of an increasing unit charge for successive blocks of water use. The objective of this approach is to ensure a basic level of water use to all users whilst promoting a stronger incentive for conservation at high levels of discretionary use (Foster, 1998). The block tariff system is a legislative requirement for all water service providers in South Africa (CoCT, 2007). The system provides a useful cross-subsidisation mechanism allowing low income communities access to an affordable water supply while those who use larger quantities of water pay a tariff related to the marginal cost of water (*ibid.*).

Another method of influencing user behaviour through the billing cycle involves the use of informative billing. The approach involves providing the user with information regarding their monthly water use in a simple and effective manner. Information could include a summary of the user's water trends over a given period, how this compares with the municipal average, and possible savings related to reducing water use. Providing this information in a format that is easy to understand initiates a feedback loop to the users thereby improving awareness of their individual water use patterns.

Promoting the conservation of water through the use of incentive schemes is a useful intervention to promote the objectives of improved water use efficiency. Incentives such as fast-tracking building approvals for water efficient or 'green' developments, or environmental recognition schemes could be used to encourage a water-sensitive approach to future developments (CoCT, 2007). Incentives schemes can also be implemented at the level of the individual user; subsidies for the purchase and installation of water efficient appliances, and recognition schemes for water efficient businesses are just two examples of incentives that could be used to promote improved water use efficiency.

2.6.5 User education and awareness campaigns

The attitudes and behaviours of water users have a major impact on the way water is used in urban areas (Hassell and Cary, 2007; Willis *et al.*, 2011). Changing user habits towards more sustainable water use practices is achieved by instilling an awareness, understanding and appreciation of water and the environment (Willis *et al.*, 2011).

User education and awareness campaigns are information campaigns designed to encourage voluntary water conservation either by altering behaviour or promoting the adoption of alternative appliances that are more water-efficient (Syme *et al.*, 2000). There are a number of interventions that can be employed to achieve these objectives; school education programs, websites, advertisements, and press releases are just some of the ways that water service providers can reach users and provide information and tips on how to reduce water use levels and save water (CoCT, 2007). Influencing user behaviour is a continuous process and it is important to invest in these projects over the long term, keeping the campaign interesting and relevant (CoCT, 2007).

2.6.6 Regulation: water conservation policies and by-laws

Policies and by-laws relating to the efficient use of water are critical to establishing standards and norms for the more efficient use of water. Compulsory building standards, minimum efficiency requirements for water using devices, water restrictions and policy development around water wastage and improved water conservation have the potential to significantly reduce the water demands in urban areas. The Water Services Act (No. 108 of 1997) assigns the responsibility of managing water provision to local Government (RSA, 1997). It is therefore at the local Government level that these regulations and policies have to be promulgated to mandate a move towards the more efficient use of water. A number of regulations that relate to the conservation of water in the urban context have been developed in South Africa. For example, The City of Cape Town has also incorporated a comprehensive set of provisions relating to water demand management (CoCT, 2007). The by-laws enforce a range of measures that focus on promoting improved water conservation largely through the use of water efficient devices to minimise the quantity of water required to complete a specific task. 4.3.Table 2-1 highlights some of the policies and by-laws adopted by three of the major metros in South Africa; Cape Town, Johannesburg, and eThekwini. The by-laws adopted by the aforementioned metros are all based on the *Model Water Services by-laws* (DWAF, 2005), which provide recommendations intended to help municipalities with the development of their own by-laws relating to the supply of potable water (Still *et al*., 2008).

Table 2-1 (a): Summary of legislation relating to water conservation

Local Authority	Policy/Bylaw	Status	Overview
City of Cape Town	Water by-law	Adopted (CoCT, 2011a)	The purpose of the by-law is, "*to provide for the control and regulation of water services in the City; and to provide for matters incidental thereto.*"
	Water and Sanitation Asset Management Policy	Adopted (CoCT, 2011b)	The City's asset management policy gives a useful platform for the effective management of the water distribution system which aims to, *"...provide the highest quality water and sanitation services that meet and/or exceed the current and future service requirements and expectations of users by ensuring the implementation and application of sound infrastructure asset management practices and principles within the Department."*

Table 2-2 (b): Summary of legislation relating to water conservation

Local Authority	Policy/Bylaw	Status	Overview
City of Johannesburg	Water Services by-Law	Adopted (CJMM, 2008)	This by-law aims to achieve the same objectives as those adopted by Cape Town. It incorporates provisions for water restrictions as well as measures to prevent water wastage; however the WC and WDM are not included.
eThekwini Municipality	Water supply by-laws	Adopted (eThekwini Municipality, 2011)	As for Johannesburg, these by-laws provide a framework for water restrictions and highlight the importance of minimising water wastage; however WC and WDM measures are not included.
	Water Conservation Guidelines	Adopted (Price, 2009)	The purpose of these guidelines is to "*provide information to users on how to save water by implementing a water use efficiency programme on residential, commercial and institutional properties*."

2.6.7 Alternative water sources

Urban areas could be considered as water supply catchments that have a wide range of water sources available within the urban boundary which can be used to supplement existing potable water supplies (Wong and Brown, 2008). Alternative water sources from within the urban catchment could be a potentially valuable resource and need to be exploited given their proximity to potential users.

One important consideration that relates to the use of alternative water sources is the 'fit-for-purpose' approach (City of Melbourne, 2009). Not all domestic water use requires potable water; toilet flushing and garden irrigation, for example, do not require high quality potable water. The goal of fit-for-purpose is to substitute potable water with alternative sources of water where the use is fit for the required purpose (Landcom, 2004a). Table 2-3 illustrates some fit-for-purpose uses of different alternative water sources which are evaluated in terms of their appropriateness for domestic use (Landcom, 2004b).

If alternative water sources are used within a household on a fit-for-purpose basis approach, some sort of infrastructural investment to facilitate a non-potable water supply is necessary, such as a 'third pipe system' in addition to the two existing – piped water supply and wastewater – systems (BMT WBM, 2009). This 'third pipe system' is known as dual reticulation; the term 'dual' is used to illustrate that there are two different water supply systems. These systems can be developed at a regional scale or at the individual household level and can incorporate any of the above alternative water sources to be used on a fit-for-purpose basis (*ibid.*).

Table 2-3: The compatibility of various water sources with end-uses (Landcom, 2004b)

Source	Garden	Toilet	Kitchen		Laundry		Bathroom	
			Hot	Cold	Hot	Cold	Hot	Cold
Potable water	3	3	2	1	2	1	2	1
Treated blackwater	1	1	4	4	4	4	4	4
Greywater	2	2	4	4	4	4	4	4
Roof stormwater	2	2	1	2	1	1	1	2
Non-roof stormwater	2	2	4	4	4	4	4	4

1: Preferred use; 2: Compatible use; 3: Non-preferred use; 4: Not compatible.

2.6.7.1 Rainwater and stormwater harvesting

Stormwater and rainwater have the potential to be a valuable water resource and should play a significant role in urban water management interventions (Revitt, 2008). Based on a fit-for-purpose approach and the quality of the water collected, the water could be used for garden irrigation, toilet flushing, and washing machines (City of Melbourne, 2009).

There is a distinction to be made between rainwater harvesting and stormwater harvesting. Rainwater harvesting usually refers to the collection of precipitation from building roofs. Stormwater harvesting refers to the capture of runoff on a larger scale with runoff being collected from surfaces such as roads and car parks. Stormwater harvesting requires larger infrastructure than rainwater harvesting in order to deal with the greater volumes of runoff. Furthermore, rainwater from roofs is usually considerably less polluted than that collected from the stormwater harvesting schemes.

Rainwater runoff from building rooftops constitutes a large proportion of total runoff from urban areas, and capturing this water will reduce urban runoff volumes as well as the frequency of flood occurrences downstream (McAlister, 2007). Additional environmental benefits include a reduction in the pollutant levels entering receiving waterways. The tanks can be fitted with a bypass device to prevent pollutants carried in the initial run off, or 'first flush', from entering the tank.

Stormwater harvesting of surface runoff can be collected in surface storage ponds and reservoirs, or alternatively it can be stored underground in an aquifer. Surface runoff requires treatment to remove pollutants carried in the stormwater, however the level of treatment is far less intensive than other sources, particularly that of wastewater (City of Melbourne, 2009). When designed using the principles of SuDS, stormwater harvesting systems incorporate treatment mechanisms within the infrastructure that collects and stores the harvested stormwater. These treatment mechanisms form a system of unit processes through which stormwater passes, with each step performing a particular role and enhancing the system as a whole (Armitage *et al.*, 2012). This set of unit processes is known as a treatment train; the approach is illustrated in Figure 2-6. There are four key intervention points in the treatment train: runoff pollution prevention and management – or 'good housekeeping' – , source controls, site local controls, and regional controls (Wilson *et al.*, 2004). The first step in the treatment train is to limit the level of contact between stormwater and potential pollutants. This is a proactive step to improving stormwater quality by addressing the causes of the problem rather than attempting to manage the impacts of stormwater pollution. The treatment-train approach attempts to manage stormwater as closely as possible to the source; water is only transferred if it cannot be adequately dealt with at that level (Woods-Ballard *et al.*, 2007a).

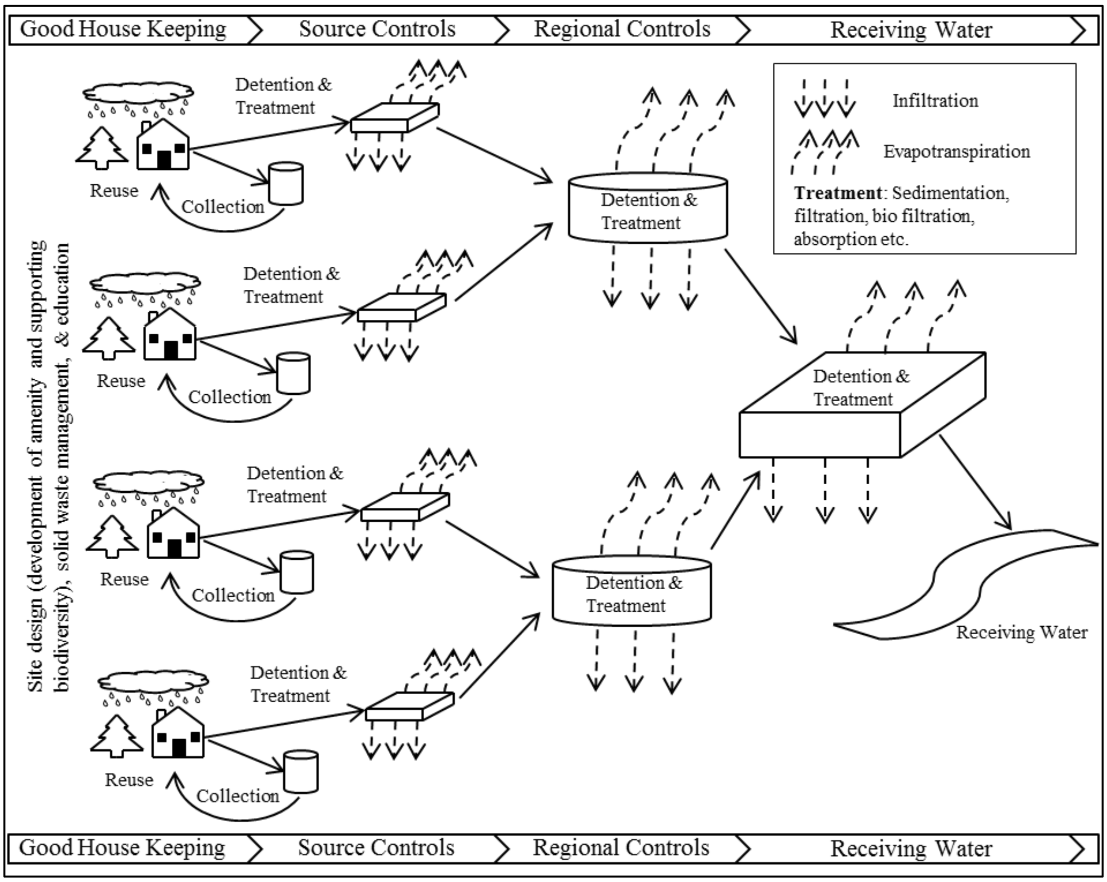

Figure 2-6: The SuDS treatment train (Armitage *et al.*, 2012)

2.6.7.2 Wastewater and greywater re-use

The use of wastewater as an alternative water supply option holds significant potential. Wastewater can be split into two broad components; blackwater and greywater. Blackwater refers to toilet water which has high concentrations of faecal matter and urine, and as a result is highly contaminated and difficult to treat for re-use. Greywater refers to the wastewater generated from all other domestic processes; greywater can be split again into dark-greywater and light-greywater. Dark-greywater refers to greywater from kitchen sinks or dishwashers which can have high concentrations of organic materials. Light-greywater refers to all other greywater sources such as baths, bath basins, showers, and washing machines which typically contain lower organic content.

Wastewater re-use has the potential to significantly reduce potable water demand as well as the quantities of wastewater discharged to treatment works (Landcom, 2004b). The level of treatment required before re-use is dependent on the quality of the wastewater recovered, as well as its intended end-use. Both greywater and blackwater require treatment before use and care should be taken to limit human contact (Eriksson *et al.*, 2002). Blackwater contains a significantly higher organic content to greywater and requires intensive treatment before re-use (City of Melbourne, 2009). Given the higher concentrations of health related micro-organisms in blackwater, for small scale schemes developed at the individual property level, the re-use of wastewater is generally limited to greywater (Rodda *et al.*, 2010).

From a fit-for-purpose perspective, greywater is most appropriate for activities such as toilet flushing and garden watering where human contact is limited. Despite the fact that toilets can use recycled greywater, there is a potential health risk during flushing where water droplets can be dispersed into the air. In addition to this, discolouration, odour, and negative perceptions about wastewater also present barriers to the use of greywater as an alternative water resource (Ilemobade *et al.*, 2012).

There are also challenges relating to the technical aspects of managing greywater systems. Unless it is to be used immediately for irrigation, the greywater will need to undergo some form of treatment and subsequently storage. Wastewater undergoes changes in quality during storage usually as a result of microbial growth within the storage tanks (Dixon *et al.*, 1999). The treatment mechanisms add a level of complexity to the harvesting process and the management of these systems require the proactive participation of users (Landcom, 2004b).

The complexity of installing and managing greywater systems presents a challenge for its broad scale adoption within an urban catchment. Greywater harvesting is a heavily decentralised approach, and the responsibilty of managing these systems falls on individual property owners. Proactive participation and involvement from the community is essential for the effective implementation of greywater systems (Landcom, 2004b).

2.6.7.3 Managed Aquifer Recharge

Managed Aquifer Recharge (MAR) is the process of introducing treated, untreated, or reclaimed water to recharge underground aquifers through pumping, gravity feed, or natural infiltration; the water can then be extracted from the aquifer for re-use at a later stage (Sheng, 2005). MAR can also provide a useful water treatment function and there is significant potential for the indirect re-use of stormwater or reclaimed water (Dillon, 2005).

One of the critical concerns associated with MAR is to ensure that the water used to recharge the aquifer does not contribute to the deterioration of ground water quality or aquifer properties (McAlister, 2007). The quality of the water prior to injection or infiltration needs to be carefully monitored and, if necessary, controlled to ensure that the long-term health of the aquifer water is not compromised. Water quality could be improved by incorporating pre-treatment mechanisms such as constructed wetlands, detention ponds, or storage tanks, all or part of which remove pollutants and temporarily store water (BMT WBM, 2009).

The feasibility of MAR schemes is dependent on a number of factors, including the hydrological and geological characteristics, the scale required and the intended use of the groundwater. MAR has great potential as a low cost alternative to surface storage systems and presents a useful solution to the storage of large volumes of stormwater runoff from urban areas.

2.7 A case study of Singapore

Most examples of the implementation of sustainable water management interventions in South Africa relate to individual, stand-alone projects. There has been very little in the way of broad scale practical implementation of sustainable water management interventions. There are numerous reasons for this, one of which can be attributed to the lack of practical examples that demonstrate the relevance of these approaches, making it difficult for water managers to justify taking the risk of using these ‘locally untested’ technologies. There are, however, regions around the world that are making significant progress in implementing sustainable water management approaches; one such example is Singapore. The city state has made significant progress with regard to exploiting alternative water sources and places heavy emphasis on the sustainable water management. Singapore’s experience provides valuable insight into the development of more sustainable water management approaches, particularly for water-stressed countries experiencing threats to the quantity and quality of their water supplies (World Bank, 2006).

Singapore has a land area of approximately 680 km^2. The country is considered to be water stressed, not due to lack of rainfall, but the limited land area on which rainfall can be collected and stored (Tortajada, 2006). In 1965, when Singapore became an independent state, its water supply was predominantly sourced from neighbouring Malaysia. Recognising that the reliance on a neighbouring state to ensure a stable water supply was not a sustainable option, Singapore began to look at alternative water supply options (Luan, 2010). The selected options known as the ‘four national taps’ include: imported water from Malaysia, water collected from local catchments, recycled water from the NEWater recycling scheme, and desalinated water (Khoo, 2009).

Approximately half of Singapore’s total land area is currently used as a catchment for stormwater (Khoo, 2009). Rainwater is collected by a network of drains, channels, rivers and stormwater collection ponds which feed into Singapore’s reservoirs for storage (PUB, 2011a). In addition to this, Singapore’s effluent recycling scheme uses treated effluent to produce potable water or NEWater (Luan, 2010) which makes up 30% of the state’s total water demand (PUB, 2011b).

The success of Singapore's water management initiatives can largely be attributed to strong governance (Luan, 2010). Water management interventions have not been limited to technical interventions – research and technology, legislation, enforcement, water pricing, and public education have also played a significant role in achieving the desired results (*ibid.*). Singapore's communities have a high level of awareness regarding water scarcity and the importance of a diverse suit of water supply options to ensure resilience (Wong and Brown, 2008). The simultaneous emphasis on supply and demand management, stormwater and wastewater management techniques, institutional effectiveness and strong political will are also significant drivers to water management in the region (Tortajada, 2006).

Although there is still room for improvement with regard to achieving a totally sustainable water supply, Singapore has made significant steps toward water sensitive development. The Public Utilities Board was recognised for its achievements when it received the Stockholm Industry Water Award in 2007 (Wong and Brown, 2008).

2.8 Modelling the benefits of sustainable water management

Examining the benefits of sustainable water management interventions through international case studies, although useful, is context specific and the findings cannot always be applied to South African conditions. The use of modelling tools is one approach that can be used to develop information to illustrate the benefits of sustainable water management interventions in South Africa.

The flow of water through an urban catchment is highly complex, one of the best ways to describe these flows is through the development of a water balance (Mitchell *et al.*, 2001). A water balance is essentially a process that applies the principle of mass conservation to water (Grimmond *et al.*, 1986). This can be done through a simple assessment of inputs and outputs, or a more detailed process that involves modelling the complex movements of water through a catchment (Mitchell *et al.*, 2001).

The modelling of urban water flow is not a new approach, and models have been used for several decades (Zoppou, 2001; Mitchell and Diaper, 2006). The software tools model the hydrological aspects (such as rainfall, infiltration, overland flows and evaporation), as well as the hydraulic aspects (pipe and channel flow) of urban environments (Siriwardene and Perera, 2006). Although numerous models are available, not many can simulate both water quantity and quality of an integrated urban water management system (Fagan *et al.*, 2010). Few models have focused on tracking water borne contaminants, and even fewer can simulate the effects of alternative water sources use on the urban water cycle and contaminant flows (Mitchell and Diaper, 2006).

Despite the limitations of computer models, these models allow one to simulate and evaluate the environmental impact of various design and operational scenarios without the need for costly and time-consuming physical testing (Butler and Schutze, 2005). However, computer modelling requires experience as well as input data that is appropriate and relevant

(Siriwardene and Perera, 2006). The models require calibration and verification of the chosen parameters in order to produce useful results (Butler and Schutze, 2005).

A wide range of models are available on the market; the purpose and functions of which vary significantly. Some models simulate specific characteristics of urban drainage such as water quantity and quality, while others are used as decision support tools to aid in the planning process. The remainder of this chapter will briefly discuss some of the prominent models that could potentially be used to model a water balance for an urban catchment.

2.8.1 WEAP

The Water Evaluation and Planning system (*WEAP*) was developed by the Stockholm Environment Institute. It is a GIS based tool that adopts a water balance approach, allocating water based on user-defined water use requirements and supply preferences *(Rodrigo et al.*, 2012). The program has a wide range of capabilities including: demand analyses, water allocation priorities, water conservation, groundwater and stream-flow simulations, reservoir operations, pollution tracking, ecosystem requirements, and project benefit-cost analyses (Sieber and Purkey, 2011). WEAP is also capable of incorporating a range of sustainable water supply options including water conservation, expanded recycling and re-use, greywater and rainwater harvesting, and groundwater recharge (Rodrigo *et al.*, 2012).

WEAP is a useful tool that can assist planners in assessing the benefits of a total water management approach, and is freely available for use. Rodrigo *et al.* (2012) illustrated the applicability of the program by modelling the city of Los Angeles "*to communicate the benefits of TWM to water management decision-makers, municipalities, and policy decision-makers and aid in the development and adoption of management techniques to improve urban water systems*." (Rodrigo *et al.*, 2012:1). In doing so, Rodrigo *et al.* were able to demonstrate some of the system wide benefits of adopting an integrated total water management approach.

2.8.2 UVQ

UVQ (Urban Volume and Quality) is a water balance analysis tool developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia to simulate the movements of water through urban areas, highlighting the interconnectedness of the three streams of the water cycle (Mitchell and Diaper, 2005). *UVQ* is capable of assessing the impacts of different urban development scenarios on the urban water cycle, as well as the implementation of a range of alternative water supply options (Mitchell and Diaper, 2006).

UVQ integrates the entire urban water cycle into a single framework and incorporates a number of land use types including: residential, commercial, and light industry (Mitchell and Diaper, 2006). The model operates three spatial scales: the unit block or individual property, neighbourhood or cluster, and catchment (Mitchell *et al.*, 2001). The software is able to incorporate a range of alternative options for water supply, stormwater, and wastewater systems at the different scales. These options include, but are not limited to: water usage efficiency, rainwater harvesting, on-site infiltration, greywater harvesting, on-site wastewater collection, treatment and re-use, aquifer storage and recovery, and stormwater harvesting (Mitchell and Diaper, 2005).

UVQ is simple to use and is a useful tool for the development of a holistic water balance for an urban catchment. The model's weaknesses include its strong focus on domestic water use with a limited availability of water management options (Last, 2010). Although there are more advanced models available, *UVQ* is freely available and provides a useful assessment tool for the impacts of alternative water management interventions on an urban catchment.

2.8.3 Urban Developer

Urban Developer is a model developed by the eWater Co-operative Research Centre. The software uses a water balance approach to simulate the movement of water within an urban catchment (Hardy and McArthur, 2011). The model incorporates water supply, stormwater and wastewater systems and enables the simulation of these three streams at a range of spatial and temporal scales within the same framework (Snowdon *et al.*, 2011). *Urban Developer* incorporates a range of different land use scenarios and is able to simulate a variety of sustainable water supply interventions including: water demand management, rainwater and stormwater harvesting, greywater re-use, and waste water reclamation (Hardy and McArthur, 2011). The model is capable of running a number of different urban development scenarios to assess and compare the impacts of different water management approaches (Snowdon *et al.*, 2011).

Urban Developer is a useful tool for supporting a range of planning, management, and design processes within urban catchments (Hardy and McArthur, 2011). The software builds on the UVQ model, offering a more sophisticated demand modelling approach (Last, 2010). The software is commercially available for use and is updated on a regular basis to improve its capabilities.

2.9 Literature review conclusion

The literature review has highlighted the water scarcity issues in South Africa: climatic limitations, pressing development concerns and poor urban water management practice all contribute to the water resources challenges. With the realisation that current water management interventions require significant improvement, there has been growing interest in finding more effective and sustainable water management approaches. These approaches promote sustainable water management through holistic management of all components of the water cycle.

Despite the benefits of its application, there has been very little in the way of broad scale practical implementation of sustainable water management interventions in South Africa. Although useful, international case studies cannot always be applied to the South

African context. The use of modelling tools is an effective approach for developing information to illustrate the benefits of sustainable water management interventions in South Africa. Computer models allow for the simulation and evaluation of the environmental impact of various design and operational models without the need for costly and time-consuming physical testing.

One of the most useful modelling approaches is the development of a water balance which performs an analysis of the inputs and outputs of water for a given catchment. There are a number of models that could be used to develop a water balance model for an urban catchment. The following chapter provides a brief overview of the selection of an appropriate case study catchment, as well as the process followed to select an appropriate water balance model for the selected catchment. The selected model was then expanded to include a number of sustainable water management interventions in order to get an indication of the benefits of adopting these approaches in South Africa.

3. Method

This chapter provides a brief overview of the catchment selected for the case study, a basic outline of the modelling process followed, and the outputs that were produced.

3.1 The Liesbeek River catchment – a case study

The catchment selected as the case study for the project was the Liesbeek River catchment in Cape Town. This catchment was selected for the convenience of its location, its size – it provided a sample of nearly 6000 properties whilst still maintaining a manageable project scope – as well as its diversity of residential development catering for lower-middle to very high income households. In addition to this, the catchment has a number of interesting potential alternative water resources options that could be used to augment the existing water supply portfolio. The catchment's highest measured annual rainfall of 1500 mm/yr is more than three times the national average, presenting significant potential for the exploitation of rainwater and stormwater harvesting. A number of springs are found in the catchment, the most notable being the Albion Spring which provides water to the South African Breweries site in Newlands. This spring is used to augment the City's potable water supply and provides 4 Mℓ/day (CoCT, 2013). The catchment also has additional groundwater sources in the form of the Newlands aquifer; although not exploited by the City, the private extraction of groundwater from boreholes does occur (CoCT, 2013).

Steeped in history, the Liesbeek River is the oldest urbanised river in South Africa (Evans, 2007), it was discovered and named by Jan Van Riebeeck on the 28th April 1652 (Murray, 2003). The river rises from a number of small streams that drain the eastern slopes of Table Mountain and is 9 km long from source to mouth (Brown and Magoba, 2009).

According Statistics South Africa (2011), the Liesbeek River catchment had a total population of approximately 31,000 people in 2011. The catchment has been heavily impacted by urbanisation, and incorporates the suburbs of Bishopscourt, Claremont, Newlands, Rondebosch, Rosebank, Mowbray, and Observatory. The catchment covers an area of approximately 2700 ha, making up approximately 1% of the Cape Town metropolitan land area. The Table Mountain National Park makes up a large proportion of the upper catchment. Figure 3-1 illustrates the catchment boundaries; the blue line represents the course of the main Liesbeek tributary through the catchment.

The Liesbeek River catchment incorporates a wide range of land uses from residential suburbs to high density flats and commercial developments. Flooding related issues have led to the canalisation of much of the river (Murray, 2003). Notable landmarks in the catchment include the Kirstenbosch Botanical Gardens, Newlands Rugby and Cricket Stadiums, the University of Cape Town, and Rhodes Memorial.

An assessment of the land use distribution throughout the catchment gives a very good insight into the structure of the catchment. Figure 3-2 illustrates the distribution of land use categories within the Liesbeek River catchment. The southern end of the catchment consists almost entirely of standalone residential suburban households. The land use scenario is significantly more complex in the central and northern parts of the catchment. The standalone residential properties are heavily interspersed with blocks of flats, educational institutions and community facilities. There is also a significant commercial presence, particularly along Main road, Lower Main road and throughout Observatory.

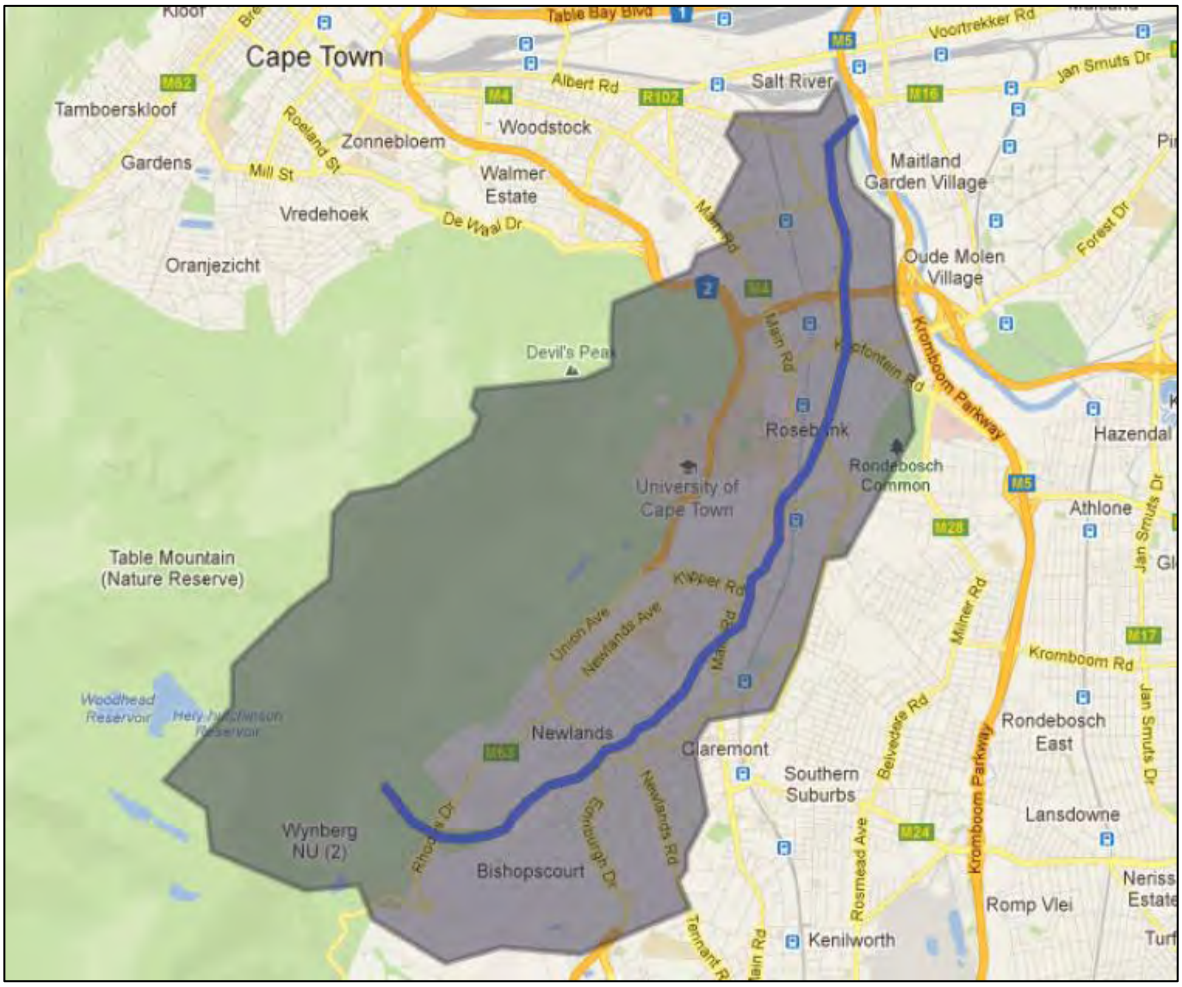

Figure 3-1: A map of the Liesbeek River catchment (Google, 2013)

Figure 3-3 illustrates the land use breakdown by property in the Liesbeek River catchment. The majority of the catchment is made up of standalone residential households; nearly 90% of all properties in the catchment fell under this land use category. Residential flats and commercial properties make up most of the remaining properties at 6% and 5% respectively; hospitals and educational facilities make up less than 1% of the land use breakdown in the catchment. Although the Newlands Brewery may be classified as an industrial site, the water used in the production of beverages originate from the Albion spring and thus – from a municipal supply perspective – the site was assumed to be a commercial development for the purposes of this investigation – thereby obviating the need to consider industrial land use categories.

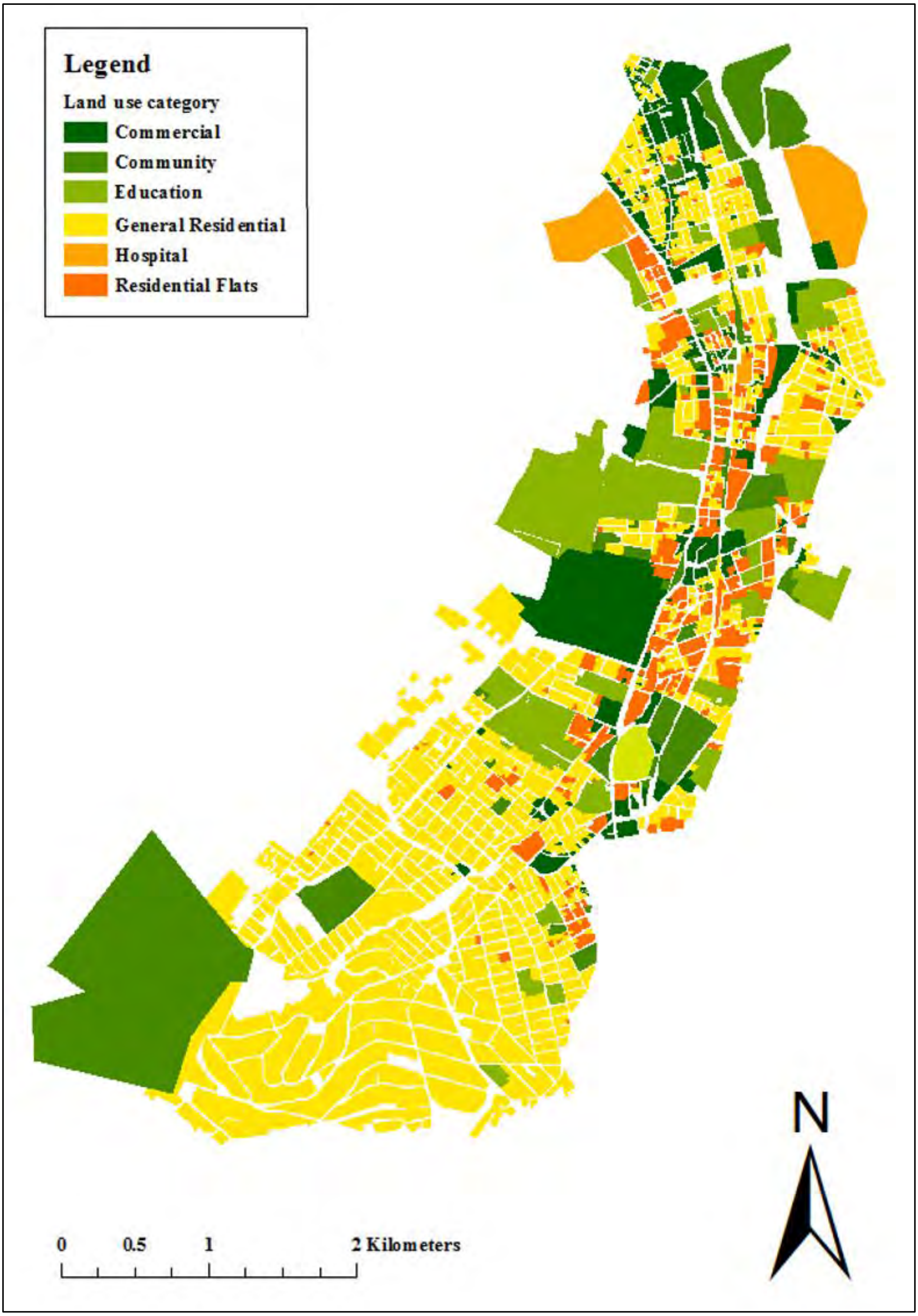

Figure 3-2: The breakdown of land use categories in the Liesbeek River catchment

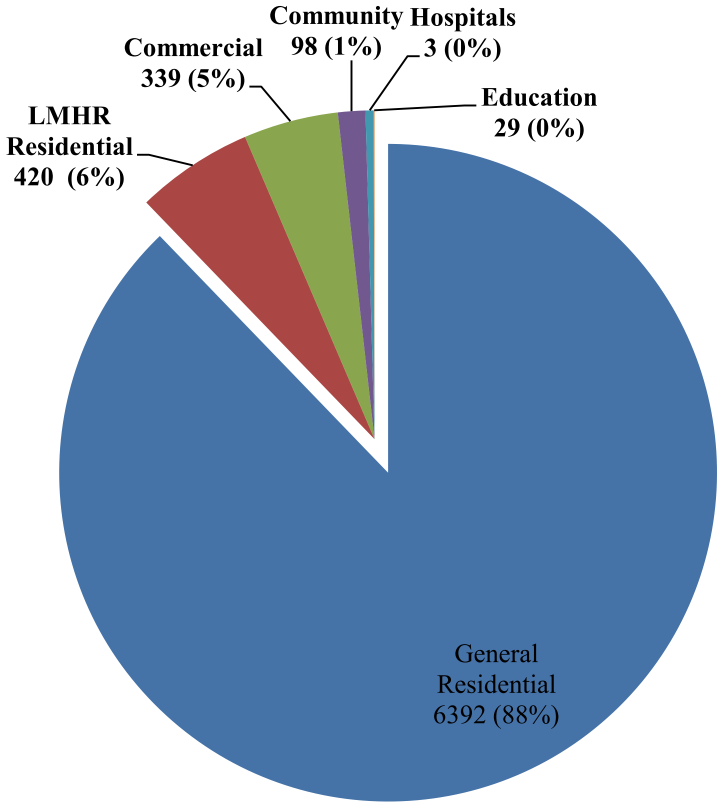

Figure 3-3: The breakdown of the land uses found in the Liesbeek River catchment

3.2 The modelling process

Quantifying the potential water savings that could be achieved through the implementation of more sustainable water management interventions was achieved through water balance modelling. The modelling can either be done through a simple assessment of inputs and outputs, or through a more detailed process that involves modelling the complex movements of water through a catchment (Mitchell *et al.*, 2001).

In the case of the Liesbeek River catchment, a detailed water balance model was used to gain insight into the existing water-use patterns at the household level; from which the impact of the implementation of various water savings interventions could be deduced. These interventions included: the implementation of water efficient appliances, leak control, rainwater harvesting and greywater re-use. The level of detail required for the water balance model was governed by the input requirements needed to estimate the potential impacts of implementation more sustainable water management interventions.

The patterns and rates of water use depend on numerous factors including: land use, income level, property size, extent of outdoor irrigation, and geographical location. The modelling process needed to capture the impact of as many of these variables as possible to simulate, as closely as possible, the actual water use scenario.

The literature review identified a number of models capable of computing urban water balances. Despite the many advantages of using pre-developed models to develop a water balance for the Liesbeek, they all had one significant drawback. In order to calculate the end-use breakdown of water use for the entire catchment, the model needed to take into account the unique characteristics of each property allowing for the calibration of the water demand calculation inputs with the metered data for each property. The Liesbeek River catchment had over 6000 registered properties, each with a unique water use profile. Calibrating the inputs for all of the properties in the catchment using a pre-developed model would have required adjustment on a property by property basis. It was for this reason that a new water balance model – designed to accommodate the complexities of calibrating the calculated results against measured data for every property in the catchment – was developed. The following list describes the key steps in the modelling process.

i) Collection of all relevant data for the catchment. Information regarding: land use, land cover types and areas, building heights, household sizes, rainfall data, evaporation data, and measured data relating to each individual property.

ii) Development of a water balance model to provide information on both domestic and non-domestic end-use water demands.

iii) Calibration of the water balance model against measured data on a plot by plot basis to ensure the validity of its inputs.

iv) Development of four different water savings models: on-site leakage, water efficient devices, rainwater harvesting, and greywater re-use.

v) Development of a new composite water balance that incorporates the different water savings models.

The water balance model that was developed for the Liesbeek River catchment primarily used GIS software in conjunction with Microsoft Excel to capture the water use patterns in the catchment on a property by property basis. Chapter 4 provides a detailed description of the modelling process which has been outlined in the list above.

4. Model design

This chapter provides a detailed description of the modelling processes used to develop both the water balance, as well as the models for the selected water savings strategies. The design of the modelling processes for the Liesbeek River catchment was completed in five incremental phases.

i) Data collection

ii) Development of a water balance model

iii) Calibrating the water balance model against measured data

iv) Identifying the water savings interventions that could be modelled

v) Modelling the selected water savings interventions.

4.1 Data collection

The collection of data used for the modelling process was captured through the use of Geographic Information Systems (GIS) software. The different components of the modelling process required a range of data which included:

- Land cover types and areas
- Building heights
- Land use types
- Household occupancy estimates
- Rainfall and Evaporation distribution
- Metered water use.

4.1.1 Land cover types and areas

Information on land cover types, building roof areas, and building heights was captured through the use of aerial photographs as land cover layers in GIS. The different land cover types were captured in GIS by manually tracing their outlines from aerial photographs to create a mosaic covering the entire catchment. The photographs were geometrically corrected to preserve the spatial scale of the images, allowing the areas of different land cover types to be calculated. This information was critical for estimating both the indoor and outdoor water use for all properties in the catchment.

Figure 4-1 illustrates an example of some of the different land cover types as captured using GIS; different colours represent different land cover types – in this case purple being roof areas, brown being impervious surfaces, and green being pervious surfaces.

Figure 4-1: An example of land cover types completed using GIS software

Distinguishing between pervious and impervious surfaces helped to establish the water demand of different vegetation types, as well as information for rainwater and stormwater runoff modelling purposes. The land cover types captured into GIS included:

- Building roof areas
- Impervious surfaces
- Pervious surfaces
- Roads
- Landscaped gardens
- Pervious recreational areas (e.g. sports fields)
- Swimming pools.

4.1.2 Building Heights

The modelling requirements for the different land use categories illustrated the need to differentiate between individual buildings such as stand-alone houses from larger structures such as blocks of flats. The calculation of building heights was captured through the use of topographical survey data – obtained from the City of Cape Town – known as Light Detection and Ranging (LIDAR); a form of aerial photogrammetry that uses laser mapping to create high resolution maps. The data which had data measurements at a spacing of roughly one meter apart was imported into GIS to create a three dimensional layer for the entire catchment. This data was then overlapped with the building roof outlines to generate an estimation of the average building height – and hence the number of storeys. The use of average building heights was particularly effective for the Liesbeek River catchment as the inaccuracies associated with incorrect readings as a result of interference from tree tops – which was significant in the residential areas of the catchment – could be mitigated.

The building heights were then used to calculate the total floor area which in turn, was used to estimate the volumes of water generated by multi-storey buildings. Figure 4-2 illustrates an example of a building roof that has been overlapped with LIDAR topographical data. The white crosses represent a height measurement, which were measured on a grid spacing of one meter. Approximating the building heights involved taking the average height reading across the entire rooftop outline.

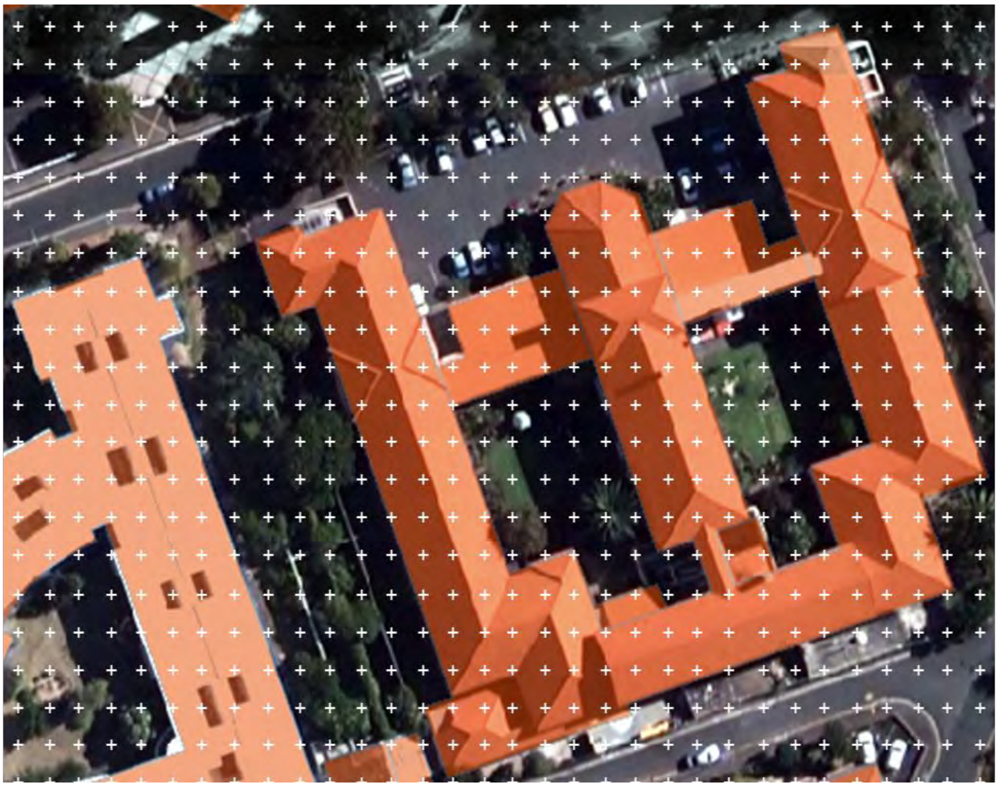

Figure 4-2: An illustration of a roof overlapped with LIDAR topographical data

Equations 4-1 and 4-2 represent the formulas used to estimate the number of floors for each building. The calculation of the average floor height for the multi-storey buildings in the catchment was based on the South African Building Regulations (SANS, 1990), which specify both the maximum and minimum height for a single storey of a building. The minimum height of a storey for any building has been specified as 2.8 m, and the maximum height between 3 m and 4 m depending on the building wall thickness. In order to get a representative value of the height of each storey for the buildings in the catchment, the specified maximum and minimum heights were averaged to give a height of 3.4 m/storey.

The calculation of the building heights also needed to take into account the fact that the average roof height for a pitched roof fell half way between the ridge and the ceiling. Calculating this height was achieved through the use of the Building Regulations (SANS, 1990) which provided a range of allowable roof slopes and the truss spans for different roof cover types and truss member sizes. The range of acceptable roof slopes fell between 15° and 35° while the allowable truss spans ranged from 3 m to 10 m; using the average of these two ranges the vertical height between the ridge and ceiling was approximately 3m, making the average height of a pitched roof 1.5 m.

Pitched Roofs: $$o.\ o \quad oor \quad \frac{e \quad e \quad red\ hei\ \ ht - \ ver \quad e\ pit\ \ hed\ roo\ \ hei\ \ ht}{ver \quad e \quad oor\ hei\ \ ht} \tag{4-1}$$

Flat Roofs: $$o.\ o \quad oor \quad \frac{e \quad e \quad red\ hei\ \ ht}{ver \quad e \quad oor\ hei\ \ ht} \tag{4-2}$$

The method used to calculate building heights was effective in most cases, however large multi-storey buildings – over six floors – had very different structural characteristics and often the floor heights would vary significantly from building to building. In order to make sure that the calculations accurately estimated the number storeys, 13 buildings were manually checked using Google Street View. A manual check of all multi-storey buildings was not possible given the large number of properties in the catchment between two and five storeys.

4.1.3 Land use categorisation

The methods used to the estimate water use varied for domestic and non-domestic land use categories. The calculation of domestic water demand included a detailed analysis of the different end-uses of water in a household, while non-domestic water demand used estimated rates of water use for different land use categories. The City of Cape Town's zoning scheme regulations defined a particular land use category for all of the properties falling within its boundaries. These regulations specify the purposes for which every property can be used, and the manner in which it may be developed (CoCT, 2012a). Table 4-1 highlights the various land uses found in the Liesbeek River catchment and their associated descriptions.

Although the land use zoning scheme shown in Table 4-1 was a useful approach for identifying general land use types; many of the land use functions overlapped, with similar land use functions applying to several different land use types. In order to develop a more comprehensive assessment of land use – and thus water use – in the catchment, each property in the catchment was assigned a water use category based on those used by the *Guidelines for human settlement planning and design* (CSIR, 2000). The water use categories selected included:

- **Domestic water use,** which consisted of all water used for household use.
- **Commercial and Industrial water use**, which consisted of all water supplied to commercial and industrial facilities for the production of goods and services.
- **Institutional water use**, which consisted of water used by community, welfare, recreational facilities, and religious institutions.
- **Education**, which referred to water used by educational institutions.
- **Hospitals**, which consisted of all water used for healthcare purposes.

Table 4-1: Land uses in the Liesbeek River catchment (CoCT, 2012a)

Classification Code	Classification Description	Land use function
SR1	Single Residential Zone 1	Predominantly single family dwellings in low to medium density neighbourhoods.
GR1	General Residential Zone 1	Medium density group housing as well as low rise flats.
GR2 and GR4	General Residential Zones 2 and 4	Higher density low rise (GR2) and medium rise flats (GR4).
RU	Rural	Small rural properties or residences for those seeking a country lifestyle.
CO1	Community Zone 1 (Local)	Local educational, worship and health needs.
CO2	Community Zone 2 (Regional)	Full range of institutional and community needs including health, welfare, education, and worship.
LB2	Local Business Zone 2	Low intensity commercial and mixed use development.
GB1 and GB5	General Business Zones 1 and 5	General business activity and mixed use development of a medium to high intensity.
MU1-3	Mixed Use Zones 1-3	Mixture of business and appropriate industrial and residential development
GI	General Industry	All forms of industry (Bar noxious trade and risk activity)
MU1-3	Mixed use	Anything (MU3 is a bigger building)
UT	Utility Zone	Provides for Utilities

Table 4-2 indicates how water use categories are linked to the different land use zones. Due to the overlapping nature of the different land use zones, water use categories often had to be assigned by manually checking the actual property using aerial photographs, Google Maps, and Google Street View. Properties zoned 'Rural' consisted entirely of large domestic households in the Bishopscourt area of the catchment and were thus assigned to the domestic water use category.

Table 4-2: Land use zones and their associated water use categories

Classification Code	**Classification Description** (CoCT, 2012a)	**Assigned Water Use Category** (CSIR, 2000)
SR1	Single Residential Zone 1	Domestic
GR1, GR2and GR4	General Residential Zone 1, 2 and 4	Domestic
RU	Rural	Domestic
CO1andCO2	Community Zone 1 (Local)	Government, Community, and Institutional OR Education
LB2	Local Business Zone 2	Business and Commercial
GB1 and GB5	General Business Zones 1 and 5	Business and Commercial
MU1-3	Mixed Use Zones 1-3	Manually assigned to one of the above water use categories
GI	General Industry	Industrial

4.1.4 Household Occupancy

Household occupancy was estimated using data from South Africa's 2011 Census, which provided population information at a cluster level known as a 'small area' (Stats SA, 2011). The census data divides the catchment into approximately 60 clusters or 'small areas'; Figure 4-3 illustrates the distribution of household size by small area throughout the catchment. The larger households were predominantly situated in the south of the catchment and included the suburbs of Bishopscourt, Claremont, and Newlands. Moving north towards the suburbs of Rondebosch, Rosebank, and Mowbray, the household size decreased before increasing once more towards Observatory.

Interestingly, the suburbs of Bishopscourt and Newlands have a similar population per household to Observatory despite the difference in income levels and property size. The smaller household sizes in the middle of the catchment coincided strongly with the presence of multi-storey residential flats which typically house fewer people per household than a conventional domestic dwelling.

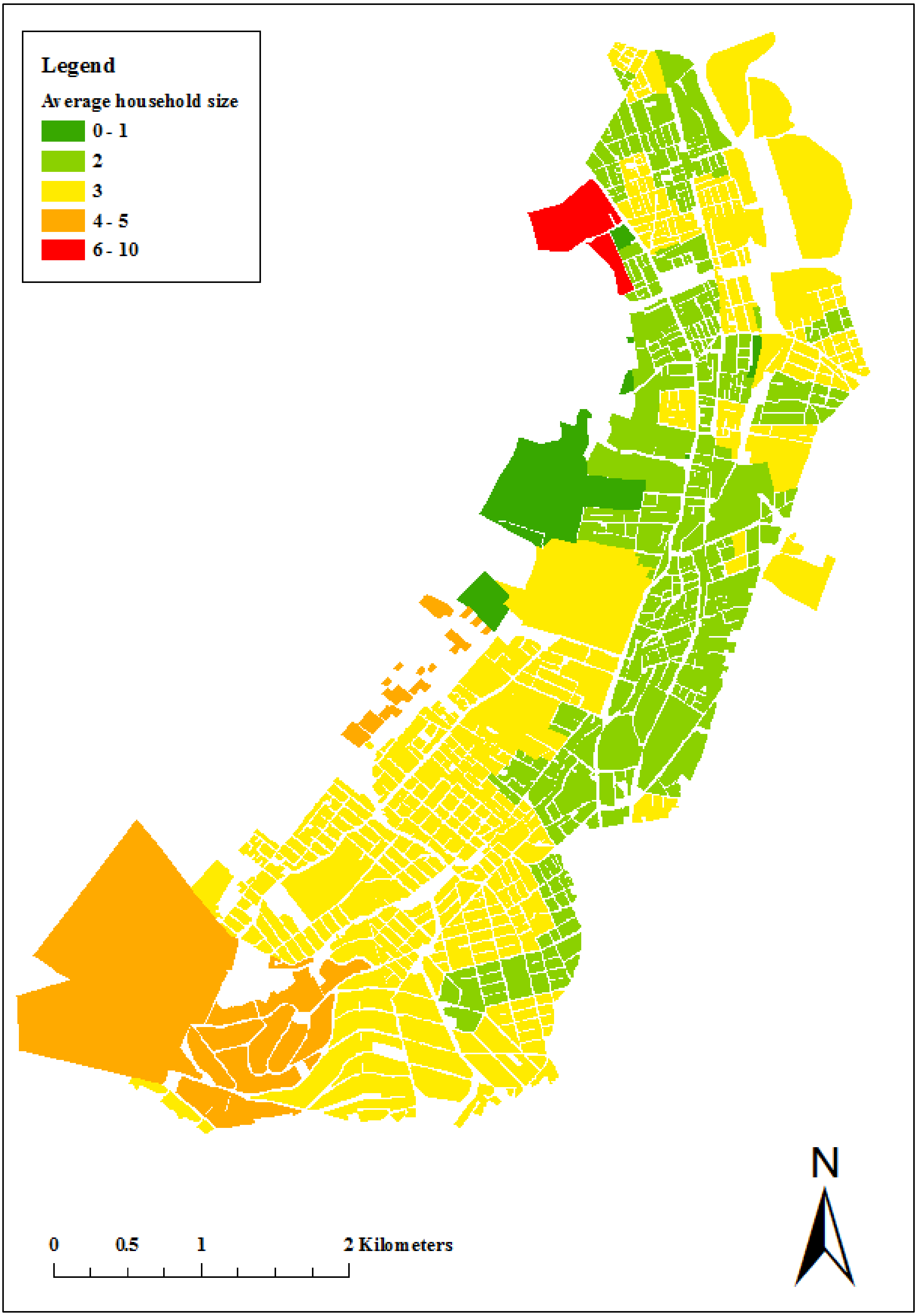

Figure 4-3: Distribution of household size by small area in the Liesbeek catchment

4.1.5 Rainfall and evaporation distributions

The collection of rainfall and evaporation was obtained from Fisher-Jeffes (2013) who collected private daily rainfall data from residents in the catchment, as well as daily rainfall data from eight meteorological stations; Observatory, Maitland, Molteno, Molteno Reservoir, Woodhead and Kirstenbosch stations operated by the South African Weather Service, and the Newlands station, operated by the Department of Water Affairs. The data was processed to remove anomalies, and interpolated between stations to create rainfall and evaporation distribution maps covering the entire catchment. Figure 4-4 illustrates the average annual rainfall distribution map generated in GIS, a larger map can be found in Appendix K. The rainfall was highest to the south of the catchment on the slopes of Table Mountain, decreasing steadily moving northwards through the catchment towards the City Bowl. The distribution map for evaporation followed an opposite pattern to that of the rainfall distribution and can also be found in Appendix K.

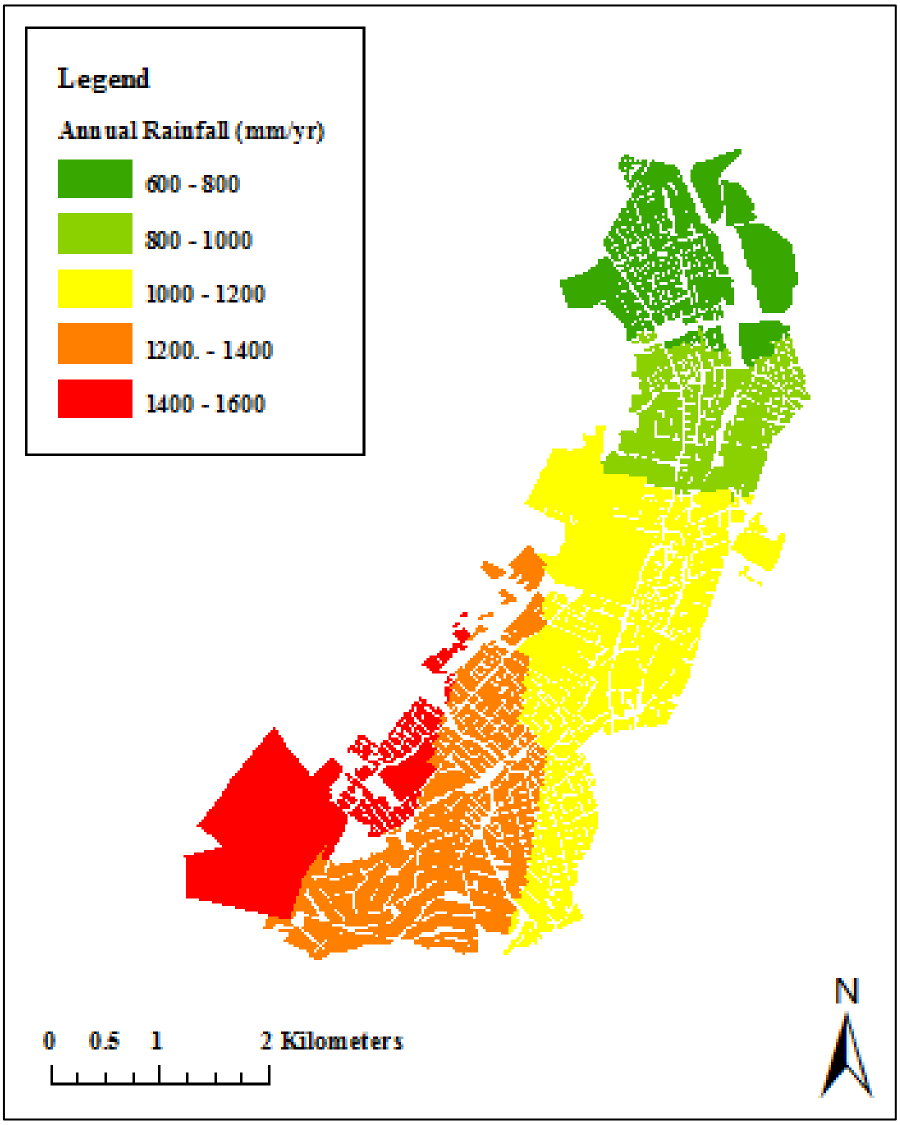

Figure 4-4: The rainfall distribution map developed for the Liesbeek River catchment

4.1.6 Metered water use

The metered water use data used for the calibration was obtained for the City of Cape Town (CoCT, 2012b). The measured data consisted of daily metered readings of total water use for each individual property, spanning from May 2010 to April 2011. This data was selected as it had been used for a previous stormwater project and some of the more prominent data errors arising from meter inaccuracies, data collection problems, and database errors had been removed. Despite its use in a previous project, there were still several problems with the measured data which required an additional cleaning process to ensure that it provided a reliable calibration benchmark. The criteria used to clean this data are described as follows:

i) Any measurements that had data validation problems were removed. This mostly consisted of water meter readings that did not have correct property reference numbers, or small properties with three or more water meter readings relating to the same property.

ii) Measured data with a zero reading over the entire year was also removed. Zero readings arise either as a result of a total meter failure, or because the particular property has been unoccupied.

4.2 Calculating domestic indoor water demands

The Liesbeek River catchment was predominantly made up of residential properties ranging from low density suburban estates, to high density multi-storey flats. Domestic water use patterns need to take into account the type of residential use; multi-storey flats had a higher population per unit of property area, and thus the water use calculations need to be adjusted accordingly. In order to accommodate this difference in the patterns of domestic water use, all residential properties in the catchment were placed into one of two water use categories:

i) **General Residential** which consisted of the standard individual dwelling typical of a high income residential area; and

ii) **Low, Medium, and High Rise Residential** which included all forms of group housing such as multi-storey flats or communal buildings.

The calculations for domestic water use in the catchment were largely based on the Residential End-use Model (REUM) developed by Jacobs and Haarhof (2004). REUM estimates the water demand for a single residential stand, based on the various end-uses for water within a household. The term ‘end-use’ refers to the smallest identifiable use of water on a stand (Jacobs and Haarhoff, 2004). Figure 4-5 illustrates some of the different end-uses one may find in a typical domestic household.

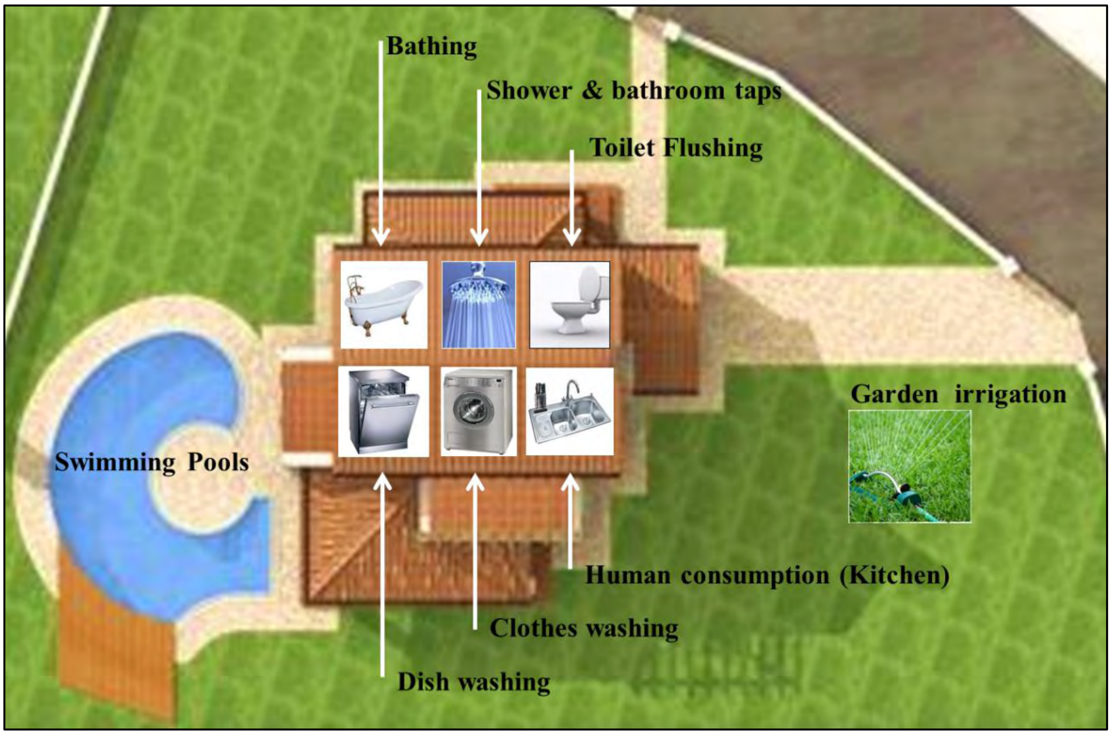

Figure 4-5: End-uses found within a typical domestic household

The REUM model calculated the average daily demand (ADD) for an individual household by estimating the number of times a particular end-use is utilised each day, and the volume of water used each time. To get a final daily water use value this was multiplied by the number of people using each end-use daily. The approach is expressed using the following basic formula:

$$ADD\ o\ \ e\ ti\ \ (ph\ \ re\ \ o\ ) \qquad (4\text{-}3)$$

Where:

Pph = People per household

$Freq_n$ = Frequency per event for a particular end-use 'n'

Vol_n = Volume per event for a particular end-use 'n'.

The volumes and frequencies for the various end-uses vary depending on the type of device used and the behaviour of the user. Estimating user characteristics for every household in the catchment would be impossible, however Jacobs and Haarhoff (2004) provide a standard range of estimations for the volumes and frequencies of the various domestic end-uses in South Africa. These estimations of low, typical, and high values for both volume and frequency are shown in Table 4-3. Appendix A provides a summary of the calculation process used to derive the domestic water demands.

Table 4-3: Volumes and frequencies for domestic end-uses (Jacobs and Haarhoff, 2004)

End-use	**Low Vol. (ℓ)**	**Medium Vol. (ℓ)**	**High Vol. (ℓ)**	**Low Freq. (n/day)**	**Medium Freq. (n/day)**	**High Freq. (n/day)**
Bath	39	80	189	0.22	0.24	0.9
Bath Basin	0.3	3.8	6	3.4	3.6	3.8
Dishwasher	15.1	25	43	0.18	0.25	0.29
Kitchen Sink	0.6	6.7	7.3	2	2	2
Shower	7.6	59.1	303	0.19	0.31	0.68
Normal Toilet	8	14.3	26.5	1.7	3.7	10.3
Dual Flush Toilet	4	6	6.1	0.9	1.9	5.2
Washing Machine	60	113.6	200	0.12	0.3	0.63

4.3 Calculating non-domestic indoor water demands

Non-domestic land uses incorporate a broad range of water use activities; the variation is not only found between different non-domestic land uses, but also within each category. Restaurants and shopping malls for example will have a very different water use profile to offices and business parks, despite the fact that they are both grouped under the commercial land use category. Given the broad spectrum of non-domestic water use, it was not possible to model the different end-uses directly - as done for the domestic land use category; the only way to calculate water use was to use a general estimate of their total water demand. In South Africa, the *Guidelines for human settlement planning and design* (CSIR, 2000) provide a basic water demand estimate for various non-domestic land uses; these guidelines formed the basis of the non-domestic water balance calculations. Table 4-4 shows the relevant water use estimates suggested by the CSIR (2000). Appendix B provides a summary of the calculation process used to derive the non-domestic water demand calculations.

Table 4-4: Water demand for non-domestic land uses (CSIR, 2000)

Type of Development	**Unit**	**Average Water Demand (ℓ /unit·day)**
Offices and Shops	100 m^2 of gross floor area	400
Community Halls	No. of Seats	65-90
Hospitals	No. of Beds	220-300
Day School	No. of Students	15-20
Boarding School	No. of Students	90-140

4.3.1 Commercial water demand estimation

The calculation of commercial water demand involved a simple multiplication of the building floor area with an average water demand which was specified as the volume of water used per unit of floor area. The calculation for commercial ADD is expressed using Equation 4-5. The *Average Water Demand* in this case is a water demand per 100 m^2 of gross floor area (ℓ/m^2·day).

$$ADD_{o \quad er\,i} \quad oor\ \ re \quad v\ er\ e \quad te\ \ r\ e \quad d \tag{4-4}$$

The gross floor area of a building was assumed to be approximately equal to the building roof area. Although there may be some disparity between gross floor areas and building roof area, the difference between the two does not have a significant impact on the results. The total floor area for multi-storey buildings was calculated by multiplying the calculated roof area by the number of storeys.

4.3.2 Community and Hospital water demand estimation

The estimation of community and hospital water demand followed a very similar process to that of commercial properties. Community Facilities required an estimation of the number of seats used while hospital required an estimation of the number of hospital beds available. These values are then multiplied by their respective average water demands; the water volume used per seat for community facilities, or per bed for hospitals.

Figure 4-6 provides a visual representation of two typical community buildings which have been assigned a theoretical seating arrangement. It is clear from the illustration that different community facilities can have different seating arrangements, making it difficult to estimate the number of seats within each facility.

In order to overcome this problem, a calculation for the number of seats found within a particular building was developed. This estimated the fraction of floor area that would be suitable for seating and multiplied this fraction by an estimated area per seat as shown in the following formula:

$$o.\,o \quad e\,t \quad re \quad i\ \ t \quad e\ or\ \ e\,ti \quad o.\,o \quad e\,t\ \ p\ er\ \ i\ \ t\ re \tag{4-5}$$

The estimation of the area suitable for seating was based on values provided by Peña and Parshall (2001) who suggested that between 50% to 70% of a buildings space can be assigned for its given function. For the initial calculations, it was assumed that and average value of 62% of the space in a community building would be available for seating. The estimation of the number of seats in the buildings was based on National Building Regulations (SANS 10400, 1990) which provide a range of allowable occupancies for different building types.

The allowable occupancies for different building types under the community water use category range from 1 m^2/person for entertainment facilities and community halls to 20 $m^{2/}$person for libraries and museums. For the initial calculations, it was assumed that 10 m^2 of floor space would be allocated for each seat. These values were used as an initial estimate and were adjusted within a specified range during the calibration process to ensure the accuracy of the results.

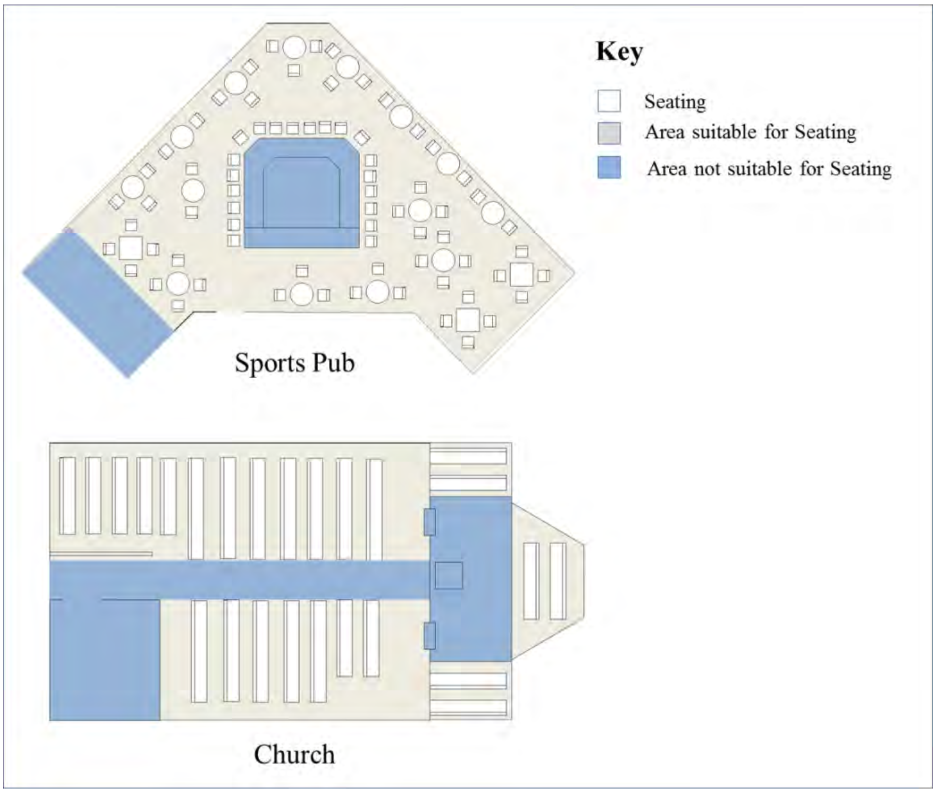

Figure 4-6: Examples of seating plans for two typical community facilities

Once the number of seats had been calculated, the ADD for community facilities could be calculated. The calculation of the ADD is shown in Equation 4-7. The *Average Water Demand* in this case is a water demand per occupant (ℓ/seat·day).

$$ADD_{o \quad it} \quad o.o \quad e\,t \quad ver\,e \quad ter \quad e\,d \qquad (4\text{-}6)$$

The calculations for hospital water demand followed the same process as for the community facilities with the exception that instead of number of seats, the number of beds was used as the driving variable. The number of beds in each hospital in the catchment was obtained from the *Comprehensive service plan for the implementation of healthcare 2010* published by the Western Cape Provincial Government (2007). Equation 4-8 shows the ADD calculation required for hospitals. In this case the *Average Water Demand* is the water demand per hospital bed (ℓ/bed·day).

$$ADD_{\quad opit} \quad o. \; o \;\; ed \qquad v \; er \; e \qquad ter \quad e \;\; d \tag{4-7}$$

4.3.3 Education water demand estimation

The water demand for educational institutions was calculated by multiplying the number of students by an *Average Water Demand* – in this case was the water demand per student (ℓ/student). The calculation is expressed using the following formula:

$$ADD \; d \quad ti \; o \qquad o. \; o \quad t \; de \;\; t \qquad ver \;\; e \qquad te \; r \;\; e \qquad d \tag{4-8}$$

The number of learners at primary and secondary educational institutions was provided by the Western Cape Department of Education (WCED, 2013). The data includes information regarding the number of learners (both boarding and day schooling) as well as teachers for all schools in the region. The estimations for the number of people at the University of Cape Town were based on statistics taken from the university's website (UCT, 2013a, 2013b). Table 4-5 highlights the estimated number of people at UCT campuses during the day in the Liesbeek River catchment. The estimations do not include water used by the university residences as these were included in the calculations for LMHR residential properties.

Table 4-5: Estimated populations of UCT campuses

Description	Estimated Person count
UCT Medical School	2000
UCT Lower Campus, Music School and Baxter	100
UCT Woolsack, Kopano and Upper Music School	100
UCT Upper and middle campus	28500

4.4 Outdoor water demand estimation

The outdoor water use estimation was calculated using the REUM model developed by Jacobs and Haarhof (2004), which calculated outdoor water demand for various different vegetation types as well as swimming pools. The REUM model was applied to all land use categories based on the assumption that the outdoor water use characteristics were similar for all land use categories. The most effective indicator of vegetation water demand is the moisture deficit which is equivalent to the potential evapotranspiration minus effective rainfall ($ET - r$) (Jacobs and Haarhoff, 2004). Evapotranspiration (ET) rates are calculated by assuming that *ET* is proportional to the pan evaporation (*p*) (*ibid.*). This is expressed in the following formula:

$$p \qquad (4\text{-}9)$$

The empirical constant *k* is a constant of proportionality known as the crop factor. The evaporation from swimming pools is calculated using the same formula, only that *k* represents the evaporation factor for the pool surface. Effective rainfall (*r*) represents the proportion of rainfall that penetrates the soil and thus has an effect on reducing vegetation water requirements.

There are various methods used to calculate effective rainfall; the method used in the REUM model was developed by Johnson (1987) to estimate garden water demand in Port Elizabeth. The effective rainfall equation – shown in Equation 4-11– assumes that all rainfall up to 25 mm is completely absorbed by the soil; after that the rate of absorption decreases linearly with increasing rainfall up to 152 mm where a maximum of 89 mm of rainfall actually penetrates the soil (Johnson, 1987; Jacobs and Haarhoff, 2004).

$$r \left[(. \quad) \quad . \quad \frac{(\quad)}{(\quad)} \right] \qquad (4\text{-}10)$$

Where:

R = Annual rainfall

Once the moisture deficit for the outdoor land cover types are calculated these are multiplied by the surface area (*SA*) of the vegetation cover type to get an approximation of the entire area's water demand. This is then multiplied by an irrigation factor (*IF*) which estimates the degree of over or under irrigation in relation to a plant's ideal water requirements. The average number of days in a month (*D*) is used to convert vegetation water demand into a daily value. The daily outdoor water demand calculation is shown in the following formula:

$$ADD \quad [(\quad) \quad (\quad)] \quad \left[\frac{(\quad p)-r}{}\right] \qquad (4\text{-}11)$$

The crop factors for different vegetation types were provided in a summary table by Jacobs and Haarhof (2004). The outdoor land cover types within the catchment were split into three major categories: landscaped gardens, sports fields, and swimming pools. Table 4-6 shows the different crop factors used for the three outdoor land use categories; the crop factors for swimming pools have a value of 1 because Jacobs and Haarhof (2004) assume that pool evaporation is equivalent to the pan evaporation value.

It was also initially assumed that the irrigation factors for all land cover types would be one; this assumes that irrigation systems are 100% efficient and provide only what the vegetation required. Given that this is unlikely to prevail in reality, this was increased or decreased where necessary during the calibration process.

Table 4-6: Crop factors for outdoor land cover types

Land Cover	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sports Fields	0.68	0.68	0.6	0.47	0.31	0.22	0.22	0.22	0.3	0.47	0.61	0.68
Swimming Pools	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Landscaped Gardens	0.78	0.78	0.75	0.7	0.65	0.5	0.4	0.55	0.65	0.73	0.78	0.78

4.5 Water Balance calibration

One of the critical phases of the modelling process was the validation of the calculated results. In order to ensure that the water balance accurately represented water use patterns in the catchment, it needed to be calibrated against measured data from the area. The analysis of the measured data after cleaning showed that there was significant variation in the water use patterns throughout the catchment. Figure 4-7 illustrates an example of how water use varied amongst domestic properties, in this case within the suburb of Newlands. The dwellings had roughly the same property size, yet measured water use varied significantly from property to property. This variation in water use applied to all suburbs in the catchment for both the domestic and non-domestic land use categories.

As a result of the large variation in water demand, the initial water demand estimates – which calculate the water demand for each property – did not accurately reflect the actual water use in the catchment. Figure 4-8 illustrates the comparison of measured and calculated water demand for every general residential stand in the catchment; the broad scatter and poor correlation is consistent for all of the land use categories in the catchment.

The calculated results were improved by calibrating against the measured data. Using the measured data as a baseline, the input variables for the model calculations were adjusted to ensure that the measured data reflected the actual water use scenario for every property in the catchment. The rules used to guide these adjustments can be found in Section 4.5.1. The purpose of the calibration was not only to ensure that the model reflected the total water demand of a property, but also the relative proportions of indoor and outdoor water use. The measured data represents the total demand of an individual property and thus the proportion of water used for indoor and outdoor purposes could not be directly determined.

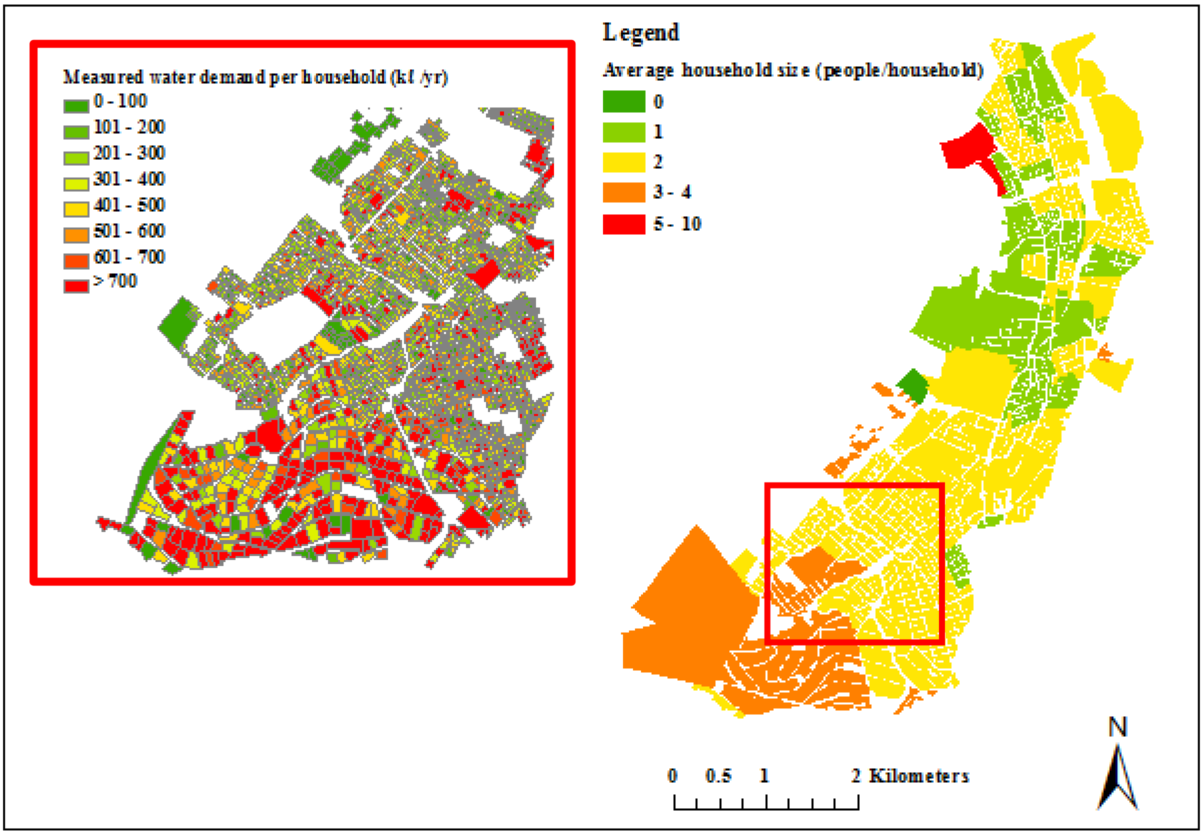

Figure 4-7: The diverse water use patterns of domestic households in Newlands

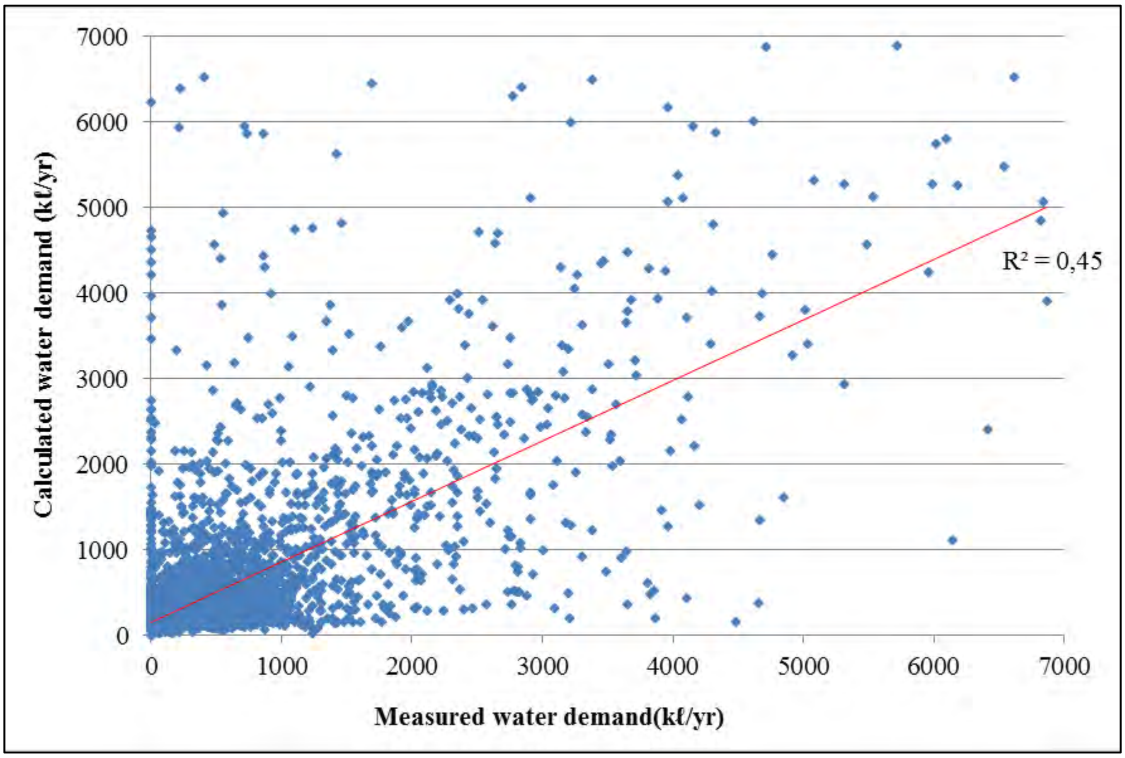

Figure 4-8: Calculated vs measured water demand for general residential properties

A solution to the problem of differentiating between indoor and outdoor water use was obtained by examining the variations in outdoor water demand requirements and the measured water demand over a one year period. Figure 4-9 illustrates the variation in calculated outdoor water demand, as well as the measured total water demand over a one year period. Figure 4-9 indicates that outdoor demand is reduced to a negligible amount over the winter months from May to September. This is because the quantity of rain falling over this period generally exceeded the water requirements for the various outdoor vegetation types throughout the catchment during the year under investigation. Using this information, the irrigation requirements over the winter months from May to September were thus assumed to be essentially zero. It follows from this that all measured water demand data over the period of May to September could be assumed to be used for indoor purposes. This explains the increase in measured water demand over the summer months when outdoor water requirements are at their highest. Using the ratios between measured water demand and calculated water demand for the months of May to September, an adjusted indoor water demand calculation was developed for every property in the catchment.

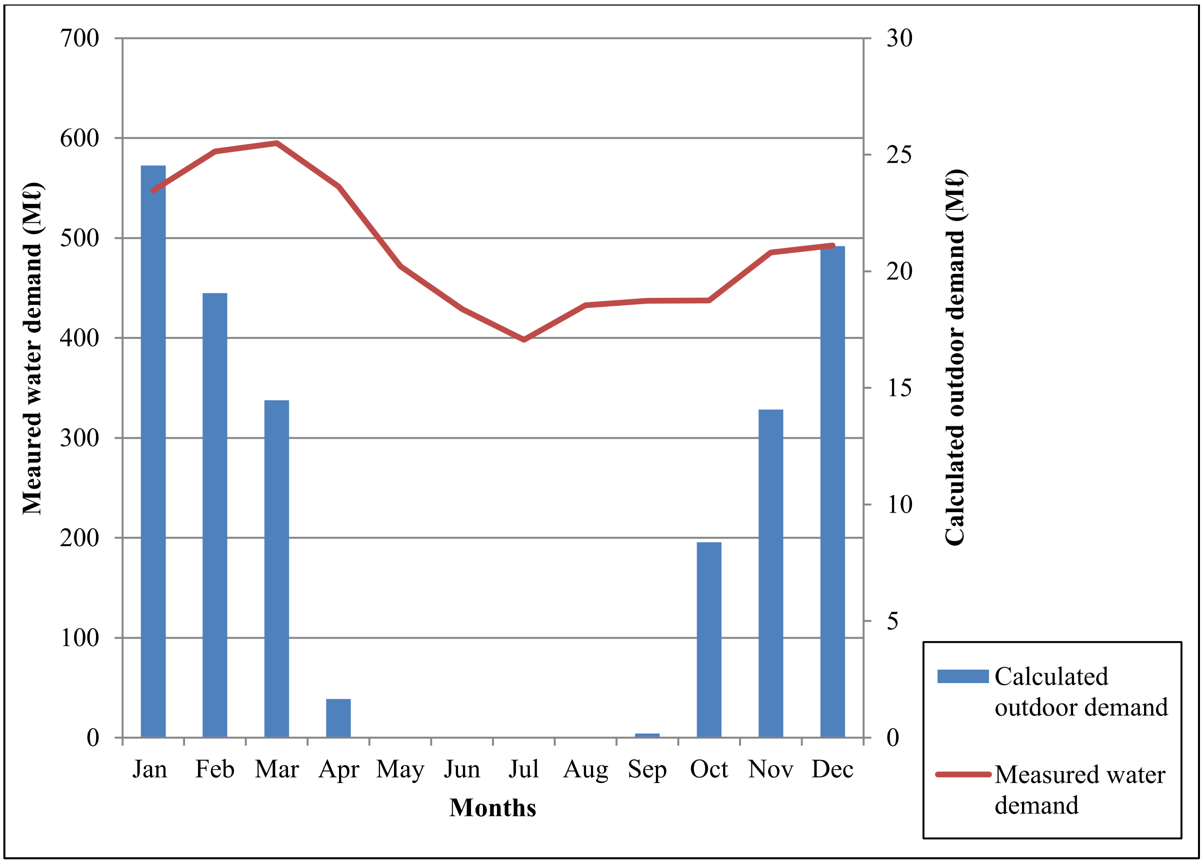

Figure 4-9: Monthly variation of calculated outdoor and measured water demand

4.5.1 Indoor calibration

The calibration process for indoor properties used the average monthly water demand measurements for the months of May to September, and compared them to the calculated monthly indoor demand as a ratio. This ratio – which was calculated for every property in the catchment – represented the factor by which the current calculated water indoor use needed to be adjusted in order to match the property's measured data. Figure 4-10 illustrates the process; the difference between the measured water demand from May to September and the calculated water demand represents the required change in calculated water demand.

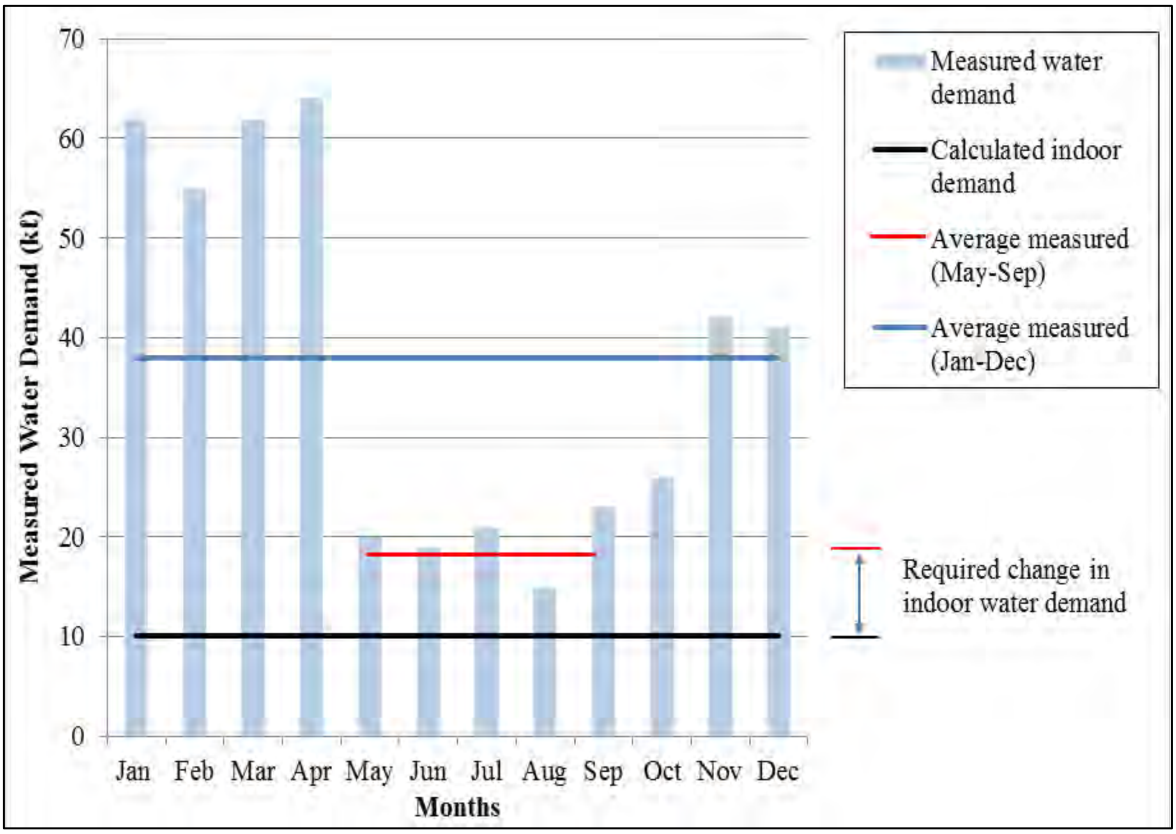

Figure 4-10: Deriving the indoor adjustment factor for an individual property

The factor by which calculated indoor water demand needed to be increased or decreased was defined as the calibration factor. The calibration factor was then applied to the model inputs in order to adjust the original water demand estimations for each property in the catchment. The effective representation of the water balance model is entirely dependent on the credibility of its inputs and thus the adjusted calculation variables for the properties in the catchment needed to fall within realistic ranges. Table 4-7 illustrates the acceptable ranges for the various calculation variables of the water balance model. The calculated water demands were adjusted to match the measured data by adjusting the inputs within these ranges. The approaches used to determine these ranges are briefly discussed on the following page.

Table 4-7: Calibration factors

Water Use Category	Calibration Factor1	Range	Calibration Factor 2	Range
General and LMHR Residential	REUM End-use Frequencies	0.23 – 5.06 (Jacobs and Haarhoff, 2004)	Household Sizes	1 – 8 (Stats SA, 2011)
Commercial	Water use rate ℓ/100m^2)	140 – 800 (Queensland Government, 2010)		
Education	Water use rate ℓ/person	Day: 15 – 50 (CSIR, 2000; Queensland Government, 2010) Boarding: 100 – 200 (CSIR, 2000)		
Community and Institutional	Water use rates ℓ/seat)	15 – 90 (CSIR, 2000)	Area per seat (m^2/seat)	0.125 – 0.9 (SANS 10400, 1990)
Hospitals	Water use rates ℓ/bed)	220 – 1800 (CSIR, 2000; Queensland Government, 2010)		

4.5.1.1 Domestic indoor calibration

The calibration of the general residential and Low, Medium, and High Rise (LMHR) residential properties was done by adjusting three of the calculation variables: the REUM end-use frequencies, end-use volumes, and the estimated household size. The end-use frequencies represent the number of times a particular end-use is utilised every day, while the end-use volumes refer to the volume of water utilised for a particular end use. In order to account for the variability of water use amongst domestic households, Jacobs and Haarhoff (2004) provided a range of values for the end-use volumes for the different domestic end-uses, as well as their associated frequencies of use. Table 4-8 illustrates the differences in calculated water demand with different frequencies of use, as well as the range of end use volumes provided by Jacobs and Haarhoff (2004).

For the purposes of the calibration process it was assumed that the end-use frequencies and volumes could fall anywhere between the ranges specified by Jacobs and Haarhoff (2004). The residential end-use water demand using low end-use frequencies and volumes was 0.23 times lower than that of the water demand calculated using medium end-use frequencies and volumes; a high frequency of use and high end-use volumes increased water demand estimates by a factor of 5.06. The derivation of the factors used in the calibration process are shown in Appendix C.

Table 4-8: Variation in calculated water demand with different frequencies of use
(Jacobs and Haarhoff, 2004)

End-use	Water demand Low Vol. x Low Freq. (ℓ/day)	Water demand Med Vol. x Med Freq. (ℓ/day)	Water demand High Vol. x High Freq. (ℓ/day)
Bath	39 x 0.22	80 x 0.24	189 x 0.9
Bath Basin	0.3 x 3.6	3.8 x 3.6	6 x 3.8
Dishwasher	15.1 x 0.18	25 x 0.25	43 x 0.29
Kitchen Sink	0.6 x 2	6.7 x 2	7.3 x 2
Shower	7.6 x 0.19	59.1 x 0.31	303 x 0.68
Normal Toilet	8 x 1.7	14.3 x 3.7	26.5 x 10.3
Dual Flush Toilet	4 x 0.9	6 x 1.9	6.1 x 5.2
Washing Machine	60 x 0.12	113.6 x 0.3	200 x 0.63
Sum	39.36	169.24	856.68
Ratio	0.23	1.00	5.06

If after the adjustment of the REUM end-use frequencies, the property still required further adjustment to match the measured data, it was assumed that any further adjustment to the residential water use categories would involve altering the assumed household size. The initial estimates of the household size of each property was based on data from South Africa's 2011 Census, which provided population information at a cluster level known as a small area (Stats SA, 2011). There are approximately 60 clusters or 'small areas' within the catchment, each of which was modelled with a homogeneous household size. In reality, household sizes would vary significantly within each cluster and in order to account for this, a range of household sizes was provided. It was assumed that household sizes would vary from 1 to 8 people. The household sizes for domestic properties were then adjusted within this range in order to match the measured data. In order to check whether this random allocation of household sizes was realistic, a summation of household size for all properties in the catchment was compared to 2011 Census data population estimates. The population for the catchment was calculated by summing the calculated household occupancies assigned during the calibration process for all residential properties. The calculated population for the catchment amounted to 31,650 people, which was relatively close to the 31,000 people estimated by summing the 2011 Census population data for all small areas in the catchment.

4.5.1.2 Commercial indoor calibration

The calibration of the commercial water use category was completed by adjusting the average water demand. The suggested average water demand provided by the *Guidelines for human* *settlement planning and design* (CSIR, 2000) was given as 400 ℓ/day for every 100 m^2 of gross floor area. In order to calibrate the calculated water demand against the measured data it was necessary to have a range of values for the average water demand of commercial properties. The Stakeholder Accord on Water Conservation (2009) provided a range of water use benchmarks for the commercial sector in South Africa; the suggested benchmarks varied from 140 to 410 ℓ/day for every 100 m^2 of gross floor area. The implementation of this range of average water demands in the calibration process did not adequately describe the actual water use in the Liesbeek River catchment as a large number of properties had average water demands that were higher than the specified 410 ℓ/day. The selection of a more appropriate upper bound for commercial water demand was based on Queensland's *Planning Guidelines for Water Supply and Sewerage* (Queensland Government, 2010), who specify between 300 and 800 ℓ/day for every 100 m^2 of gross floor area for a range of commercial developments. It was decided that a range of 140 to 800 ℓ/day for every 100 m^2 was an acceptable range for commercial properties, particularly given the diverse range of water use profiles that different commercial sectors produce. If any properties fell outside of this range they were assigned the minimum or maximum value as required.

4.5.1.3 Community indoor calibration

The calibration of the community water use category was based on adjusting two variables; the number of seats per unit area, and the water use ratio. The suggested average water demand provided by the *Guidelines for human settlement planning and design* (CSIR, 2000) was given as 90 ℓ/day for every seat in a community facility. Given that the functions of community facilities varied from libraries and community halls, to sports grounds and churches, the number of seats per unit area and the average water demand per seat varied significantly and the model inputs were required to reflect these variations.

The estimation of the area suitable for seating was based on values provided by Peña and Parshall (2001) who suggested that between 50% to 70% of a buildings space can be assigned for its given function. The estimation of the number of seats in the buildings was based on National Building Regulations (SANS, 1990) which provide a range of allowable occupancies for different building types. The allowable occupancies for different building types under the community water use category range from 1 m^2/ person for entertainment facilities and community halls to 20 m^2/person for libraries and museums. For the purpose of the calibration, it was assumed that the area available for seating for any community building could range between 50% and 70%, while the area per seat would range between 1 m^2/person and 20 m^2/person.

The range of water use rates was set at 15 to 90 ℓ/person·day. The lower bound of 15 ℓ was based on the premise that facilities such as bus stations were included in the community water use category which have a specified water demand of 15 ℓ/person·day in the *Guidelines for human settlement planning and design* (CSIR, 2000). The upper bound of 90 ℓ was taken from the same guidelines which stipulate a maximum value of 90 ℓ/person·day for community halls and restaurants.

4.5.1.4 Hospital indoor calibration

The calibration process for hospitals was based on the adjustment of the average water demand per bed. The initial calculation used a water use ratio of 220 ℓ/bed·day however on examination of the results, it was found that the hospitals in the catchment were using significantly more water than that which was specified. The selection of a more appropriate upper bound for hospital water demand in the catchment was based on Queensland's *Planning Guidelines for Water Supply and Sewerage* (Queensland Government, 2010), who specify between 500 to 1800 ℓ/bed·day.

4.5.1.5 Education indoor calibration

The calibration process for education institutions was completed by adjusting the average water demand. The *Guidelines for human settlement planning and design* (CSIR, 2000) recommend an average water demand of 15 to 20 ℓ/person·day for day schools, and 90 to 150 ℓ/person·day for boarding schools. The implementation of this range of average water demands in the calibration process did not adequately describe the actual water use in the Liesbeek River catchment as a number of schools were using more than 20 ℓ/person·day. In order to provide a more adequate upper bound of average water demands for schools within the catchment, the *Planning Guidelines for Water Supply and Sewerage* (Queensland Government, 2010) were utilised; the guidelines specify 50 ℓ/person·day as an adequate water demand for educational facilities.

The calibration of educational institutions by use of the winter measured water demand method required an adjustment for school holidays. Table 4-9 highlights the 2010 school calendar as well as the number of school days falling within the months of May to September. Over the period of May to September 2010, 112 days of 153 (73%) fell within the school term. In order to account for this, a factor of 0.73 was applied to the calculated indoor demand.

Table 4-9: The 2010 South African schools calendar

Term	Duration	Number of school days between May and Sept
2	12 Apr - 9 Jun	40
3	13 Jul - 23 Sept	72
	Total	**112**

4.5.1.6 Indoor calibration results

Once all of the calibration processes had been completed for all of the different land use categories, the adjusted indoor water demand measurements were once again compared to the measured water demand. In order for the measured water demand to reflect the indoor proportion of the water use, the comparison was made over the months of May to September when it was assumed that all outdoor water requirements were negligible.

Figure 4-12 illustrates a frequency histogram of the different indoor calibration factors applied to each property in the catchment. The distribution of indoor calibration factors follows a normal distribution pattern that is slightly skewed towards the calibration factors greater than One. This distribution shows that a larger number of properties required an increase in their calculated indoor water demand than those requiring reductions. This increase in calculated indoor water demand indicates that more properties were using water at a faster rate than that which was assumed in the initial calculations, or had a larger household population than the assumed average for their given area.

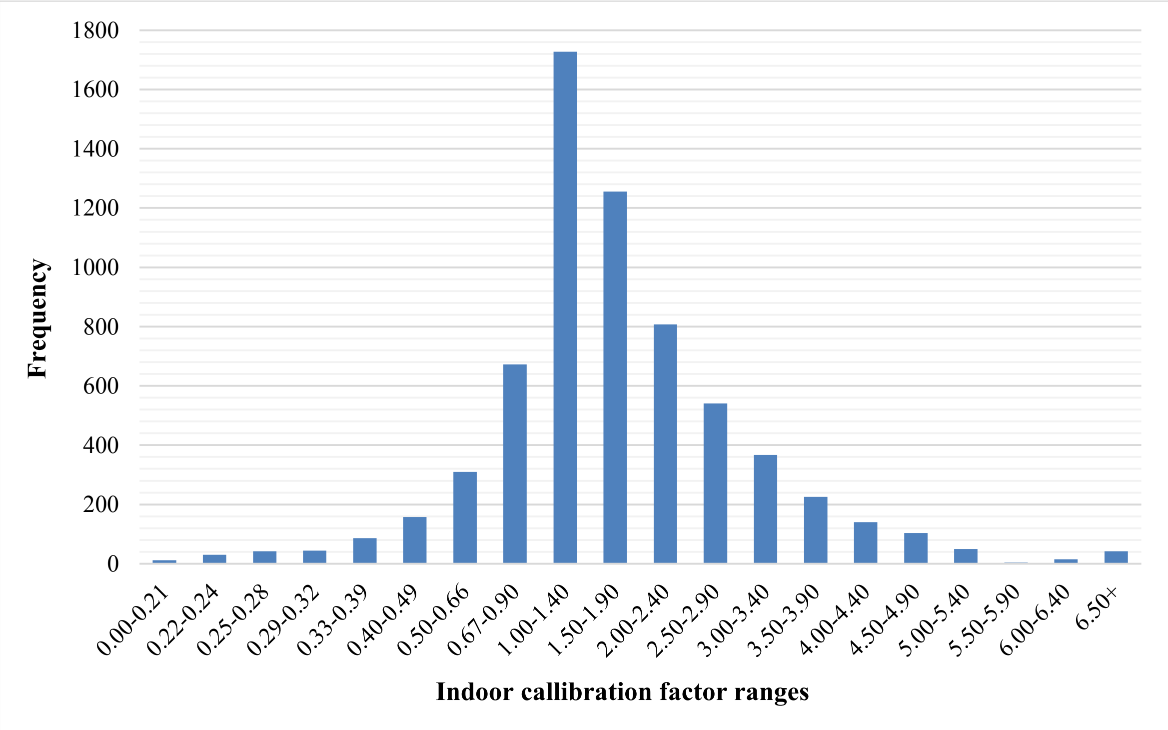

Figure 4-11: Summary of the indoor calibration factors applied to every property

Figure 4-12 illustrates the comparison of the calculated indoor water demand with measured values for all of the properties in the catchment over May to September after calibration. The correlation between the two shows a marked improvement on the initial results as illustrated by the correlation coefficient of nearly 0.94.

Despite the improvements made to the calculated indoor water demand after the calibration process, there were still a few properties that did not match the measured data. These anomalies represent properties that required calculation inputs that fell out of the stipulated ranges suggested during the calibration process. The nature of water use within the Liesbeek River catchment was complex, and it is not surprising that anomalies such as these are found. Given that the majority of properties in the catchment correlate well with the measured results these anomalies were ignored as the combined errors are unlikely to significantly impact the overall results of the water balance model.

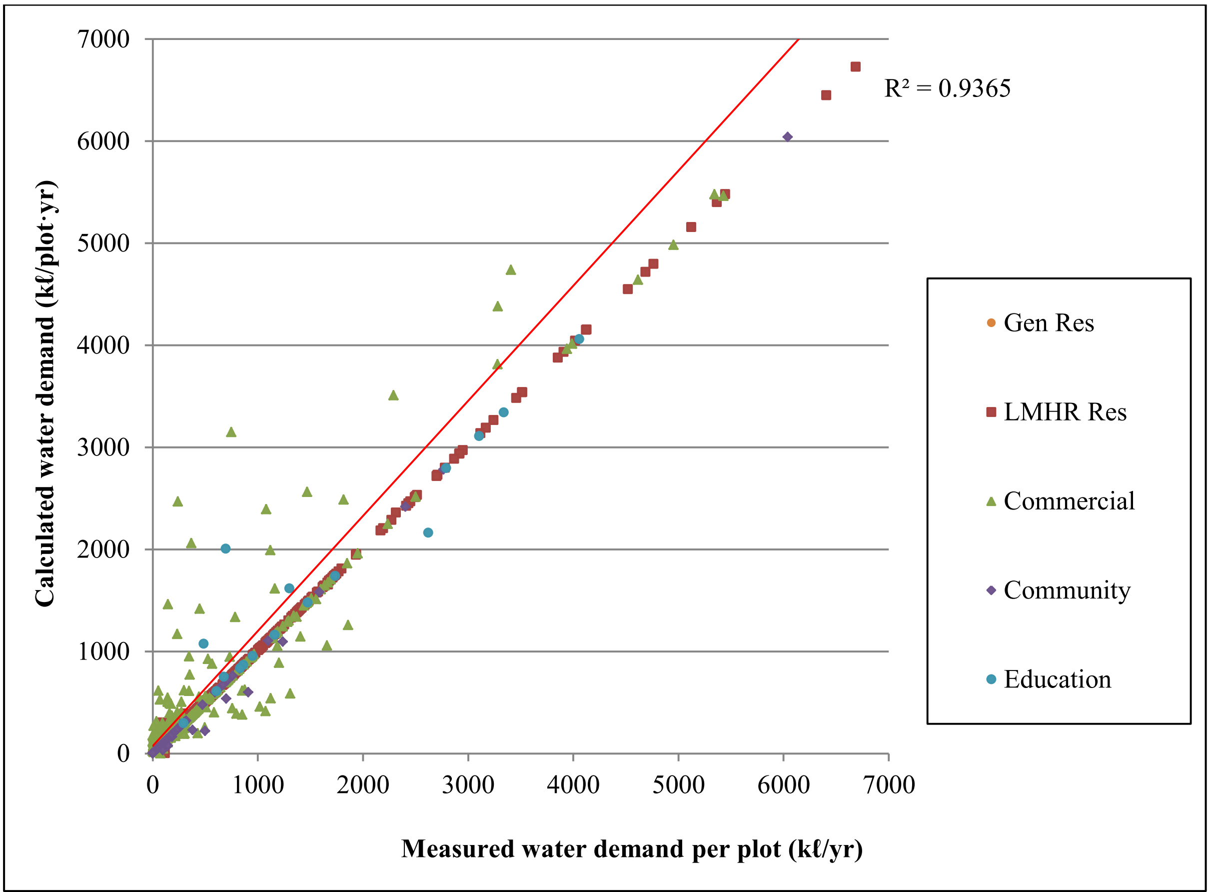

Figure 4-12: Measured vs calculated indoor water demand after indoor calibration

4.5.2 Outdoor calibration

After the adjustment of the calculated indoor demand had been completed, it was assumed that any remaining differences between measured and calculated water demand could be attributed to outdoor water demand. The calculated outdoor water demand only had single variable to be adjusted – the irrigation factor. The irrigation factor refers to the over or under-irrigation of a vegetation type in relation to its ideal water requirement (Jacobs and Haarhoff, 2004). The initial calculations employed an irrigation factor of one. However, it was unlikely that this occurred in reality as some properties would have watered too much and others too little or not at all. Some properties for example may have automatic sprinkler systems, which water their gardens too frequently or for too long. In addition to this, these automatic sprinkler systems could water gardens at inappropriate times such as during rainfall events when irrigation would not be necessary.

In order to make sure that the outdoor water demand calculations were realistic, a range of irrigation factors were applied to the model. This range of values was based on information from Jacobs and Haarhoff (2004) who suggest an irrigation factor range of 0 to 2. The lower bound estimation was based on the fact that some properties would not irrigate at all, making the irrigation factor zero. The upper bound was based on information from accounts for properties that irrigated over and above their ideal outdoor water requirements.

Figure 4-13 illustrates a frequency of the different outdoor calibration factors applied to each property in the catchment. The distribution of outdoor calibration factors is heavily skewed towards factors less than one, meaning that a larger number of properties required a decrease in their calculated outdoor water demand than those requiring increases. This decrease the in calculated outdoor water demand indicates that the majority of properties in the catchment are watering their gardens far less frequently than assumed in the initial outdoor water demand calculations.

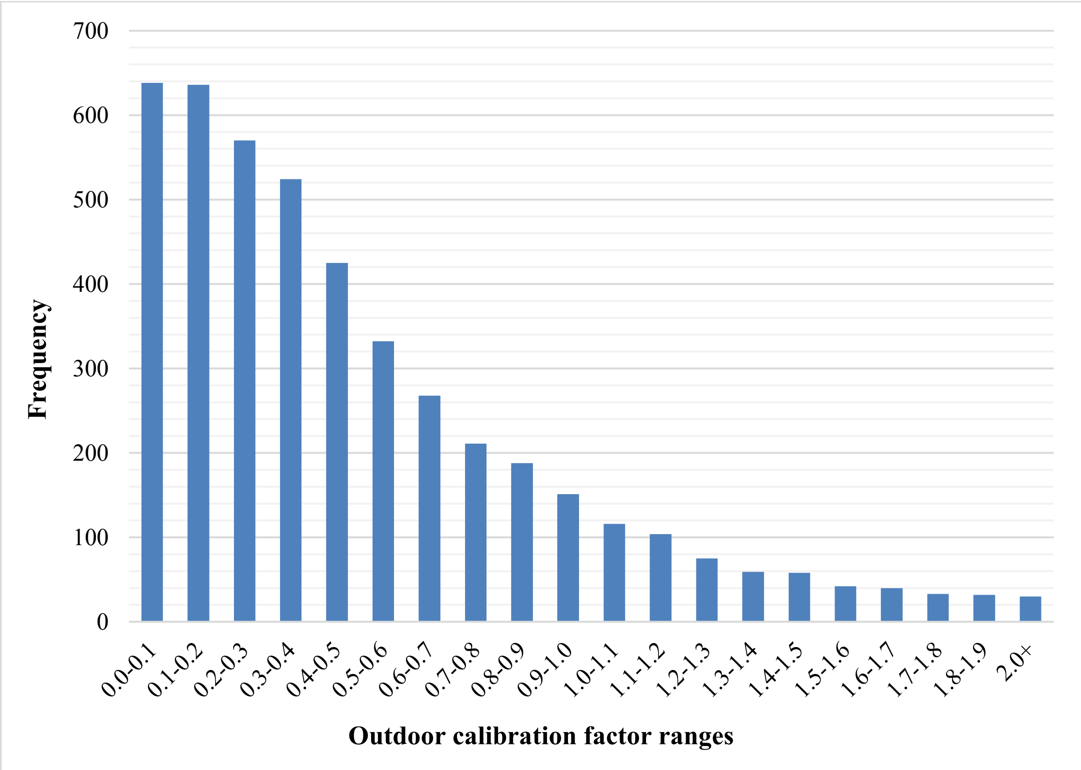

Figure 4-13: Summary of the outdoor calibration factors applied to every property

4.5.3 Final calibration results

The final calibration results after both the indoor and outdoor components had been calibrated are shown in Figure 4-14. Despite the marked improvement in the final calculated results from the initial calculations, there were still properties that did not match well with the measured data. This was a result of the inconsistent variation of measured data over the year for those particular properties. These mismatches resulted in the final results yielding a lower correlation co-efficient than that for the indoor calibration.

The results from the validation process of the measured data for the Liesbeek River indicated that some of the properties in the catchment did not have adequate measured data which meant that the calculated water use for these properties could not be calibrated. This mostly consisted of properties with water meter readings that did not have correct property reference numbers, or properties that had measured data with a zero reading over the entire year. In order to ensure that all of the data gaps in the model were substituted with a water demand value that was representative of their respective land use categories, the properties that could not be calibrated were assigned an average water demand. This average water demand value was taken as the average of all of the calibrated data for each particular land use.

The calibration process for all land use categories was completed using Microsoft Excel; a sample of the calibration model layout can be found in Appendix H.

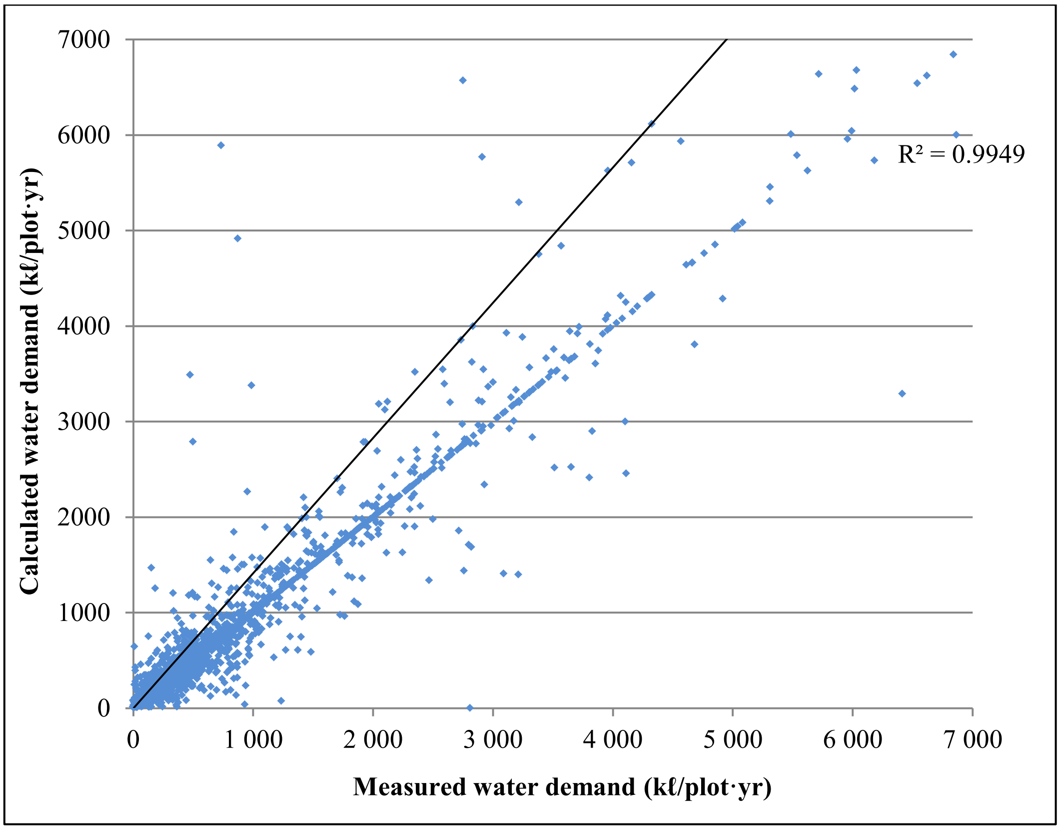

Figure 4-14: Calculated vs measured total water demand after final calibration

4.6 Identifying water saving interventions

The completion of the initial water balance provided a useful breakdown of water use by land use. The breakdowns of water end-use for the different land use categories were then used as inputs for the modelling of the different water saving interventions. Sustainable water management approaches incorporate numerous interventions that could improve the efficiency of water use. These interventions apply to a broad spectrum of urban planning and management disciplines, from policy development and regulation to the detailed design of urban spaces.

Figure 4-15 illustrates the potential sustainable water management interventions that apply to the distribution and use of water in the Liesbeek River catchment. Water savings can be achieved through three primary points of intervention. The first relates to the management of the distribution system; preventing water losses through effective operation and maintenance of the water reticulation network. The second approach involves reducing water by influencing how it is used; this involves both physical and non-physical intervention. The third approach promotes the use of alternative water resources to augment potable water supply requirements.

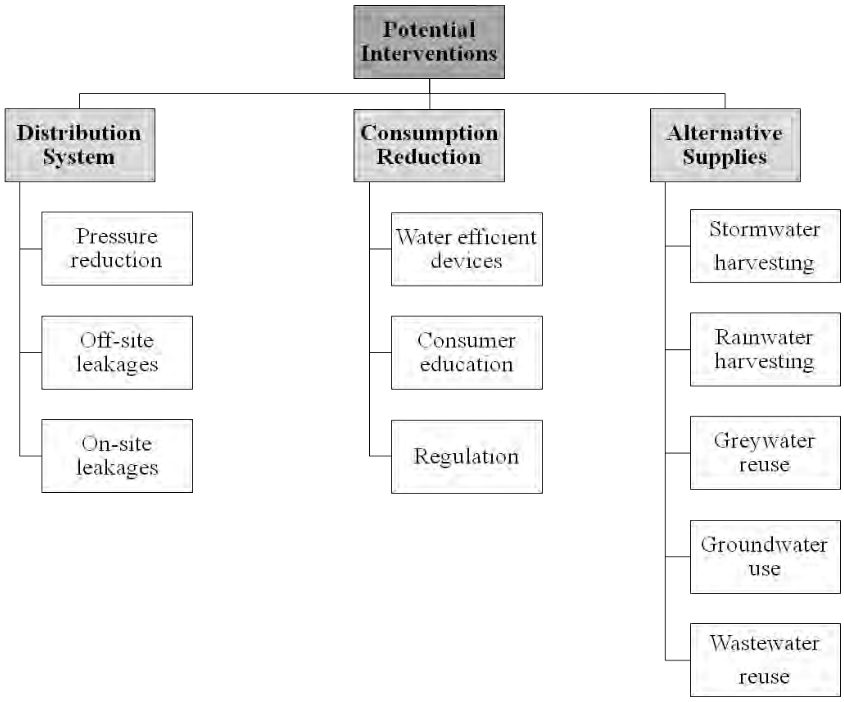

Figure 4-15: List of potential sustainable water supply interventions

(Adapted from CoCT, 2007)

4.6.1 The distribution system

The interventions that applied directly to the distribution system relate to any processes which have been developed to reduce physical water losses within the water reticulation network. Water leakage rates are directly linked to the pressure in the distribution system – if the pressures in the distribution system and the minimum night flows are known, the rate of water loss as a result of leakage can be estimated.

It was not possible to estimate the potential water savings as a result of the implementation of pressure reduction, and similarly, off-site leakages using the data available. In order to quantify water losses from the distribution system, detailed water meter readings and pressure readings were needed at strategic points in the distribution network; unfortunately this information was not available for the Liesbeek River catchment.

On-site leakage rates were therefore based on the work of Couvelis (2012) who provided estimates for the proportion of properties experiencing on-site leakage, as well as average flow rates of these leaks for most of the suburbs in the Liesbeek River catchment. This information was then used to approximate the total on-site leakage rates for the whole catchment.

4.6.2 Water use reduction

The interventions that applied to water use reduction related to any processes that focused on reducing the amount of water required by the user. Estimating the potential water savings from the installation of water efficient devices was possible as there was sufficient data available with which to quantify the water savings. The estimation of the impact of user education and regulation however, was not possible given that their contribution to saving water could not be quantified.

4.6.3 Alternative water supplies

The interventions that applied to alternative water supply related to any sources of water that could be used as a substitute for potable water; of all the interventions only rainwater and greywater harvesting were included in the model.

Stormwater harvesting models were not included as they require large quantities of data, and involved complex modelling processes which were beyond the scope of the project. The use of groundwater as an alternative resource was excluded on the grounds that there was limited information on the storage capacity or potential yield for the aquifers found in the catchment. Finally, the exclusion of wastewater was based on the fact that the provision of treated effluent to the Liesbeek would require an expensive pumping system to reach users in the catchment. Given that there are a variety of potential users – including two golf courses and two stadiums – situated much closer to the Athlone Treatment Works it was decided that it would be more appropriate to facilitate wastewater re-use closer to the treatment works rather than in the Liesbeek River catchment.

4.6.4 Summary of selected water saving interventions

Table 4-10 illustrates which of the sustainable water management interventions were incorporated into the water balance model. The model did not incorporate the full range of interventions, however as water management practice develops and more information becomes available, new opportunities for improving the modelling processes will arise. The inclusion of the selected interventions will at least provide a preliminary insight to the benefits of adopting more sustainable water management approaches in the Liesbeek River catchment

Table 4-10 (a): Alternative water management interventions included in the model

Intervention Category	Description	Included in Model	Reason for exclusion
Distribution Systems	Pressure Reduction	No	Insufficient data
	Off-site Leakage	No	Insufficient data
	On-site Leakage	Yes	

Table 4-11 (b): Alternative water management interventions included in the model

Intervention Category	Description	Included in Model	Reason for exclusion
Water Use Reduction	Water Efficient Devices	Yes	
	User Education	No	Indeterminate
	Regulation	No	Indeterminate
Alternative Water Supply	Stormwater Harvesting	No	Complex modelling process beyond scope
	Rainwater Harvesting	Yes	
	Greywater Re-use	Yes	
	Groundwater	No	Insufficient data
	Wastewater	No	Economically unfeasible

4.7 Modelling the water savings interventions

4.7.1 On-site leakage

The estimation of water losses as a result of on-site leakages was based on an MSc dissertation entitled *Apparent water loss due to consumer meter inaccuracies in selected areas of South Africa* (Couvelis, 2012). Couvelis performed a study on 405 properties in Cape Town, providing estimates of the percentage occurrence of on-site leakages, as well as the mean leakage flowrates for selected suburbs, most of which were situated within the Liesbeek River catchment. Table 4-12 shows the breakdown of estimates for the percentage occurrence of on-site leaks, and their average flow rates for the suburbs situated in the catchment.

Table 4-12: Estimated on-site leakage for selected Cape Town suburbs (Couvelis, 2012)

Suburb	No. of properties	Number of leaks	% leaks	Mean flowrate (ℓ/h)
Rosebank	17	3	18	7.2
Newlands	29	5	17	11.3
Observatory	27	4	15	9.3
Claremont	29	4	14	6.8
Mowbray	26	1	4	5.4

Couvelis' work was particularly useful as it incorporated every suburb found in the Liesbeek River catchment with the exception of Bishopscourt and Rondebosch. The percentage occurrence of on-site leakages was fairly consistent for all of the suburbs except Mowbray, which was significantly lower. Given the small sample size of properties in each suburb – between 17 and 29 – it was decided that an average of the percentage occurrence of leaks and the flow rates measured – weighted according to the number of properties sampled –would provide a better indication of on-site leakage across the catchment. The weighted averages indicated that 13% of properties in the catchment would have an on-site leakage problem with an average flowrate of 8 ℓ/h. These values were then multiplied by the total number of properties in the catchment to establish an estimate of the total on-site leakage losses.

4.7.2 Water efficient appliances

The estimation of the potential water savings that could result from the use of water efficient devices was quantified using a Water Research Commission report produced by Still *et al.* (2008). The report provides a review of the different water efficient fittings used in the domestic sector. A range of water efficient devices are available, each with different efficiency ratings and costs. The devices that use water more efficiently are more costly to install, but will be more effective at reducing the user's water use costs. From a water savings perspective, installation of the most efficient devices would be preferable, however the selection of which device to install would ultimately be up to the user.

Table 4-13 illustrates the flow rates and water requirements for fittings and devices which have been categorised into the following three categories:

i) **Typical use**, which represents the typical devices used in the domestic sector

ii) **Medium savings**, which represent devices that use reduced amounts of water to perform a specific task in comparison to typical use. These devices are not the most efficient devices on the market, however are cheaper than the high savings devices.

iii) **High savings**, which represents devices and fittings that have the highest efficiency ratings and use the least water to perform a specific task of all the available device.

The percentage water savings that could be achieved through the installation of the medium or high savings devices represented the reduction in water use relative to the standard devices, assuming that all of the catchment used standard devices and fittings. The devices that use flow rate as the basis of their efficiency rating were assumed to have end uses that were time dependant rather than volume dependant. This means that the defining factor in determining the volume of water used, is the length of time the device provides water with each use.

Estimating the potential savings for non-domestic land uses required additional information of the end-use breakdowns. Given that there was very little information on the end-use breakdowns for non-domestic water use in South Africa, the United States Environmental Protection Agency report on water use efficiency (US EPA, 2009), was used as a guideline.

Table 4-14 highlights the breakdown of the critical indoor end-uses of water for various non-domestic categories as suggested by the US EPA.

Table 4-13: Potential water savings as a result of the use of water efficient devices (adapted from Still *et al.*, 2008)

End-use	High Savings	Medium Savings	Typical Use	% Savings for High Savings Scenario	% Savings for Medium Savings Scenario
Bath			80 ℓ	n/a	n/a
Bath basin	2.4 ℓ/min	6.0 ℓ/min	9.0 ℓ/min	73.3	33.3
Dishwasher	15.0 ℓ	18.0 ℓ	22.0 ℓ	31.8	18.2
Kitchen sink	2.4 ℓ/min	6.0 ℓ/min	12.0 ℓ/min	80.0	50.0
Shower	6.0 ℓ/min	8.0 ℓ/min	12.0 ℓ/min	50.0	33.3
Toilets	6.0 ℓ	9.0 ℓ	14.0 ℓ	57.0	35.7
Washing machine	38.0 ℓ	57.0 ℓ	114.0 ℓ	66.7	50.0

Table 4-14: Breakdown of non-domestic end-uses of water (adapted from US EPA, 2009)

Water Use Category	Restroom	Kitchens	Laundry
Hospitals	35%	7%	9%
Office Buildings	37%	13%	NA
Schools	45%	7%	3%
Restaurants	31%	48%	n/a

The estimation of end-use breakdowns for land uses such as churches, libraries or community halls was not provided. For the purposes of the model it was assumed that community facilities would have the same end use requirements to that of schools. Both community facilities and schools are largely utilised by day visitors, with the majority of water being used for bathrooms or restrooms, these two land uses also have overlapping functions particularly with regard to sports facilities, libraries and community halls. The final assumptions for non-domestic indoor water use are listed in Table 4-15. Although the US EPA report (US EPA, 2009) did provide end-use breakdowns for kitchen and laundry use, these were excluded. This was based on the assumption that non-domestic properties were likely to use industrial dishwashers or washing machines, whose water efficiency ratings were unknown.

Table 4-15: Non-domestic indoor water use (adapted from US EPA, 2009)

Water Use Category	Domestic/Restroom
Hospitals	35%
Commercial	37%
Education	45%
Community	45%

The implementation of water-efficient devices has a direct impact on the implementation of other strategies such as greywater and rainwater harvesting; more efficient devices reduce the end-use requirements for alternative water supplies and reduce the greywater yield. In order to get an idea of the potential water savings – and therefore the impact on rainwater and greywater harvesting – that could be achieved through the incremental implementation of water efficient devices, five scenarios were developed. Each assumed the use of different proportions of standard, medium savings, and high savings devices for all of the properties in the catchment. Table 4-16 shows the different ratios of adoption selected for the five different scenarios.

Table 4-16: Scenarios for the different ratios of adoption of water efficient devices

Devices Used	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Standard Devices	0.8	0.6	0.5	0.1	0
Medium Savings Devices	0.1	0.2	0.25	0.45	0.5
High Savings Devices	0.1	0.2	0.25	0.45	0.5

The designation of the type of water efficient devices used by each property – standard, medium savings, or high savings – was completed through the use of a random number generator, which assigned the different devices to each property based on the ratios stipulated in each of the five scenarios. In Scenario 1 for example, 80% of the properties in the catchment were randomly assigned standard devices, 10 % were assigned medium savings devices, and 10% high savings devices. Given that the allocation of different devices to each property was random, the model would produce slightly different results each time. In order to get an average value for the water savings for each scenario, the calculation process was repeated using a macro in Microsoft Excel, the macro tabulated the results for each calculation set and then repeated the calculation 1000 times.

Figure 4-16 provides a simplified illustration of the problem. Each square represents a property in the catchment; the random number generator assigned to each ‘property’ standard (grey), medium savings (green), or high savings (blue) devices. The water savings results for this particular allocation of devices are summed up and tabulated in the model. The calculation cycle was then repeated with the water efficient devices again randomly assigned to different properties and summed up. Using the model results after every cycle, it was possible to identify an upper and lower bound for the potential water savings that could be achieved through the use of water efficient devices.

A summary of the calculation process used to develop the water efficient devices model can be found in Appendix G.

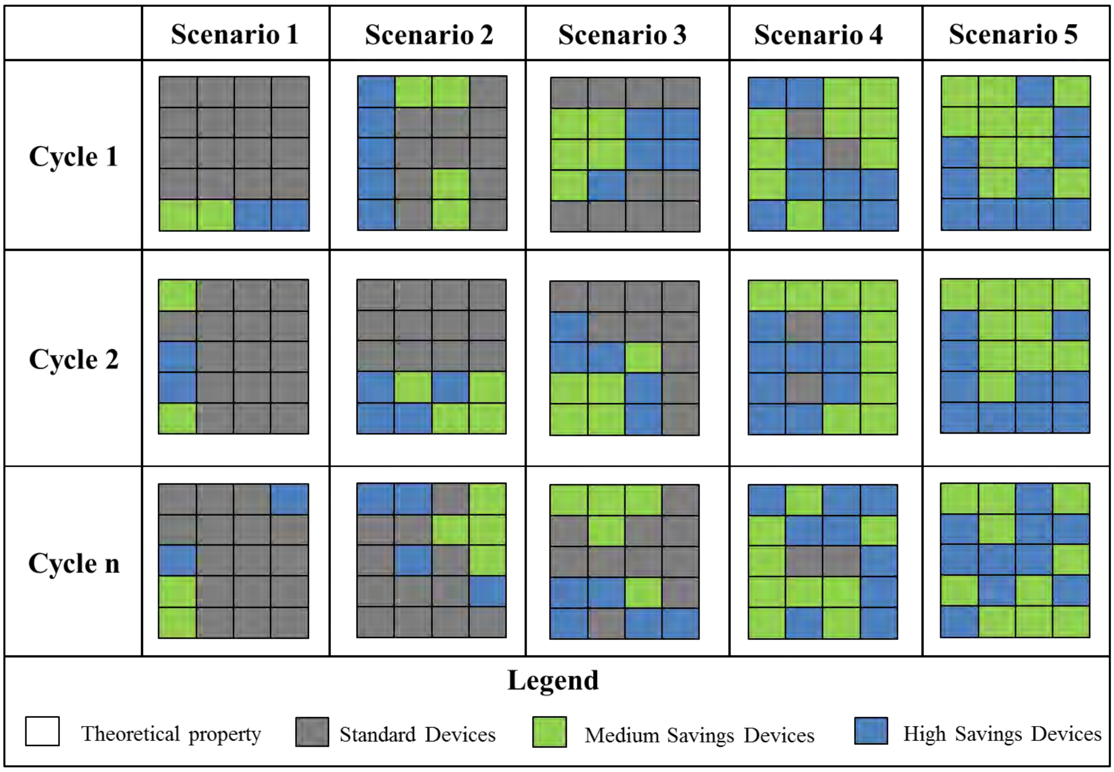

Figure 4-16: Example of the random allocation of adoption rates

4.7.3 Rainwater harvesting

The potential water savings from the implementation of rainwater harvesting was completed through the use of a rainwater harvesting model developed by Fisher-Jeffes (2013). The model calculated the potential rainwater harvesting yield for a particular property based on the rainfall in the catchment; the required demand for rainwater, as well as various life cycle costing variables that determined the economic viability of the rainwater tanks.

The modelling process involved two steps; the first step involved an optimisation process to select the ideal tank size for each individual property, and the second step calculated the impact of incremental increases in the adoption of rainwater harvesting systems within the catchment.

The optimisation of the rainwater harvesting scenario for each individual property was based on two variables:

i) The volume of rainwater that could be collected and used; and

ii) The costs associated with the collection and storage of this rainwater.

The available rainwater supply was calculated by using rainfall data and property roof areas to determine how much runoff could be captured during a rainfall event. Daily rainfall data spanning over a period of ten years was used for the model calculations. It was assumed that the rainwater tank would collect water from the entire roof surface, and a simple calculation involving rainfall depth, roof area, and a runoff factor produced the volume of rainwater harvested each day.

The demand for rainwater for a property was calculated by combining the water use requirements for any end-use demand that was deemed fit for a particular purpose. In the case of rainwater harvesting, it was decided that toilet flushing, clothes washing, and swimming pool top ups would be appropriate end-uses for the harvested rainwater. The end-uses that require potable water, such as bathing and kitchen use were deemed unacceptable, because of the health risks associated with ingesting untreated water.

The selection of an appropriate tank size for each property was achieved through an optimisation process, using the rainwater yield, and the end-use demand for the harvested rainwater. Figure 4-17 shows the relationship between tank sizes and their associated costs; a larger tank stores more water and could thus provide water for a longer period with no rainfall, however these tanks have higher capital and maintenance costs making the harvesting process more costly. The rainwater harvesting model calculated the volume of rainwater used by each property for ten different standard tank sizes ranging from 0.25 kℓ to 20 kℓ. Using the lifecycle costs associated with the different tank sizes, the cost per kℓ of rainwater collected was then calculated for each tank size.

The cost per kℓ of rainwater used was then compared to a cost estimate for the municipal supply of potable water; the tank size that best met the required end-use demand for rainwater was selected, but only if the cost per kℓ of rainwater used fell below the stipulated potable water cost. The estimated cost of municipal water was set at R50/kℓ, this estimation was based on the upper bound of the municipal water supply block tariff for the City of Cape Town, taking into account the added sewage charge (CoCT, 2014).

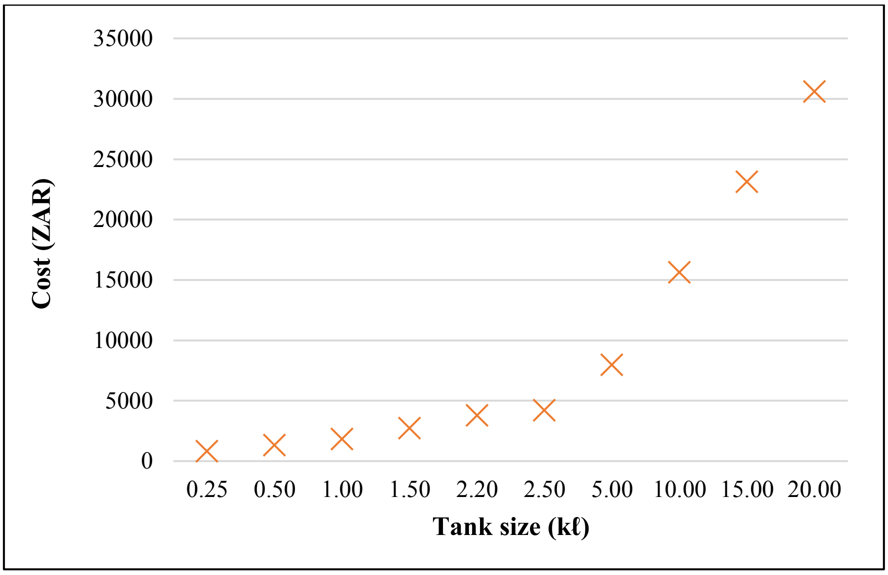

Figure 4-17: Illustration of the tank size selection for the rainwater harvesting model

Figure 4-18 illustrates the tank selection process for a single property in the catchment. The graph shows that the rainwater used by the property increases with larger tank sizes, with the 20 kℓ tank satisfying nearly all of the property's potential demand for rainwater. The cost per kℓ of rainwater harvested initially decreases for the 0.5 ℓ and 1 kℓ tank sizes and then rises with increasing tank size. The model optimisation process selected the tank size that provided the greatest rainwater use without exceeding the municipal cost of water. In the example shown in Figure 4-18, the tank size that was selected was the 15 kℓ tank.

After the optimisation of tank size had been completed for each property, scenarios for the incremental increase in the adoption of rainwater harvesting systems throughout the catchment were developed. The model ran ten scenarios with rates of adoption ranging from 10% to 100%. Determining which households would adopt the rainwater harvesting systems was done using exactly the same process used for water efficient devices. A random number generator determined which properties would use rainwater harvesting based on the adoption ratio stipulated for each scenario. The calculations were then run through multiple cycles, with the results being summed up and tabulated in the model at the end of each cycle. It was then possible to identify an upper and lower bound for the potential rainwater used through the use of rainwater harvesting systems for varying rates of adoption.

A brief summary of the rainwater harvesting model calculations can be found in Appendix E. The input variables into the model are also shown in Appendix D.

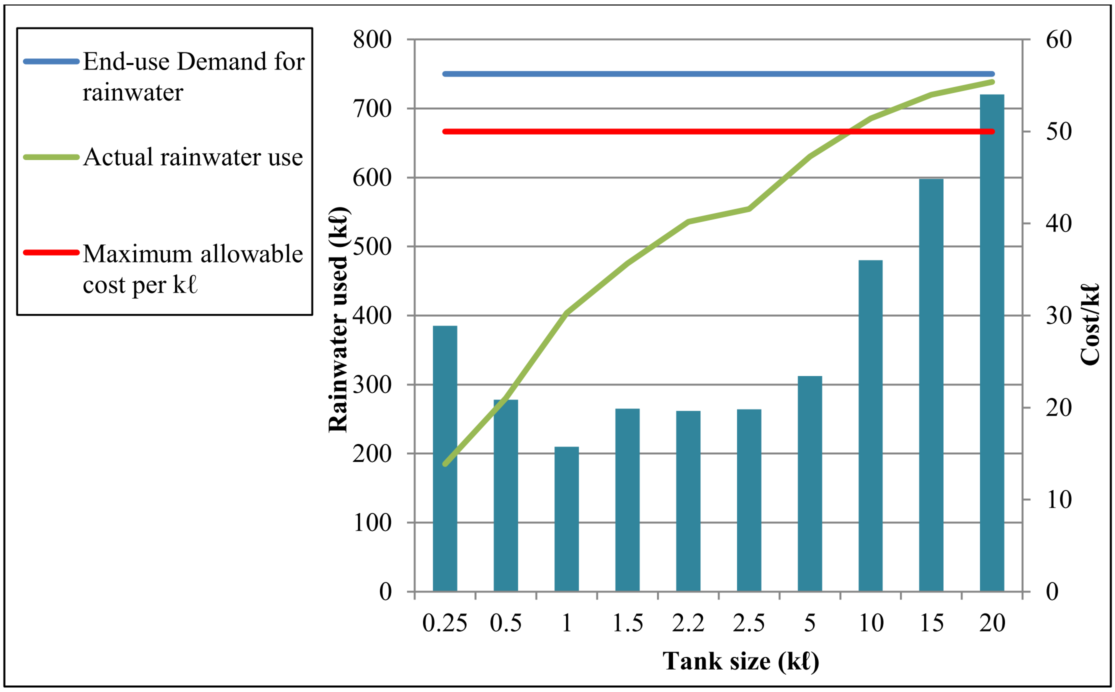

Figure 4-18: Rainwater harvesting tank selection process for a single property

4.7.4 Greywater harvesting

The greywater harvesting model followed exactly the same process as the rainwater harvesting model; the only difference between the two models was that the water supply consisted of greywater rather than roof runoff as a result of precipitation. The use of harvested greywater was initially prescribed for toilet flushing and garden watering however this was revised to only include garden watering the reasons for which are discussed in Section 5.4.

The greywater yield from domestic households was calculated by applying a return factor of 1 to all indoor end-uses – with the exception of toilet water – as suggested by Jacobs and Haarhoff (2004). This was based on the assumption that all indoor water use on a domestic property passes through into the sewer system. Toilet water was removed from the calculation because it was considered as blackwater and would require high levels of treatment before being considered for harvesting. Table 4-17 illustrates the estimated proportions of blackwater and greywater for domestic indoor water use.

Table 4-17: Estimations of wastewater yield for domestic properties

Water Use Category	Blackwater	Greywater
Domestic	38%	62%

The estimation of the proportion greywater and blackwater within the non-domestic sector required additional information on the end-use breakdowns of non-domestic water use. This was achieved through the use of the non-domestic end-use breakdowns developed for the water efficient devices model based on the United States Environmental Protection Agency (US EPA) report *Water Efficiency in the Commercial and Institutional Sector: Considerations for a Water Sense Program* (US EPA, 2009). The greywater yield was calculated by assuming that all indoor water use that was not designated as toilet water was to be considered as greywater. Table 4-18 illustrates the estimated proportions of blackwater and greywater for non-domestic indoor water use. A brief summary of the greywater harvesting model calculation process can be found in Appendix F.

Table 4-18: Estimations of wastewater yield for non-domestic properties

Water Use Category	Restroom (Blackwater)	Greywater
Hospitals	35%	65%
Commercial	37%	63%
Education	45%	55%
Community	45%	55%

4.8 The final model compilation

This chapter has provided a comprehensive summary of the model design for both the water balance model, as well as the three different water saving interventions models. Although linked to one another, the water balance model, water efficient devices model, rainwater harvesting model, greywater harvesting model are standalone, and each provided an output which was used to develop the final water use results in the Liesbeek River catchment. The results of the analyses performed for the different models are presented in the following chapter.

5. Modelling results

This chapter will discuss the results from the modelling of the water balance, as well as the selected water savings strategies. The catchment's water use prior to the implementation of the water savings strategies is analysed, followed by an analysis of the impact of the selected water savings interventions on reducing potable water demand in the Liesbeek River catchment.

The water balance indicated that the Liesbeek River catchment used approximately 6134 Mℓ of potable water over a one year period between May 2010 and April 2011. This amounted to nearly 2% of Cape Town's total water demand of 326 000 Mℓ/yr. Figure 5-1 shows the breakdown of total water demand in the catchment by land use. Given that the majority of the catchment consisted of domestic properties, it was not surprising that domestic water use made up the bulk of the water demand. The domestic land use category accounted for about 3368 Mℓ/yr – nearly 55% of the catchment's total water demand. The relative proportion of domestic water use in relation to the total catchment water demand was similar to the 59% estimated for the entire Cape Town metropolitan area (CoCT, 2011c). The non-domestic water requirements in the catchment were significantly lower – the commercial, hospital and education sectors used 853 Mℓ/yr, 768 Mℓ/yr, and 831 Mℓ/yr respectively. Community facilities had the lowest annual water demand with 315 Mℓ/yr.

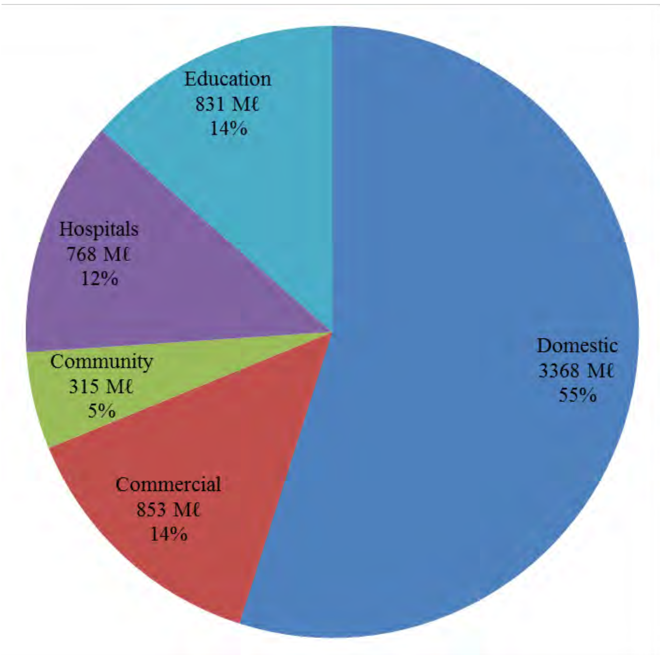

Figure 5-1: Total water demand in the Liesbeek River catchment according to land use

The water demand requirements for the hospitals water use category made up a significant proportion of the catchment's non-domestic demand despite the fact that there were only three major hospitals in the catchment: Groote Schuur, Mowbray Maternity, and Valkenberg hospitals. The high demand was accounted for by the Groote Schuur hospital, which used nearly 643 Mℓ/yr of potable water, 10% of the catchment's total water demand.

Figure 5-2 illustrates the total water demand per stand for all of the properties in the Liesbeek River catchment. The water use per property was relatively low in the residential suburbs of the catchment; this can be attributed to the fact that these areas largely consist of general residential properties with one household per stand. The variation in water use amongst the general residential water use category is clear with the larger properties in the south of the catchment using more water than the smaller properties in the north. The heavily urbanised areas in the centre of the catchment showed higher water demand in comparison to the residential suburbs. The high demand could be attributed to the large numbers of high rise flats, as well as the increased presence of non-domestic land uses such as office blocks, commercial centres, community facilities, and educational institutions. These land uses generally accommodate greater numbers of water users on a daily basis, leading to higher water use rates. Properties with water use higher than 8000 kℓ/yr were mostly associated with properties that accommodate educational institutions, large blocks of flats, or community facilities.

In terms of an indoor-outdoor split for the catchment, indoor water demand made up 86% of the total water demand, amounting to 5271 Mℓ/yr. The outdoor fraction made up the remaining 14% with a water demand requirement of 863 Mℓ/yr. These results appear to be reasonable as Cape Town, and the Liesbeek River catchment in particular, receives a relatively high annual rainfall. This meant that the irrigation requirements for gardens and fields would have been low or non-existent for large parts of the year. Figure 5-3 illustrates the total outdoor water demand for all of the properties in the Liesbeek River catchment. The distribution of outdoor water use was noticeably larger in the south of the catchment where the larger suburban properties were situated. In the north of the catchment, around Mowbray and Observatory, the properties were far smaller and did not have large gardens resulting in lower outdoor water demands. Some of the larger properties in the catchment showed little or no outdoor water demand; these properties were known to have boreholes on-site and it was assumed that these properties had satisfied any outdoor water requirements by means of borehole water. This was particularly common for schools and sports grounds which use large quantities of water for irrigation.

Figure 5-4 illustrates the proportion of indoor and outdoor water use broken down according to land use. It was estimated that nearly 65% of outdoor water use was utilised by the domestic properties amounting to 585 Mℓ/yr. The Liesbeek River catchment has an affluent demographic and most households have a garden, and in many cases, a swimming pool. It was therefore expected that the bulk of the outdoor demand would be used by domestic households. The second largest outdoor water users were the community and education land users, which used 16% and 12% of the total outdoor water demand respectively. Commercial had the lowest outdoor water requirements making up 7% of the outdoor water demand. Although many community and educational facilities had large swimming pools and/or sport fields, some of these properties use borehole water to irrigate fields, thus reducing the demand for municipal water supply for irrigation purposes.

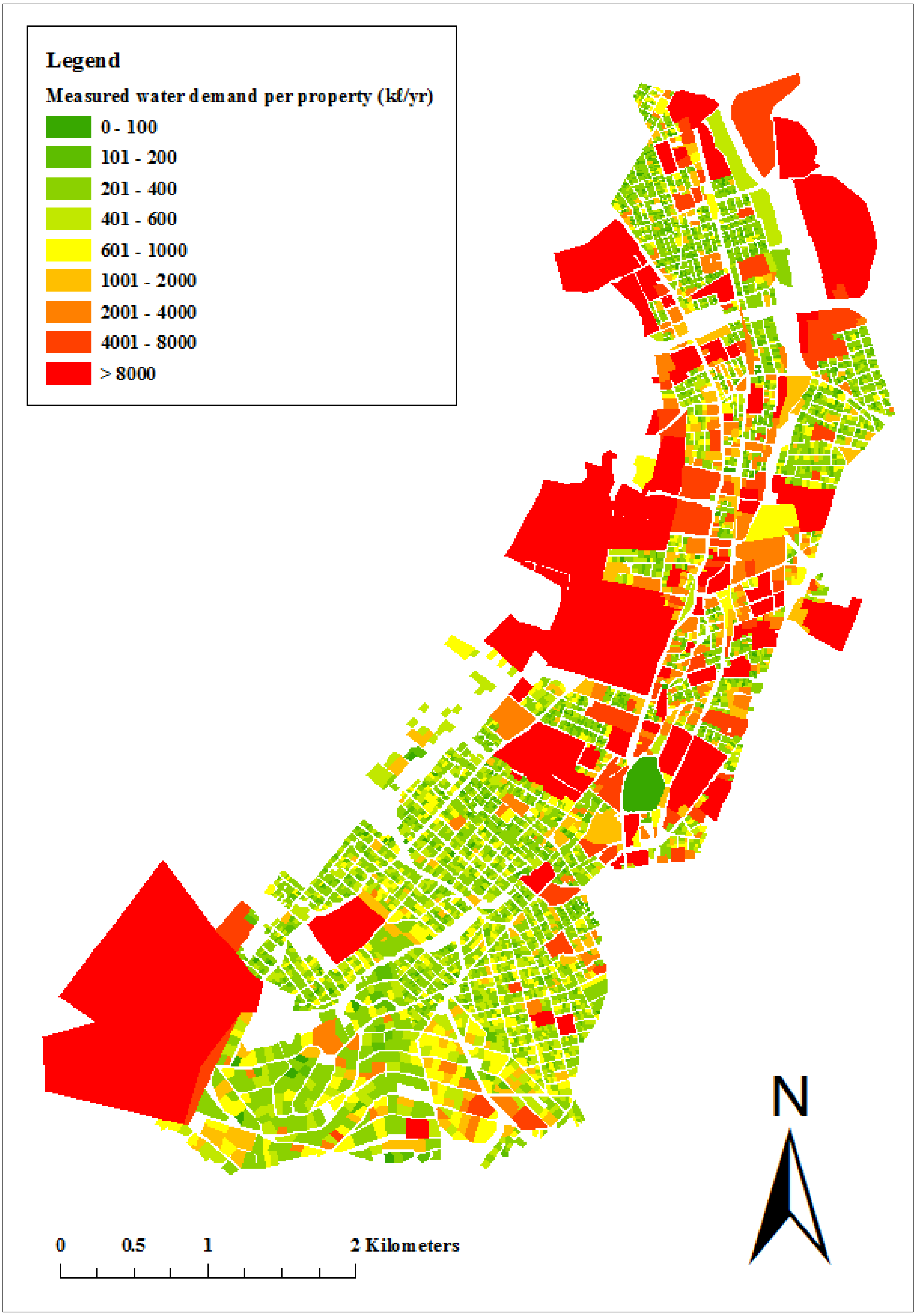

Figure 5-2: The distribution of calculated water demand in the Liesbeek River catchment

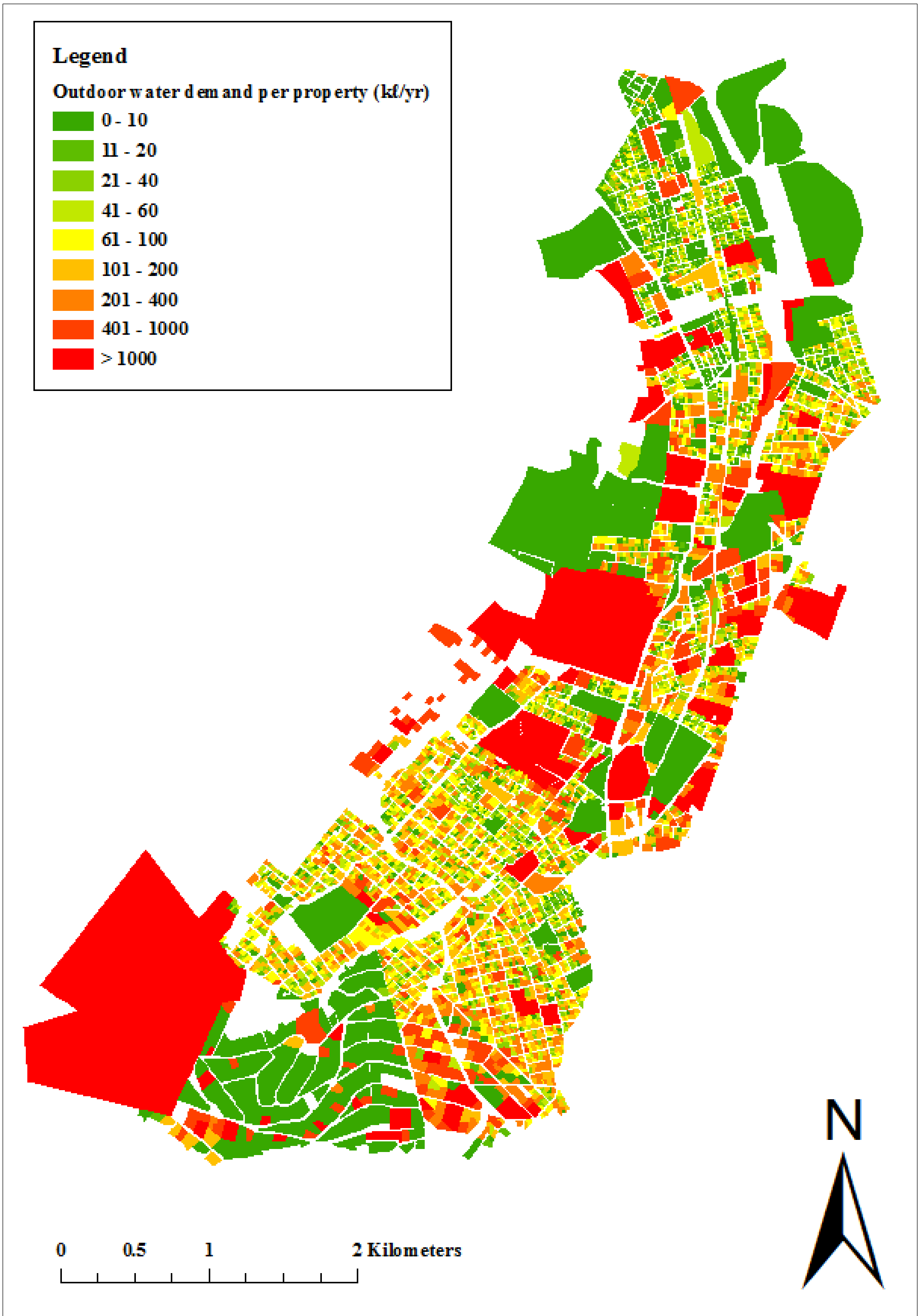

Figure 5-3: The distribution of outdoor water demand in the Liesbeek River catchment

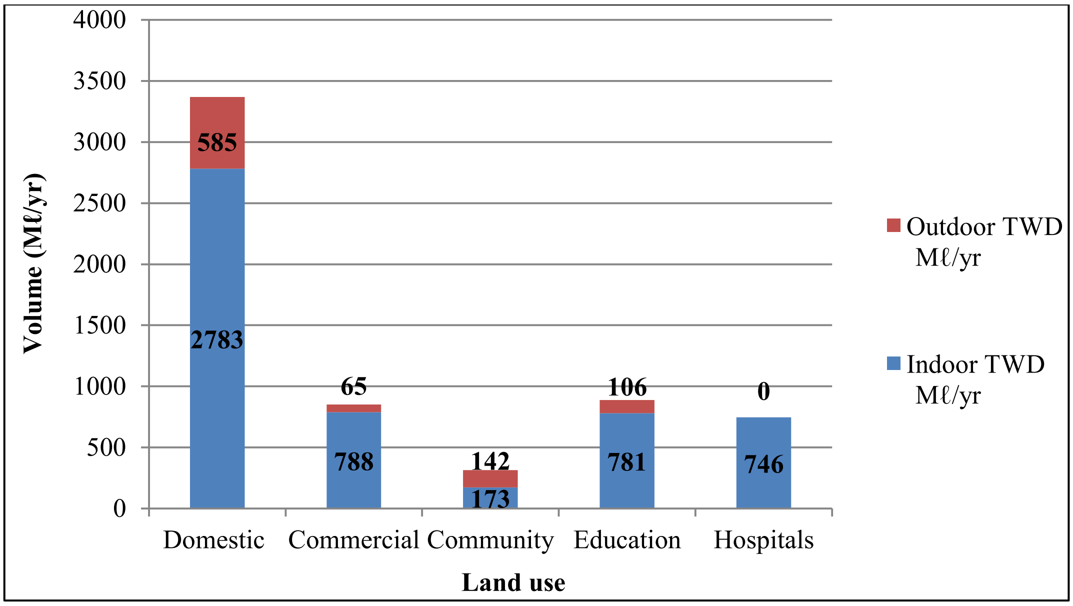

Figure 5-4: Indoor and outdoor water demand broken down according to land use

Figure 5-5 illustrates the final water balance results for the current water use in the Liesbeek River catchment. Approximately 6134 Mℓ of potable water is imported into the catchment every year. The majority of this water – approximately 86% – is then discarded into the sewage system where it leaves the catchment in the form of wastewater. The remaining 14% of water that does not leave the catchment as wastewater can be attributed to outdoor water use. This water is either lost to the atmosphere as a result of evapotranspiration, or alternatively infiltrates into the soil and forms part of the groundwater system.

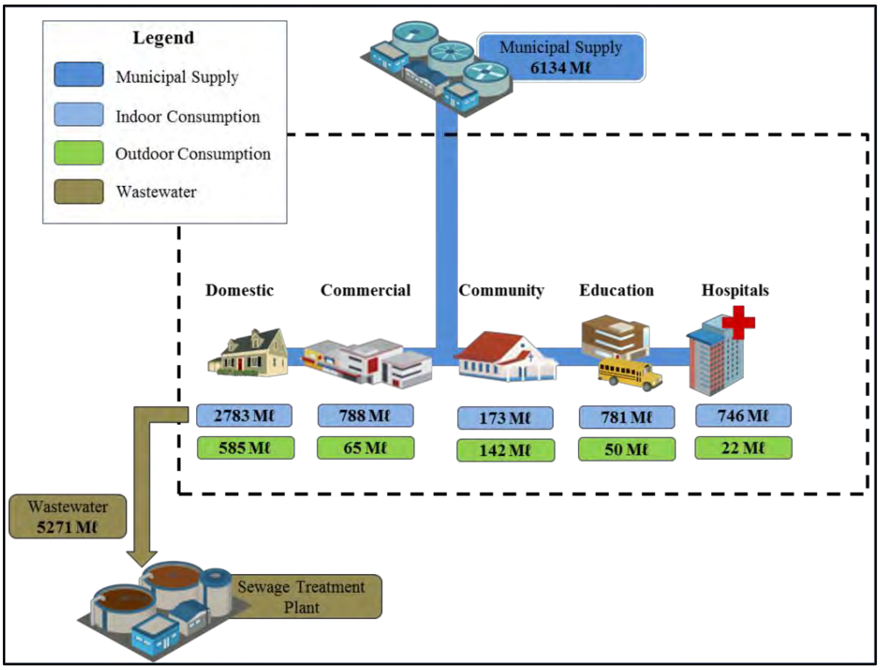

Figure 5-5: A summary of the water balance results for the Liesbeek River catchment

5.1 Water savings through the use of water efficient devices

The implementation of water efficient devices has the potential to make a significant impact on reducing water use in the Liesbeek River catchment. Figure 5-6 illustrates the modelled reduction of indoor water demand with increasing rates of adoption of water efficient devices. The lower and upper bounds represent the lowest and highest possible reductions when randomly assigning the given rates of adoption to different properties within the catchment. At a 40% adoption rate, water efficient devices could save between 569 Mℓ/yr and 965 Mℓ/yr; this represents an 11 to 18% savings in indoor water use. At 100% adoption – all properties within the Liesbeek River catchment adopted the use of water efficient devices – water savings of up to 37% could be achieved, saving 1947 Mℓ/yr.

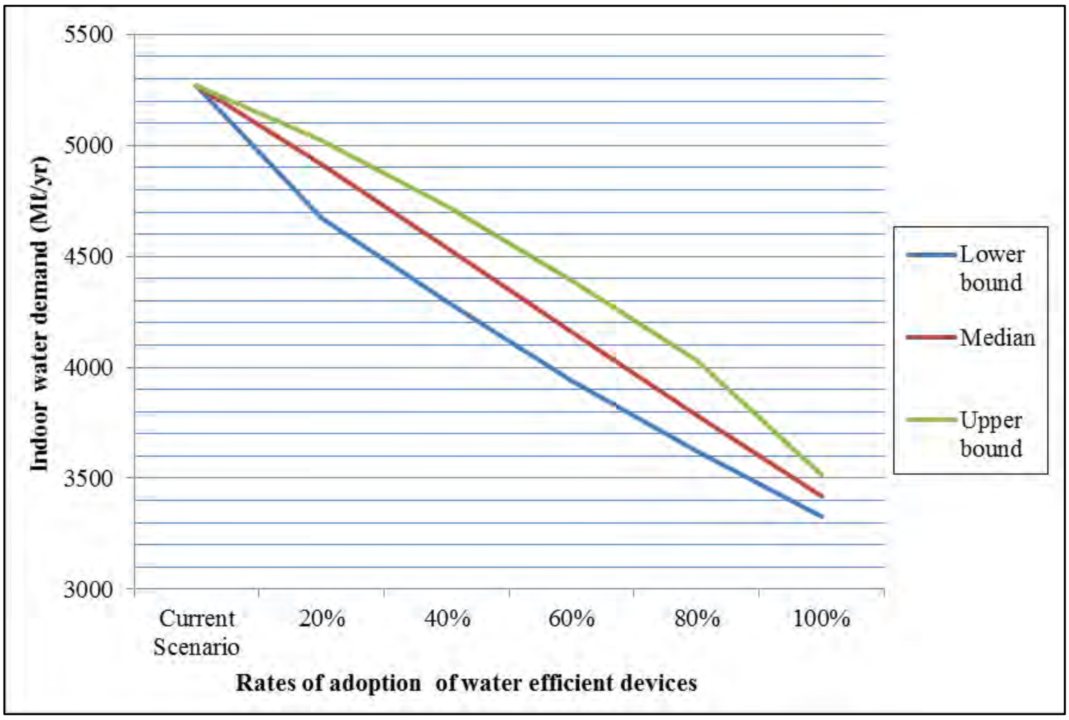

Figure 5-6: Reduction in indoor demand with increasing use of water efficient devices

Figure 5-7 illustrates the total indoor water demand for the different land use categories both before and after the implementation of water efficient devices. The implementation of water efficient devices has the greatest impact on the domestic sector. Installing water efficient devices in domestic properties could potentially reduce indoor water use by nearly 50%, saving 1385 Mℓ/yr. The savings achieved by installing water efficient devices are significantly lower for the non-domestic sector. Potential water savings range from 17% for the commercial sector, 23% for community facilities, 25% for educational institutions, and 12% for hospitals. Although not as effective as in the domestic sector, the use of water efficient devices in the non-domestic sector could still save 463 Mℓ/yr, 7.5% of the catchment's total indoor water demand.

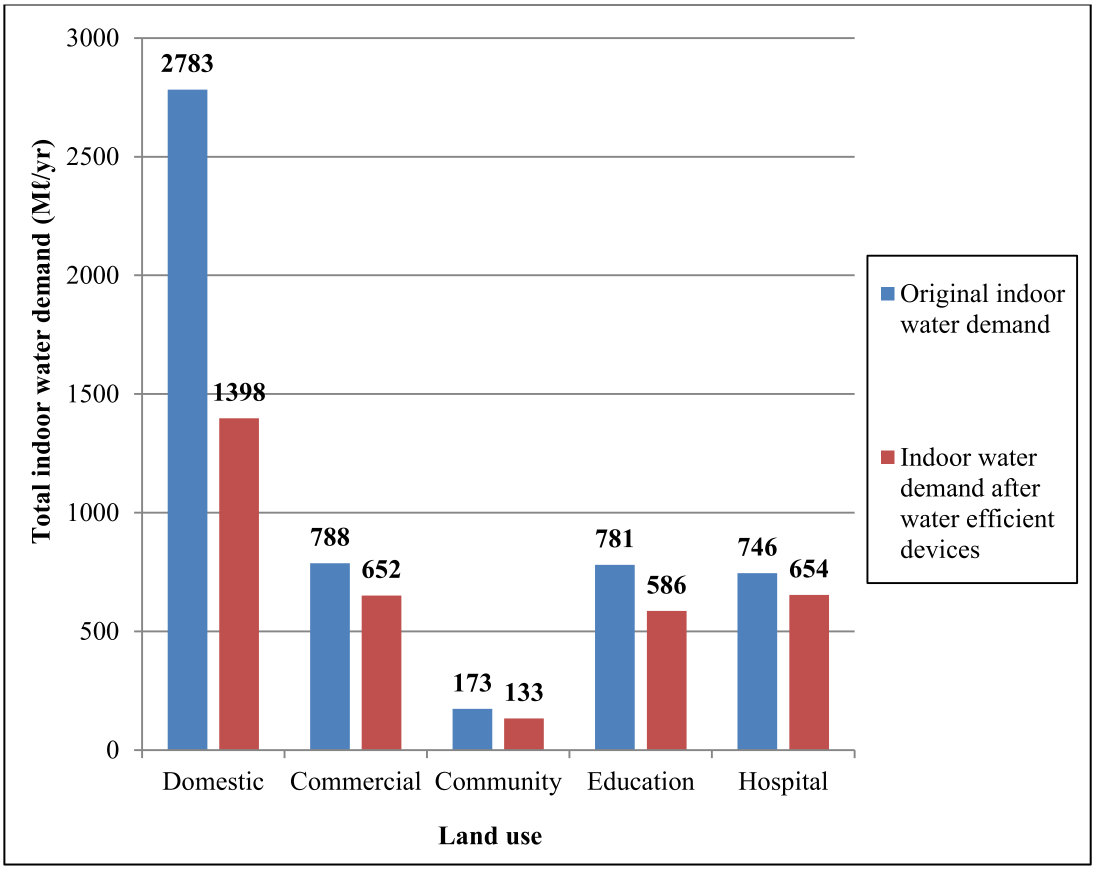

Figure 5-7: Total indoor demand before and after water efficient devices

5.2 Estimating on-site leakage rates

The estimation of on-site leakage provided a single water loss value based on two variables; the average percentage of properties that were experiencing leaks, and the average leakage flow rate. Using the data provided by Couvelis (2012) as the basis for the estimation, it was found that approximately 66 Mℓ/yr of water a year could be lost as a result of on-site leakage. This amounts to nearly 1% of the catchment's total water demand.

5.3 Rainwater harvesting results

The results of the rainwater harvesting model highlight the potential savings that could be achieved through the implementation of rainwater harvesting in the Liesbeek River catchment. The implementation of rainwater harvesting throughout a catchment would require significant organisation, investment, and institutional backing and the process would be incremental. Figure 5-8 illustrates the different potable water savings that could be achieved with increasing rates of adoption of rainwater harvesting systems. The maximum and minimum yield represent the lowest and highest possible rainwater yields, when randomly assigning the given rates of adoption to different properties within the catchment. The increase in rainwater yield was proportional to the rates of adoption of rainwater harvesting in the catchment; if half of the properties in the catchment were to adopt rainwater harvesting systems, roughly 446 Mℓ/yr of rainwater could be collected. The yield increased linearly with increasing rates of adoption until all of the properties in the catchment were harvesting rainwater, potentially yielding 892 Mℓ/yr, roughly 15% of the catchment's total water demand.

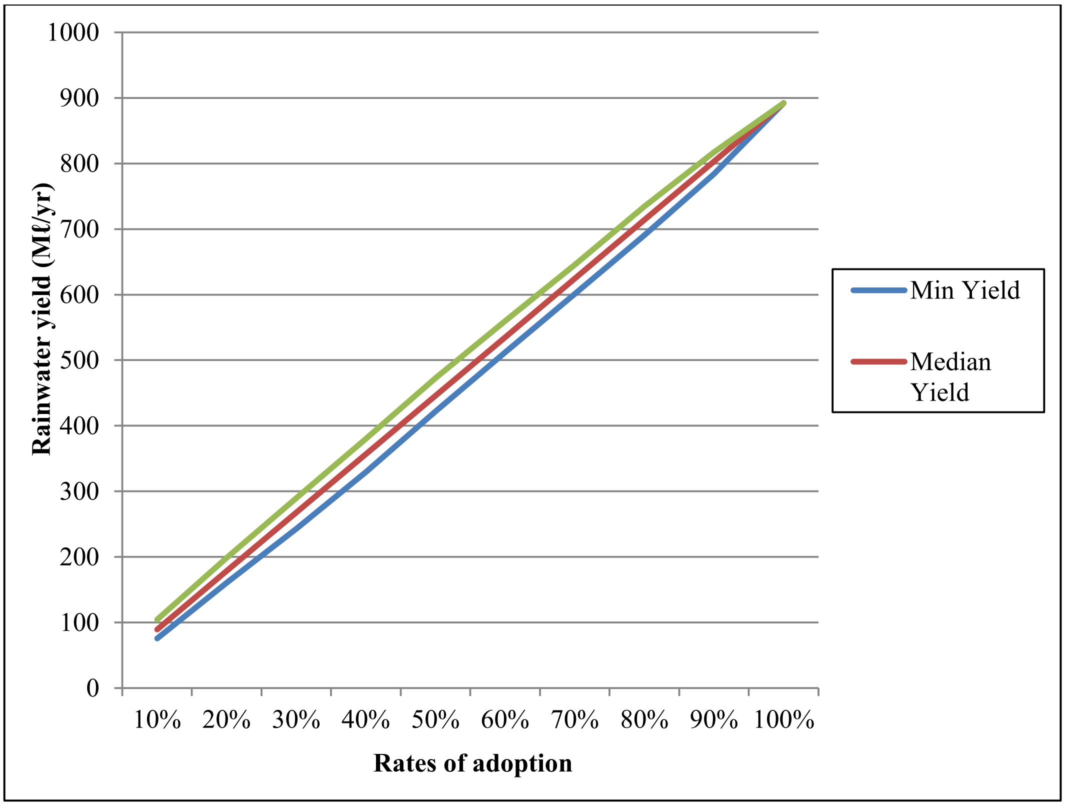

Figure 5-8: Potential water savings with increased adoption of rainwater harvesting

The rainwater yield shown in Figure 5-8 is based on the assumption that the harvested rainwater is used to supplement toilet flushing, washing machine use, and pool top-ups. Figure 5-9 illustrates the increase in rainwater use with the addition of new end-use requirements. Using rainwater harvesting to supplement toilet flushing provides the greatest individual rainwater yield of 692 Mℓ/yr, potentially saving 11% of the catchment's total water demand. Toilets make the largest impact because of their prominence across all land use categories, as well as their consistency of use throughout the year. The inclusion of washing machines increases the potential rainwater yield by nearly 191 Mℓ, only one third of the rainwater demand for toilet flushing. This can be attributed to the fact that washing machines are only typically used in domestic properties, and are used far less frequently than toilets. It must be noted that the use of rainwater for washing machines would require a booster pump to provide sufficient pressure, making their implementation more problematic and costly. The inclusion of swimming pools does not produce any major increase in the demand for rainwater. Swimming pools only required approximately 9 Mℓ/yr of rainwater, increasing the potential rainwater yield by approximately 1%.

The low contribution of swimming pools to the rainwater harvesting yield is a result of the fact that swimming pool water demands are low over the wet winter season. The low water demands were consistent for all of the outdoor end-uses whose demands would have been adequately catered for during precipitation events. This meant that rainwater harvesting was an ineffective alternative water source for outdoor use, unless the storage volume of the tanks was large enough to store water throughout the dry summer months. A rainwater tank would need to have a storage volume in excess of 30 kℓ in order to provide sufficient water for a typical domestic swimming pool over the duration of the dry season. Given the size and space requirements for such installations, as well as the high costs for purchase, installation, and maintenance, the economic viability of this approach is difficult to justify. Thus, in order to ensure rainwater harvesting schemes are more cost effective, indoor end-use demands such as toilets and washing machines are preferable as they provide a more constant demand during the wet winter months. It must be noted that this reasoning is only applicable to the Western Cape's climate and not necessarily the rest of South Africa which predominantly has a summer rainfall climate.

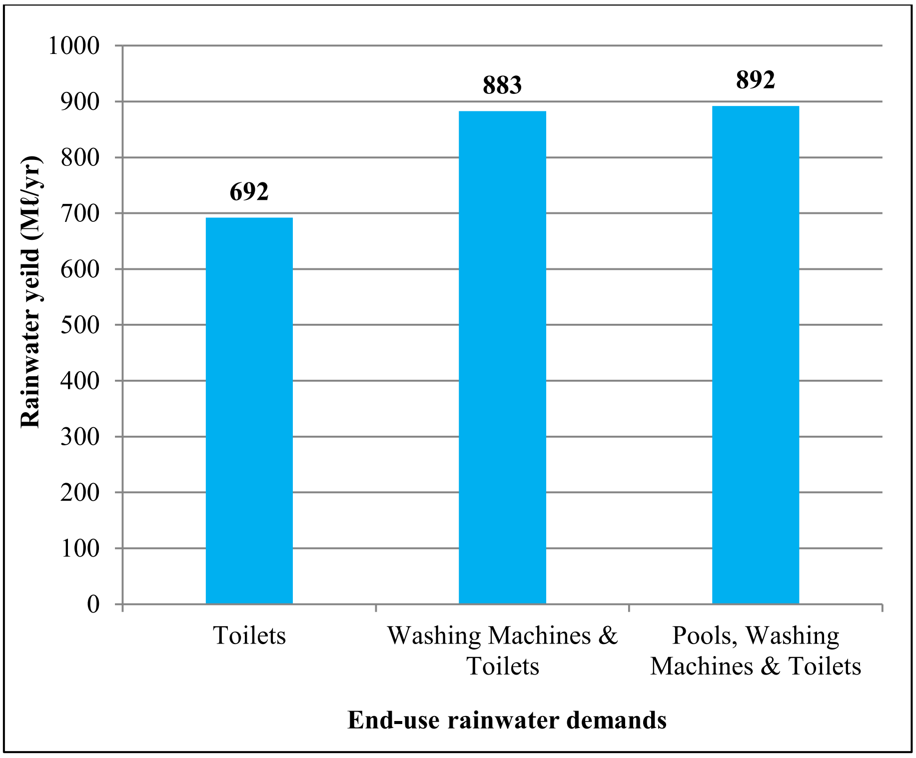

Figure 5-9: Rainwater yield for different end-use requirements

Figure 5-10 illustrates the distribution of rainwater tank sizes, as modelled for all properties in the Liesbeek River catchment for the different potential end-uses. As the end-use demand increases, the tank size distribution shifts towards the higher end of the range. This was a result of the fact that higher rainwater end-use requirements needed larger tank sizes to satisfy the demand in a cost effective manner. The results presented in Figure 5-10 illustrate the point that rainwater harvesting tanks do not necessarily need to be large enough to store water for use over the dry summer months if being used for toilets and washing machines. Smaller tanks that provide water for these two end-use demands and are refilled periodically with each rainfall event can also deliver large quantities of harvested rainwater.

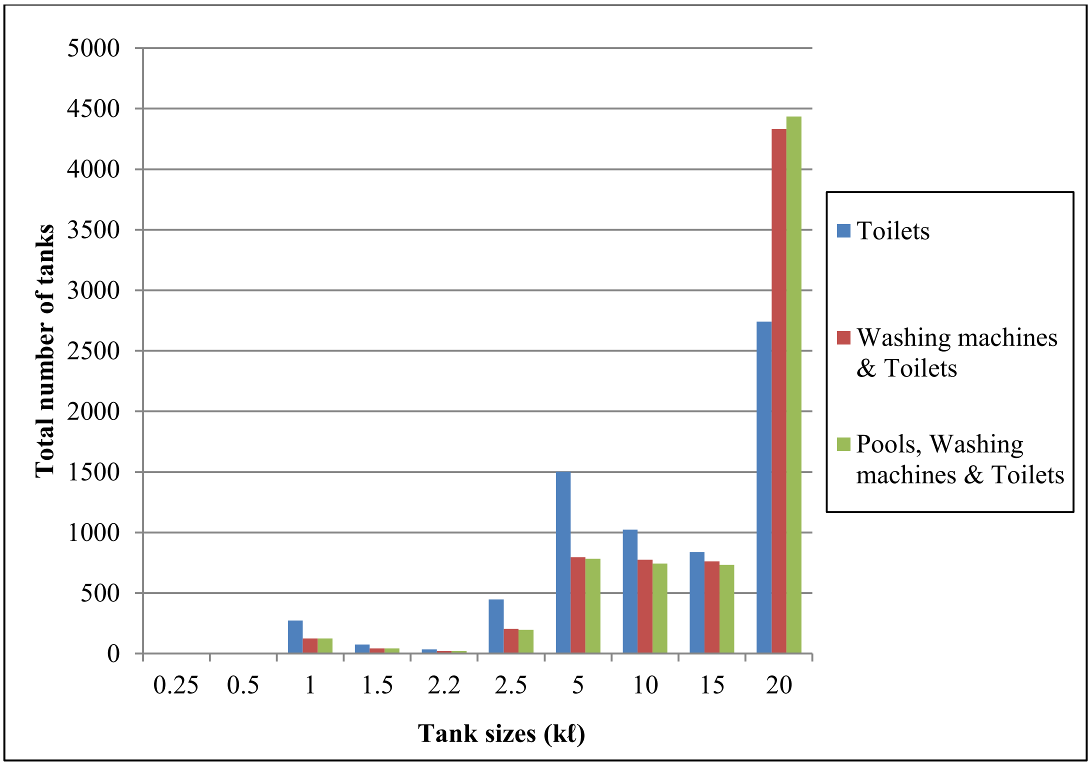

Figure 5-10: Distribution of tank sizes for different rainwater harvesting scenarios

The distribution of the demand for harvested rainwater throughout the catchment is illustrated in Figure 5-11; the harvesting scenario selected included pools, toilets, and washing machines. The rainwater demands were highest around the centre of the catchment where the larger properties – multi-storey buildings, and a range of educational and community facilities – in the catchment were able to take advantage of rainwater harvesting as a result of their high water demands which presented greater opportunity for rainwater as an alternative water source. From a general residential perspective, the rainwater harvesting yield was greater to the south of the catchment, particularly in Bishopscourt. In addition to larger roof areas and increased water demand, these larger properties in the south of the catchment had the added advantage of a higher annual rainfall.

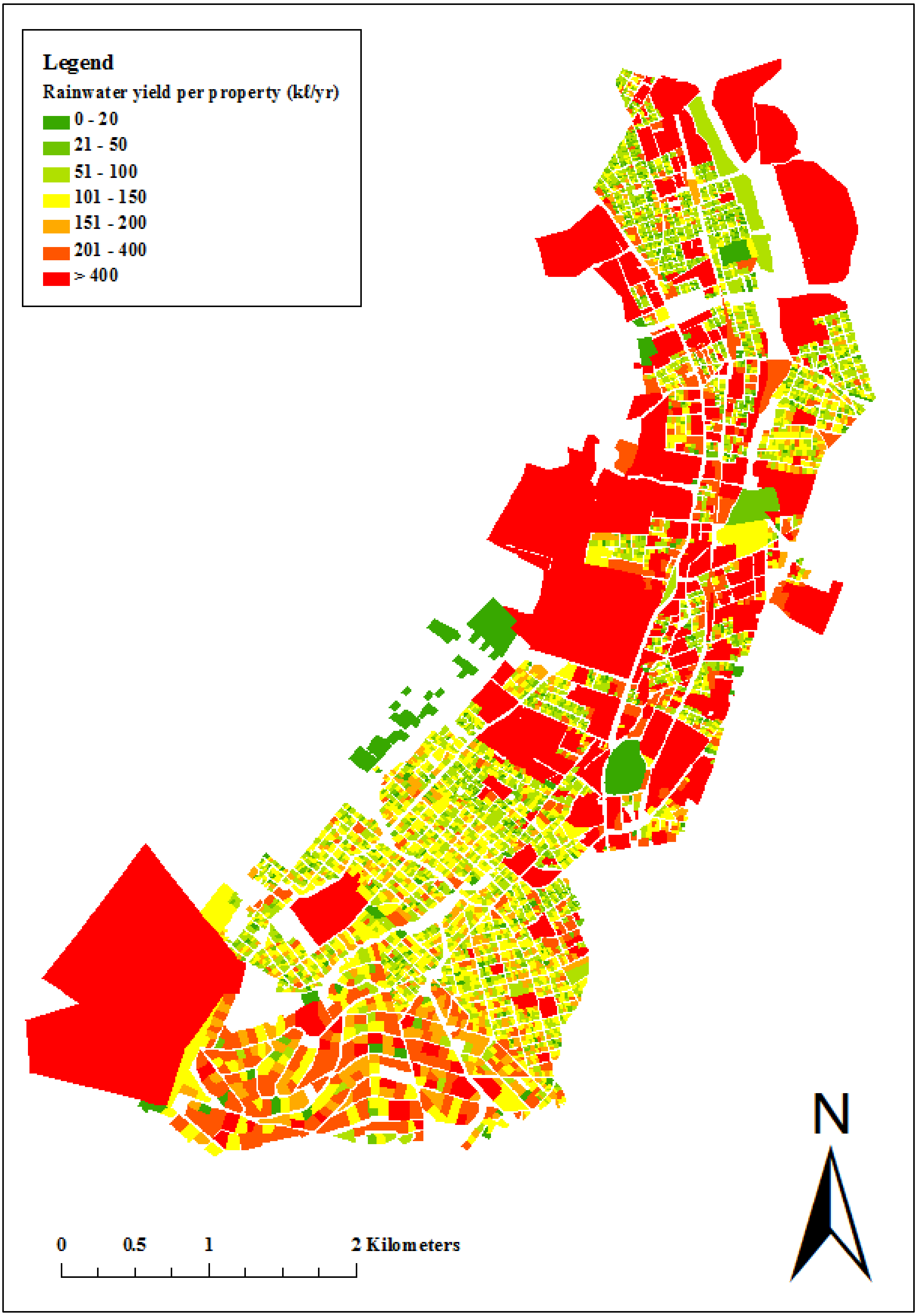

Figure 5-11: The distribution of calculated rainwater harvesting yield per property

Figure 5-12 illustrates the total volume of rainwater harvested from the catchment broken down according to land use. The majority of rainwater is used by domestic properties; up to 756 Mℓ/yr of potable water could be used to augment potable water supplies for both toilets and washing machines, which amounts to roughly 12% of the catchment's total water demand. The commercial land use category has the second largest rainwater demand of 86 Mℓ/yr, one tenth of the domestic rainwater demand. The three remaining land use categories, community, education, and hospitals use 20 Mℓ/yr, 25 Mℓ/yr, and 5 Mℓ/yr of rainwater respectively, a combined total of 50 Mℓ/yr.

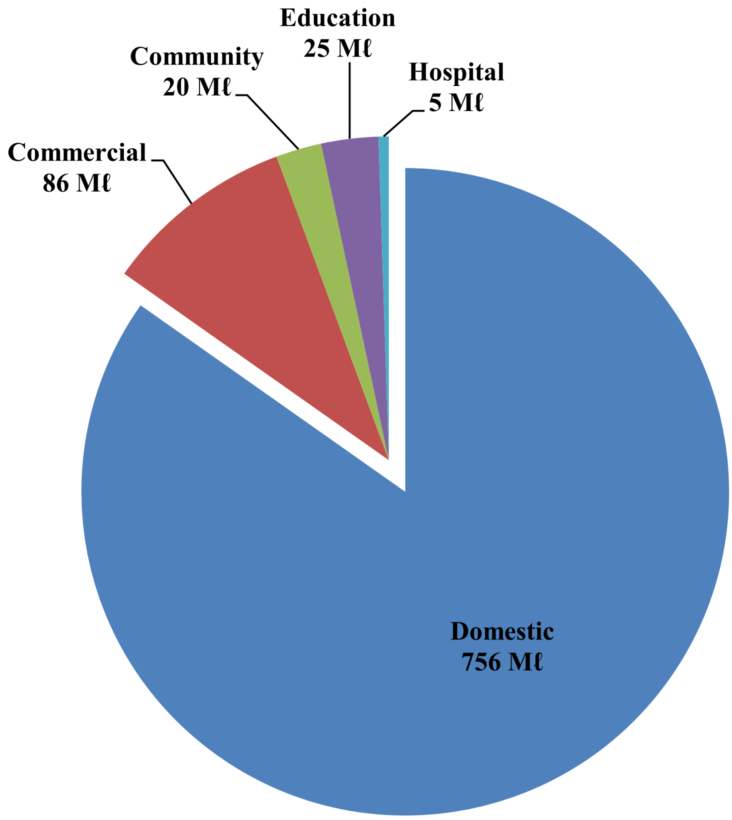

Figure 5-12: The breakdown of rainwater harvesting yield according to land use

The contribution of the rainwater harvesting to the total water use for each land use category is illustrated in Figure 5-13. Rainwater harvesting has the greatest impact on the domestic land use category, providing up to 22% of the total water demand for the domestic sector. The rainwater harvesting contribution to the commercial land use category is significantly lower, with rainwater potentially providing 10% of the annual water demand. community facilities, education and hospitals all have relatively low rainwater contributions with 6%, 3% and 0.6% of their respective total water demands being supplied by rainwater harvesting.

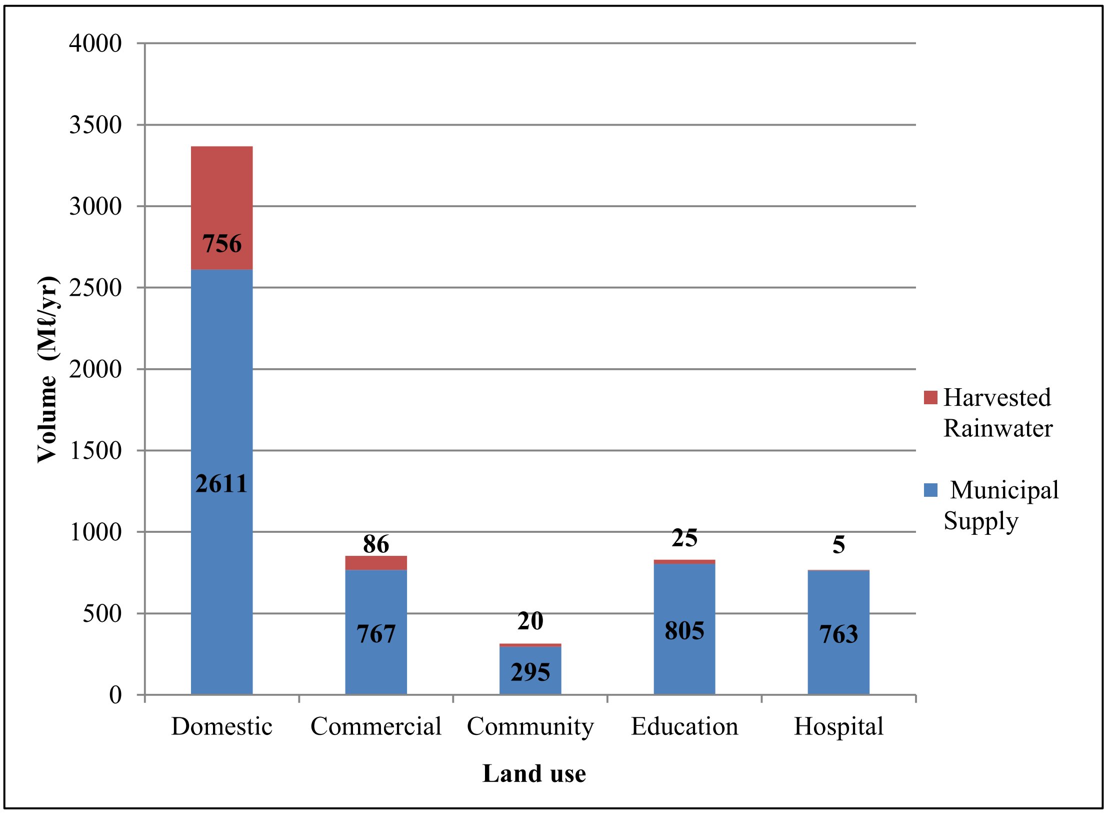

Figure 5-13: Contribution of rainwater harvesting to total water demand

5.4 Greywater harvesting results

The results of the greywater harvesting model highlight the potential savings that could be achieved through the implementation of greywater harvesting in the Liesbeek River catchment. Figure 5-14 illustrates the greywater yields that could be achieved with increasing rates of adoption of greywater harvesting systems; the harvesting scenario selected included toilets, and garden watering. As with rainwater harvesting, the increase in greywater yield is proportional to the rate of its adoption in the catchment. The maximum and minimum yield represents the lowest and highest possible greywater yields when randomly assigning the given rates of adoption to different properties within the catchment. If half of the properties in the catchment were to adopt greywater harvesting systems, approximately 700 Mℓ of greywater could be collected every year. The yield increases linearly with increasing rates of adoption until all of the properties in the catchment harvest greywater, potentially yielding 1500 Mℓ/yr of harvested greywater, approximately 25% of the catchment's total water demand.

Two end-uses could use greywater as a substitute to municipal water supply: toilet flushing and garden watering. For both of these end-uses the level of human contact is relatively low, meaning that the health risks associated with exposure to greywater are mitigated. Given that the supply of greywater remains relatively constant over the hot dry summer months, it provided an ideal water source for garden irrigation which had the highest demand over this period. Despite the low levels of human contact, greywater still requires a basic level of treatment before being used for irrigation; the use of subsurface irrigation techniques also helps to limit human contact and minimise health risks (Christova-boal *et al*., 1996; Jeppesen, 1996).

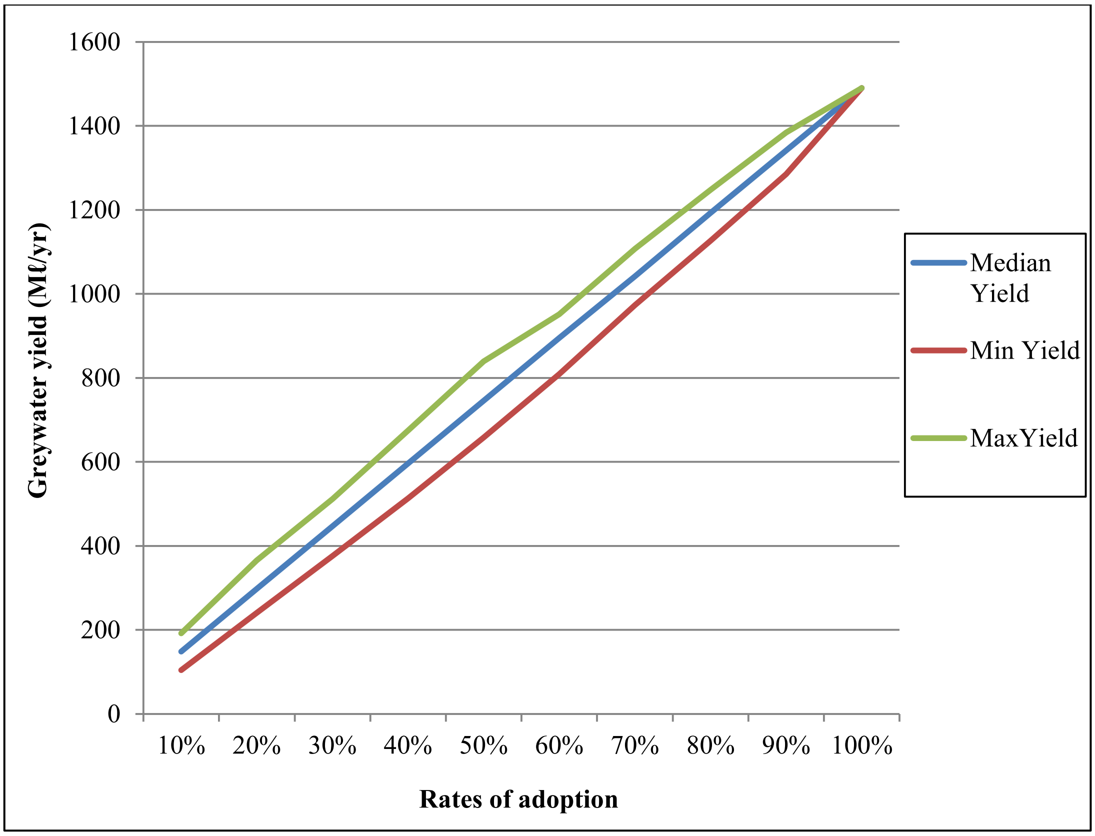

Figure 5-14: Potential water savings with increased adoption of greywater harvesting

Despite the fact that recycled greywater can be used for toilets, there is still a potential health risk during flushing where water droplets can be transferred into the air. In addition to this, discolouration, odour, and negative perceptions about wastewater also present barriers to the use of greywater as an alternative water resource (Ilemobade *et al.*, 2012). Another significant drawback of greywater harvesting systems for toilet use is the limited potential for storage. The prolonged storage of greywater leads to the generation of offensive oudours as well as the growth of micro-organisms (Rodda *et al*., 2010). Murphy (2006) recommends that gryewater should not be stored for more than 24 hours, however Rodda *et al*. (2010) suggest that 12 hours woud be a more appropriate maximum storage time. The requirement for short storage times places an additional constraint onto the use of greywater for toilet flushing as the water would linkely require an extended storage time before use.

The complexity of installing and managing greywater systems presents a challenge for its broad scale adoption within an urban catchment. Greywater harvesting is a heavily decentralised approach, and the responsibilty of managing these systems falls on individual property owners. Improper storage and use presents a number of serious health risks, and the proactive participation of users is essential. Given the complex nature of greywater harvesting and its associated health risks, it was decided that the greywater harvesting model would limit greywater use only to garden irrigation. This would mitigate any problems associated with pro-longed storage as the greywater can be used almost immediately for garden watering. It is important to note that the greywater tanks would need to be fitted with a bypass device to allow unused greywater to flow into the sewage system when it was not required for garden irrigation.

Figure 5-15 illustrates the potential greywater yields that could be achieved through the implementation of greywater harvesting for the purposes of garden watering. The maximum greywater yield amounts to 390 Mℓ/yr, roughly 6% of the catchment's total water demand. This is significantly lower than the estimated 1500 Mℓ/yr that could be harvested from all of the properties in the catchment, however given the limitations of greywater harvesting at the individual property level, it is a more realistic result.

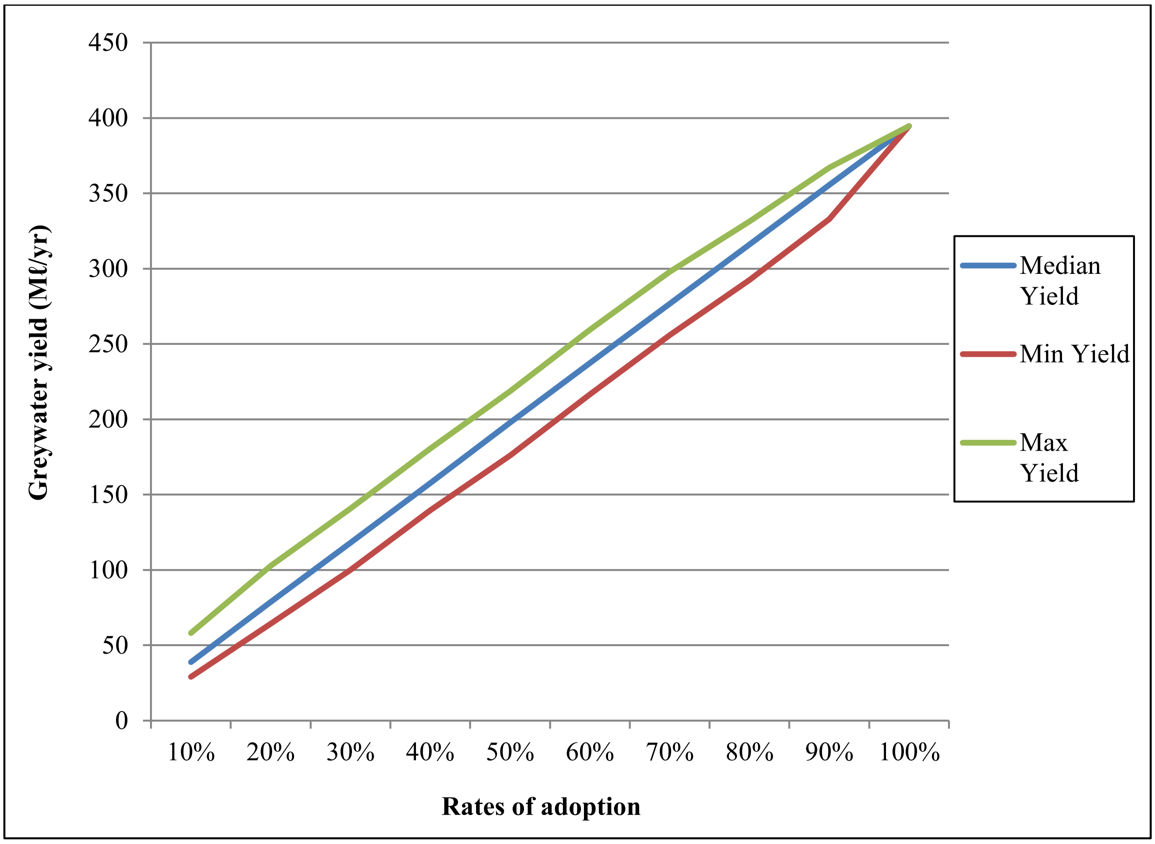

Figure 5-15: Greywater yields after exclusion of general residential properties

Due to the fact that greywater systems provide a regular and reliable source of water – which is subsequently used in as short a time as possible for garden watering – it was possible to optimise the tank sizes used. The greywater harvesting model assumed that greywater tanks serve only as a temporary holding facility with a holding time not longer than 24 hours; in cases where the production of greywater exceeded the outdoor water requirements for a particular day, the water is assumed to have passed through a bypass device into the sewage system.

Figure 5-16 illustrates the total volumes of greywater harvested from the catchment broken down according to land use. Domestic properties account for the bulk of the yield with 339 Mℓ/yr; approximately 6% of the catchment's total water demand. Commercial properties have the next highest potential yield with 22 Mℓ/yr, less than one tenth of the domestic greywater yield. The community and education land use categories could potentially use 9 Mℓ/yr and 20 Mℓ/yr of greywater respectively. The hospital land use category was omitted from the greywater harvesting model as it was decided that the potential risks of cross connection with or contamination of potable supplies would put already vulnerable patients at risk.

Figure 5-17 illustrates the distribution of the greywater demands throughout the catchment. Much like the rainwater demand, the high greywater demands concentrated around the dense urban areas in the centre of the catchment. The larger properties – multi-storey buildings, and a range of educational and community facilities – have higher greywater end-use demands which allowed for an increased greywater harvesting yield.

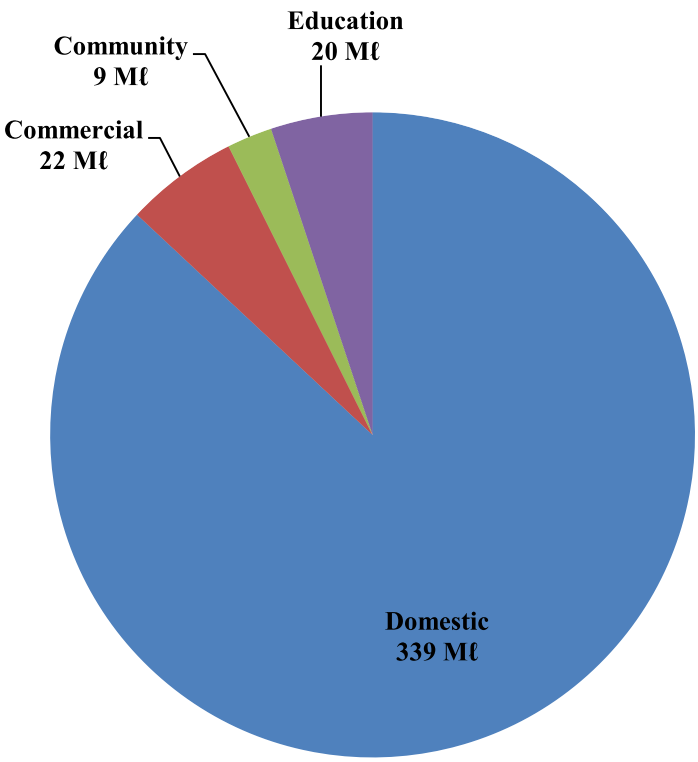

Figure 5-16: The breakdown of greywater harvesting yield according to land use

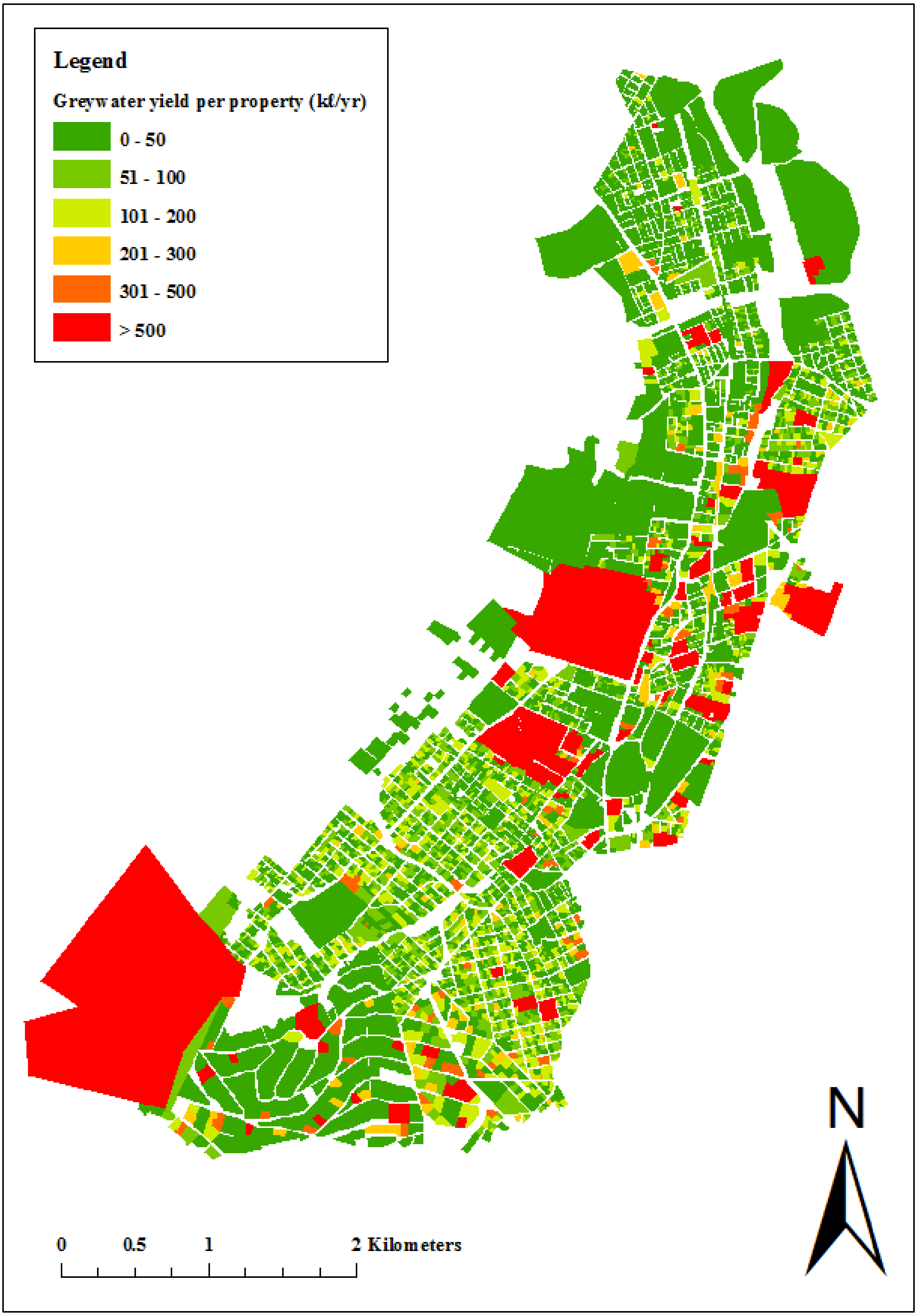

Figure 5-17: Calculated greywater yield per property in the Liesbeek River catchment

Figure 5-18 illustrates the relative contributions of greywater harvesting to the total water demand for the different land uses in the catchment. The domestic land use category has the highest potential greywater contribution augmenting nearly 7% of the total domestic water demand. The potential savings achieved in the commercial sector amount to 3% of the total commercial water demand. The community and education have similar greywater contributions to the commercial sector and were able to augment 2% and 3% of their total water demand respectively.

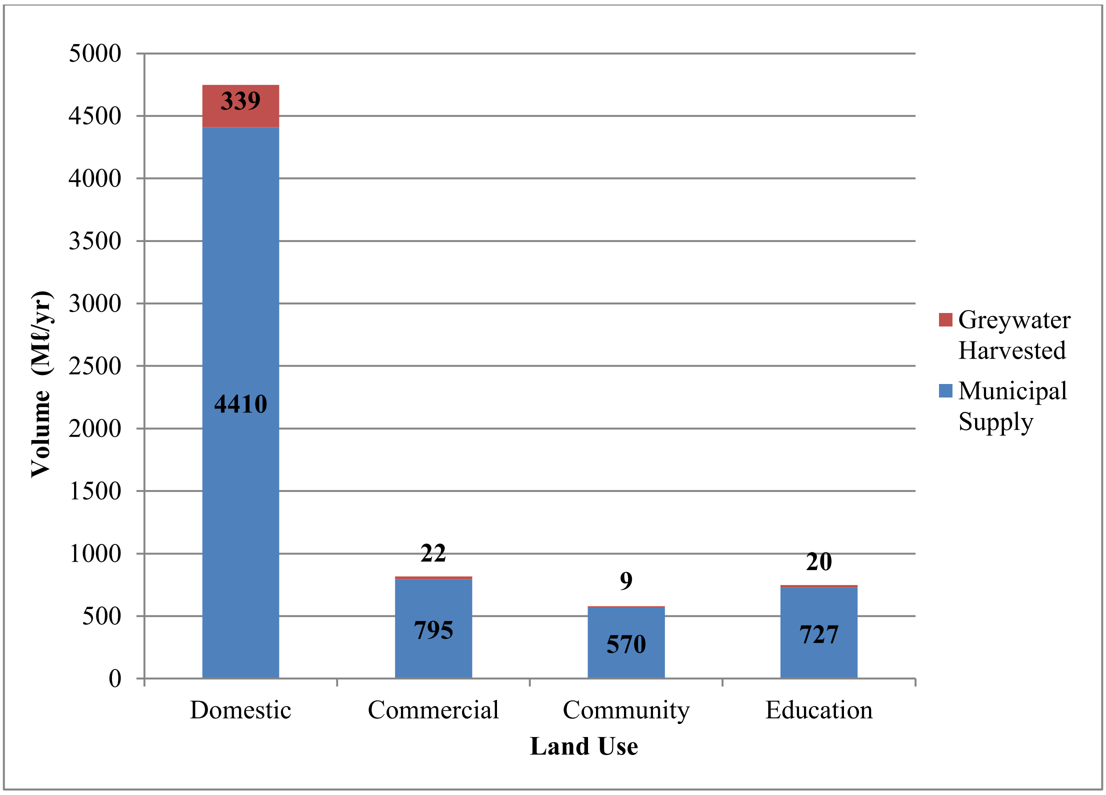

Figure 5-18: Contribution of greywater harvesting to total water demand

5.5 Comparing the different water saving interventions

This research has focused on four interventions that could help improve the efficiency of water use within urban catchments: on-site leakage, water efficient devices, rainwater harvesting, and greywater harvesting. Two of these interventions – rainwater and greywater harvesting – were modelled for three different scenarios with different end-use demands. Figure 5-19 illustrates the potential impact that could result from the implementation of the four interventions if they were to be implemented individually at full scale throughout the catchment.

The implementation of water efficient devices has the most significant impact on the water demands within the catchment. Nearly 32% of the catchment's total water demand could be saved through the effective implementation of water efficient devices. The three different rainwater harvesting scenarios are the next most effective approach, potentially augmenting between 11% and 15% of the catchment's total water demand. The potential greywater harvesting demand is not as high as that of rainwater, augmenting roughly 6% of the catchment's total water demand. The additional operation and maintenance required to ensure that the greywater systems operate safely and effectively were a significant drawback to their implementation on all properties in the catchment. On-site leakages represent a relatively small proportion of the total water demand, however if the management of on-site leakages could be undertaken effectively the water demand in the catchment could be reduced by nearly 1%.

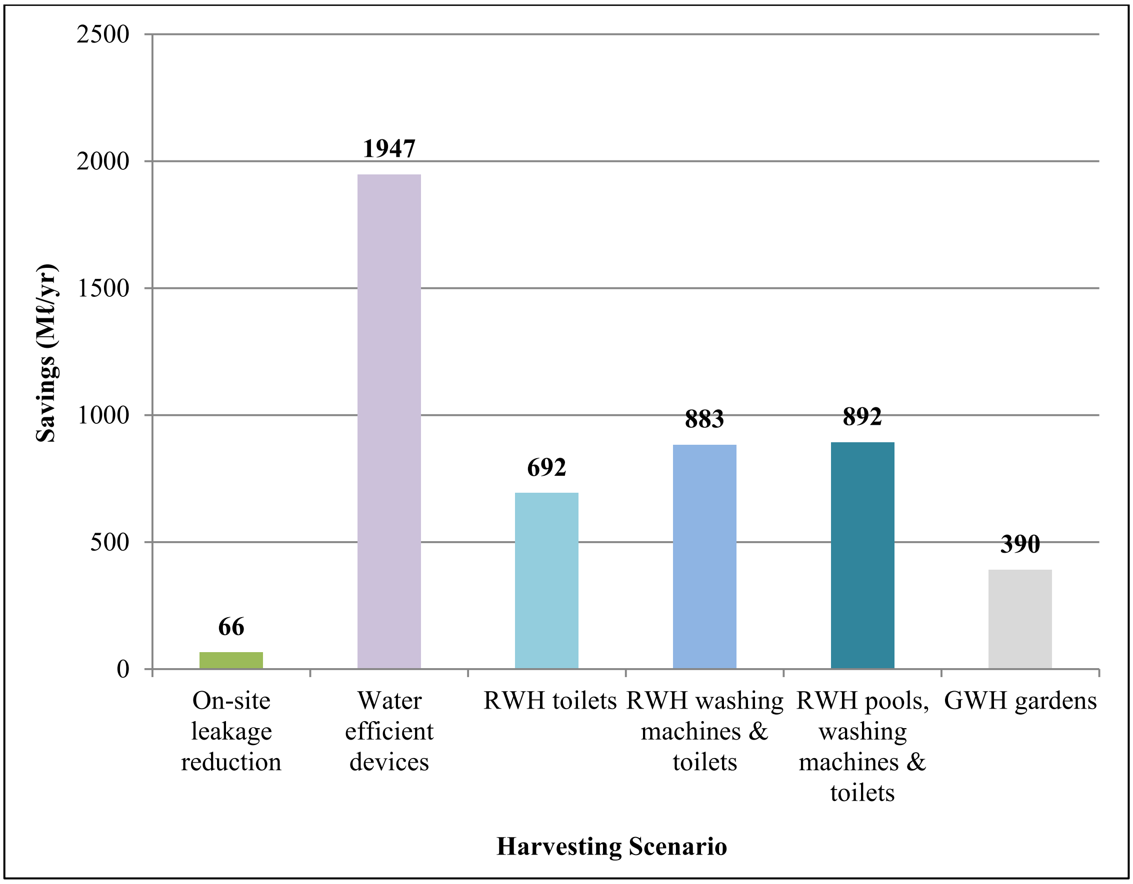

Figure 5-19: The impact of four different water saving interventions on water demand

The implementation of each of these four interventions within the Liesbeek River catchment would present numerous challenges, and although some interventions may provide greater water savings, the barriers to their implementation could negatively impact their water savings benefits. The installation of rainwater and greywater harvesting systems for example requires significant capital investment and thus without subsidisation, it may be difficult to convince land owners in the catchment to install these systems. Additionally the management of water services in the catchment would require organisational changes to manage the decentralised nature of these rainwater harvesting systems. The operation and maintenance of greywater and rainwater systems would also need to be done by each individual property owner which could give rise to a whole host of management problems.

5.6 Building a final water balance scenario

The results in Figure 5-19 assumed that each of the four interventions was implemented individually at full scale. When implemented independently, the different interventions have a significant impact on the catchment's water demand however, when implemented in conjunction with one another their individual contributions will be reduced. The implementation of water efficient devices for example reduces the opportunity for potable water reduction through the use of rainwater and greywater harvesting as there is less demand for these alternative water sources which could render their implementation economically unfeasible.

In addition to the reduced end use demands as a result of the implementation of water efficient devices, the rainwater harvesting models assumed that 100% of the roof area would be used to capture rainwater; this may not necessarily have been the case and buildings with pitched roofs may for example have collected rainwater from only one side of the roof. In order to gauge the impact of reduced roof area the rainwater harvesting models were run again assuming that 50% of the roof area would be considered for the collection of rainwater.

Figure 5-20 illustrates the impact that reduced roof area and the implementation of water efficient devices had on the rainwater and greywater harvesting demands. The implementation of water efficient devices reduces the potential rainwater yield by 22% to 34% for the different end-use scenarios. The reduction in the potential greywater yield as a result of water efficient devices amounts to nearly 29%. The impact of reduced roof area for rainwater collection has a greater impact on reducing rainwater supply than that of the implementation of water efficient devices. Reducing the roof area results in a 232 Mℓ/yr reduction in rainwater harvesting supply, 32 Mℓ/yr more than the reductions from the implementation of water efficient devices. Although the reduced runoff from building roofs has the greatest impact on rainwater harvesting yield, the problem could be overcome at reasonable cost through additional plumbing.

Achieving the full scale implementation rainwater and greywater harvesting systems would require a major paradigm shift in the management of water resources in the Liesbeek River catchment. Current organisational structures of water management institutions are not suited to dealing with the heavily decentralised nature of these systems. If the implementation of rainwater and greywater harvesting was to be pursued in the Liesbeek River catchment, there would need to be a well-structured agreement between the City and individual property owners with regard to the operation and maintenance of these systems.

In order to develop a water balance that reflected the combined impact of the different water savings interventions, it was necessary to consider how the interventions would affect one another. This was achieved through the development of a final composite water balance scenario for the Liesbeek River catchment. There are many different combinations for the different rates of adoption of the four water savings interventions. The rates of adoption depend on factors including but not limited to: the level of institutional backing; the effectiveness of planning and regulation frameworks; customer acceptance and economic viability. The composite scenario serves to provide insight to the combined impact of the water saving interventions on the catchment's water demand, in a manner that maximises the potential water savings.

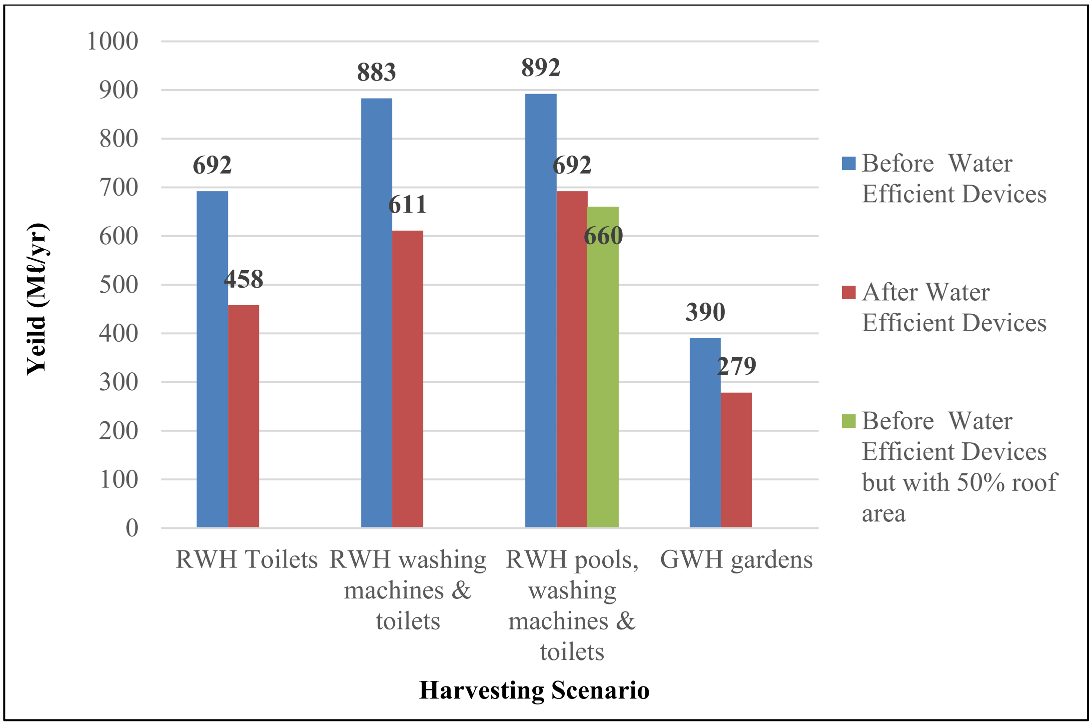

Figure 5-20: Impact of water efficient devices on rainwater and greywater harvesting

The full scale implementation of both rainwater and greywater systems on every property would be uneconomical, particularly for the smaller properties that do not generate large end-use demands. The implementation of greywater harvesting systems provides a more constant water supply than rainwater harvesting, however they are more difficult to operate and maintain. Given the difficulties associated with the use of greywater harvesting systems, the composite scenario assumed that 20% of the catchment would adopt the use of greywater systems and 50% of the catchment would adopt the use of rainwater harvesting systems.

Figure 5-21 illustrates the composite water balance for the Liesbeek River catchment after the implementation of the different water saving interventions; the final results are summarised in Table 5-1. It shows significant reductions in potable water demand; the total volume of water supplied to the catchment may be reduced by approximately 37%, amounting to a water savings of 2249 Mℓ/yr. The water savings from the implementation of water efficient devices is expressed as a percentage of the original water demand. The demand reduction is most prominent for domestic households which could potentially save 41% of their total water demand. Water efficient devices are also effective for education and commercial facilities, potentially saving 23% and 16% of their total water demand respectively. The potential demand reductions in the community and hospitals categories amount to 13% and 12% respectively.

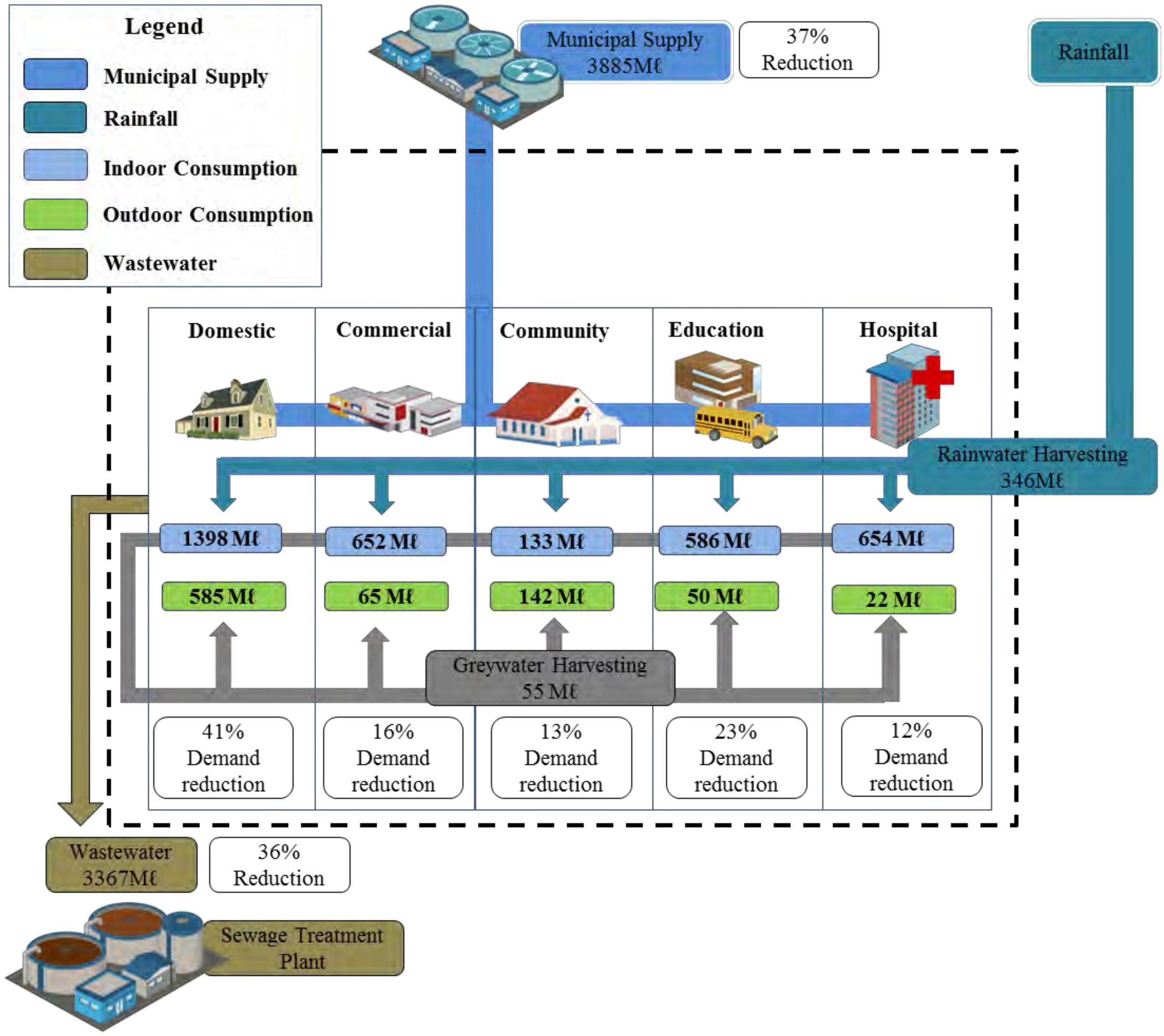

Figure 5-21: A composite water balance scenario for the Liesbeek River catchment with the inclusion of rainwater harvesting, greywater harvesting and water efficient devices

Rainwater harvesting in the catchment could potentially save 346 Mℓ/yr of potable water; approximately 6% of the catchment's total water demand. Greywater harvesting demands could be 55 Mℓ/yr, nearly 1% of the catchment's total water demand.

It was assumed that all of the indoor water use is discharged from the property as wastewater. Any reduction of indoor water use as a result of the implementation of water efficient devices would result in a reduction in wastewater production. Wastewater would be reduced further through the implementation of greywater harvesting which recycles a portion of the wastewater for re-use. The production of wastewater from within the catchment could be reduced by 37%; amounting to 1904 Mℓ/yr. Provided that these reductions did not hamper sewage flows or treatment processes at sewage treatment plants, they help to free up extra treatment capacity, and delay the need for costly expansions of sewage treatment works.

Table 5-1: Summary of the final water balance scenario water imports and exports

Land use	Original Value (Mℓ)	New Value (Mℓ)	Savings (Mℓ)	Percentage savings (%)
Total Domestic water use	3368	1983	1385	41%
Total Commercial water use	853	717	136	16%
Total Community water use	315	275	40	13%
Total Education water use	831	636	195	23%
Hospital water use	768	676	92	12%
Total Municipal Water supply	6134	3885	2249	37%
Total Rainwater Harvesting yield	n/a	346	n/a	n/a
Total Greywater Harvesting yield	n/a	55	n/a	n/a
Total Wastewater production	5271	3367	1904	36%

6. Conclusions and Recommendations

The vulnerability of South Africa's water resources has been identified as a significant threat to the country's future development. With the realisation that current water management interventions require significant improvement, there has been growing interest in finding more effective and sustainable approaches to water management. Although the sustainable water management paradigm provides a useful platform for relieving pressure on existing water resources, in South Africa there has been very little practical implementation of these approaches outside isolated individual projects. One of the most significant barriers affecting the implementation of sustainable water management interventions is the institutional inertia associated with shifting water management practice from conventional thinking, toward a more integrated, holistic approach.

Overcoming the problem of institutional inertia in South Africa will require the development of a more positive perception of sustainable water management approaches within water management institutions. Gathering reliable information to illustrate the benefits of implementing more sustainable water management approaches is important to help convince the relevant authorities responsible of their viability and so lead to their implementation. In order to develop information relevant to the South African context this dissertation used a case study to illustrate the impact of using more sustainable water management on an existing urban catchment. The catchment used for the study was the Liesbeek River Catchment in Cape Town. A detailed water balance model was used to gain insight to the existing water-use patterns at the household level; from which the impact of the implementation of various water savings interventions could be deduced. These interventions included: the implementation of water efficient appliances, leak control, rainwater harvesting and greywater re-use. The level of detail required for the water balance model was governed by the input requirements needed to estimate the potential impact of implementing more sustainable water management interventions.

The selection of water saving interventions to be used in the water balance model was restricted by the lack of available data. Interventions which focused on the distribution system required pressure data and information on minimum night flows, both of which were not available for the Liesbeek River catchment. Additionally, an investigation into the inclusion of groundwater as an alternative resource was also not possible as the extent of potential groundwater sources in the catchment were unknown. Despite the fact that not all of the water saving interventions could be included in the model, the selected interventions were at least able to provide a preliminary insight to the benefits of adopting more sustainable water management approaches in the Liesbeek River catchment.

The water balance results indicated that the Liesbeek River catchment had a potable water demand of 6134 Mℓ/yr, approximately 2% of Cape Town's total water demand. Given that the catchment only makes up 1% of the city metropolitan area and less than 1% of its total population, the catchment's water use is relatively high. The majority of the water use can be attributed to the domestic sector which used 55% of the catchment's total water supply; an unsurprising figure given that domestic properties make up nearly 90% of the properties in the catchment. The remaining 45% of the catchment's total water use is spread almost evenly between the four non-domestic water use categories found in the catchment. In terms of an indoor-outdoor split, 86% of the catchment's potable water demand is used for indoor purposes. The proportion of outdoor water use is relatively low in comparison to other cities in South Africa. This is due to the high annual rainfall in the catchment.

The adoption of water efficient devices has the greatest potential impact on reducing water demand in the catchment. If all properties in the catchment were to install devices that used water in a more efficient manner, the catchment's water use could drop by as much as 30%, potentially saving in the region of 1849 Mℓ/yr. The implementation of water efficient devices has the greatest impact on the domestic sector, potentially reducing water use by approximately 41% which could amount to a water savings 1386 Mℓ/yr. The potential savings achieved through the installation of water efficient devices is significantly lower for the non-domestic sector. Potential water savings range from 13% for community facilities, to 23% for educational institutions, with commercial properties potentially saving 16% and hospitals 12%. Although not as effective as in the domestic sector, water efficient devices could still save 463 Mℓ/yr in the non-domestic sector, 7.5% of the catchment's total water demand.

The quantity of water lost as a result of on-site leakage in the catchment amounts to 66 Mℓ/yr. This is approximately 1% of the catchment's total water demand, a large proportion of which could be saved through more effective water management.

The use of alternative water sources in the Liesbeek River catchment shows significant promise. Rainwater harvesting systems could collect up to 892 Mℓ of rainwater annually, augmenting 15% of the catchment's total water demand. Rainwater harvesting has the greatest impact on the domestic land use category largely as a result of its use for toilet flushing, potentially providing up to 22% of the total water demand for the domestic sector. The rainwater harvesting contribution to the commercial land use category is significantly lower, with rainwater potentially providing 10% of the annual water demand. Community facilities, education and hospitals all have relatively low rainwater contributions with 6%, 3% and 0.6% of their respective total water demands potentially being supplied by rainwater harvesting. Greywater harvesting could potentially provide 390 Mℓ/yr, nearly 6.5% of the catchment's total water demand. Domestic properties account for the bulk of the yield with 339 Mℓ/yr; approximately 5.5% of the catchment's total water demand. Commercial properties have the next highest yield with 22 Mℓ/yr, less than one tenth of the domestic greywater yield. The community and education land use categories could potentially use 9 Mℓ/yr and 20 Mℓ/yr of greywater respectively, together making up roughly 0.5% of the catchment's total water demand.

When implemented independently, the different interventions have a significant impact on the catchment's water demand. However, these interventions could not be implemented simultaneously at full scale throughout the catchment without negatively affecting one another. In order to understand the combined impact of all of these interventions, a composite scenario was developed for the catchment. The composite scenario provides insight to the combined impact of the water saving interventions on the catchment's water demand in a manner that maximised the potential water savings, while still reflecting a water management scenario that may in the future become more feasible. The scenario assumes that the entire catchment adopts water efficient devices, 20% install greywater harvesting systems and a further 50% install rainwater harvesting systems. The results from the composite scenario show that the total water demand could be reduced by 37%. The water supply portfolio for the catchment would then consist of 3885 Mℓ/yr of municipal supply, 346 Mℓ/yr of rainwater, and 55 Mℓ/yr of greywater; 91%, 8%, and 1% of the catchment's total water demand respectively. The production of wastewater from within the catchment could be reduced by approximately 36%, or 1904 Mℓ/yr.

This dissertation has successfully shown the significant impact that hypothetical water saving interventions could have in the Liesbeek River catchment. By applying the findings of the Liesbeek River catchment case study to other catchments with a largely residential development profile similar water savings can be anticipated.

Recommendations for further work

The following recommendations were made to improve the research process and develop a better understanding of the benefits of adopting more sustainable water management approaches:

i) Perform the modelling process conducted on the Liesbeek River catchment on a different catchment in South Africa with different characteristics

ii) Develop a more effective mechanism for estimating the end-use water use breakdowns for non-domestic properties

iii) Test the validity of the REUM model in estimating indoor domestic water demand for a range of different household types

iv) Develop a more effective approach for calibrating the outdoor water use against measured data

v) Quantify the extent of groundwater use in the Liesbeek River catchment and the additional yield that could be generated though expanded use.

vi) Model the impacts of pressure reduction on reducing water leakage rates in the catchment's water distribution system

vii) Determine the extent of borehole use in the catchment as well as the potential water yield

viii) Develop a more effective method for estimating the levels of on-site leakage within properties and urban catchments.

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Appendices

Appendix A

Domestic water balance model calculations

This appendix describes the calculation process for the domestic water balance model. The steps in the process are as follows:

Low, Medium and High Rise Residential

i) Multiply the building roof area with the number of floors in the building to get the total building floor area.

i) Divide the building area by the estimated area per flat to obtain the number of flats in each building.

ii) Tabulate the end-use frequencies and volumes for the medium water use scenario provided by Jacobs & Haarhoff (2004).

iii) For each end-use multiply the end-use frequency with its corresponding volume.

iv) Sum the calculated values above. These values represent the volume of water used per person per day for all domestic properties in the catchment.

v) Multiply the summed REUM coefficients with the average population for each particular stand to get the average water demand.

vi) The calculated average water demand is then multiplied by the number of flats calculated in step ii.

General Residential

i) Tabulate the end-use frequencies and volumes for the medium water use scenario provided by Jacobs & Haarhoff (2004).

ii) For each end-use multiply the end-use frequency with its corresponding volume.

iii) Sum the calculated values above. These values represent the volume of water used per person per day for all domestic properties in the catchment.

iv) Multiply the summed REUM coefficients with the average population for each particular stand to get the average water demand.

The calculation process for both Low, Medium and High Rise Residential and General Residential properties is shown in Figure A over page.

Type of Development	Unit	Average water use (ℓ /day)
Offices and Shops	100 m^2 of gross floor area	400
Community Halls	No. of Seats	65-90
Hospitals	No. of Beds	220-300
Day School	No. of Students	15-20
Boarding School	No. of Students	90-140

Land use	Roof Area (m^2)	No. of Floors	Total Floor Area (m^2)	Population per m^2	Total Population	Average water use (ℓ/person)	Calculated water demand (ℓ)
Community Facilities	GIS data	GIS data	Roof Area x No. of floors	GIS data	Total floor area x Population per m^2	78	Total Population x Average water use
Hospitals	n/a	n/a	n/a	n/a	GIS Data	260	Total Population x Average water use
Commercial	GIS data	GIS data	Roof Area x No. of floors	n/a	n/a	400	Total Population x Average water use
Education	n/a	n/a	n/a	n/a	GIS Data	17	Total Population x Average water use

Figure A: The water balance model calculation process for non-domestic properties

Appendix B

Non-domestic water balance model calculations

This appendix describes the calculation process for the non-domestic water balance model. The steps in the process are as follows:

Commercial

i) Multiply the building roof area with the number of floors in the building to get the total building floor area.

ii) Multiply the building floor area by the average water use prescribed for commercial properties to get the calculated water demand.

Community Facilities

i) Multiply the building roof area with the number of floors in the building to get the total building floor area.

ii) Multiply the building floor area by the prescribed population density to get the total population for a particular property – in this case the number of seats/m^2.

iii) Multiply the total calculated population by the average water use prescribed for community facilities to get the calculated water demand.

Hospitals

i) Multiply the total population – in this case the number of beds – by the average water use prescribed for hospitals to get the calculated water demand.

Education

i) Multiply the total population – in this case the number of students and staff – by the average water use prescribed for hospitals to get the calculated water demand.

The calculation process for all non-domestic properties is illustrated in Figure B over page.

Type of Development	Unit	Average water use (ℓ /day)
Offices and Shops	100 m^2 of gross floor area	400
Community Halls	No. of Seats	65-90
Hospitals	No. of Beds	220-300
Day School	No. of Students	15-20
Boarding School	No. of Students	90-140

Land use	Roof Area (m^2)	No. of Floors	Total Floor Area (m^2)	Population per m^2	Total Population	Average water use (ℓ/person)	Calculated water demand (ℓ)
Community Facilities	GIS data	GIS data	Roof Area x No. of floors	GIS data	Total floor area x Population per m^2	78	Total Population x Average water use
Hospitals	n/a	n/a	n/a	n/a	GIS Data	260	Total Population x Average water use
Commercial	GIS data	GIS data	Roof Area x No. of floors	n/a	n/a	400	Total Population x Average water use
Education	n/a	n/a	n/a	n/a	GIS Data	17	Total Population x Average water use

Figure B: The water balance model calculation process for non-domestic properties

Appendix C

REUM calibration coefficients

This appendix describes the calculation process for the REUM coefficients used during the calibration of domestic properties. The steps in the process are as follows:

ii) Tabulate the end-use frequencies and volumes for the low medium and high water use scenarios provided by Jacobs & Haarhoff (2004).

iii) For each end-use multiply the end-use frequency with its corresponding volume. This is to be completed for the low, medium, and high water use scenarios.

iv) Sum the calculated values above for each of the three water use scenarios. These values represent the volume of water used per person per day for the low, medium, and high water use scenarios.

v) Divide the low water use scenario by the medium water use scenario to establish the lower bound ratio.

vi) Divide the high water use scenario by the medium water use scenario to establish the upper bound ratio.

The lower bound and upper bound ratios describe the minimum and maximum decrease or increase in per capita water use from the average per capita water use assumed during the calculation process. Table C illustrates the calculation procedure used.

End-use	Medium Vol. (ℓ)	Low Freq.	End use breakdown	Medium Vol. (ℓ)	Medium Freq.	End use breakdown	Medium Vol. (ℓ)	High Freq.	End use breakdown
Bath	80	0.22	Medium Freq. x Medium Vol.	80	0.24	Medium Freq. x Medium Vol.	80	0.9	Medium Freq. x Medium Vol.
Bath Basin	3.8	3.4		3.8	3.6		3.8	3.8	
Dishwasher	25	0.18		25	0.25		25	0.29	
Kitchen Sink	6.7	2		6.7	2		6.7	2	
Shower	59.1	0.19		59.1	0.31		59.1	0.68	
Normal Toilet	14.3	1.7		14.3	3.7		14.3	10.3	
Dual Flush Toilet	6	0.9		6	1.9		6	5.2	
Washing Machine	113.6	0.12		113.6	0.3		113.6	0.63	
		Sum	**90.991**		**Sum**	**169.241**		**Sum**	**397.336**
		Lower bound ratio	90.991 / 169.241			169.241 / 169.241		**Upper bound ratio**	397.336 / 169.241
			0.54			1			**2.35**

Table C: The calculation procedure for the REUM calibration coefficients

Appendix D

Rainwater harvesting model input data

This appendix describes the input data for the rainwater harvesting model. The model inputs include the following information:

i) Lifecycle costing data for rainwater tanks varying in size from 0.25 kℓ to 20 kℓ. The costing data includes the capital cost, as well as the maintenance costs associated with the different tank sizes. Table D1 – over page – provides a summary of the lifecycle costing information used for the different tank sizes.

ii) Daily rainfall data over the period of 10 years from 01/01/2003 to 31/12/2013. Table D2 – over page – provides a summary of the information. Each column represents a different measuring station, the names of which are shown in Table D3 over page.

iii) Various control inputs including roof runoff factors, municipal cost of water, and the equivalent useful life of rainwater tanks. Table D4 – over page – indicates the various control inputs used in the rainwater harvesting model

Table D1: Life cycle costing information for different rainwater tank sizes

Life Cycle Costing								
Tank Sizes				Corrective Maintenance		Corrective Maintenance - Pump		
No.	Size	Capital	Annual Maintenance	Cost	Recurrence	Cost	Recurrence	Electricity per m^3
1	0,25	500	310	1,75	5	0	0	0
2	0,5	1000	310	3,5	5	0	0	0
3	1	1500	310	7	5	0	0	0
4	1,5	2250	460	10,5	5	0	0	0
5	2,2	3300	460	15,4	5	0	0	0
6	2,5	3750	460	17,5	5	0	0	0
7	5	7500	460	35	5	0	0	0
8	10	15000	610	70	5	0	0	0
9	15	22500	610	105	5	0	0	0
10	20	30000	610	140	5	0	0	0

Table D2: Daily rainfall data

Daily Rainfall (mm)						
	Station					
Date	1	2	3	4	5	6
2003-01-01	0	0	0	0	0	0
2003-01-02	0	0	0	0	0	0
2003-01-03	0	0	0	0	0	0
2003-01-04	0	0	0	0	0	0
…	…	…	…	…	…	…
2006-07-11	19	7,5	20,5	24	19	0
2006-07-12	15	10,5	27,5	16	10	14
2006-07-13	12,5	10,1	8	14	10	8
2006-07-14	12,7	0	5	12,5	5	7
2006-07-15	20	0	18,5	23	17	15
…	…	…	…	…	…	…
2012-12-28	0	0	0	0	0	0
2012-12-29	0	0	0	0	0	0
2012-12-30	0	0	0	0	0	0
2012-12-31	0	0	0	0	0	0

Table D3: Measuring stations

Annual Rainfall		
Station	Station Name	mm
1	Kirstenbosch	1347
2	Observatory	622
3	Newlands Reserviour	1449
4	Boschoff Road	1461
5	Roukoop Road	1072
6	Spin Street	856

Table D4: Model control inputs

Control Inputs	
Runoff Factors	
Flat roof	0,85
Sloped Roof	0,85
Discount Rate	4
EUL	25
Initial storage/First Flush (mm)	5
Storage Before consumption	Y
Monte-Carlo Simulation	1000
Cost per kℓ	30
Sensitivity Analysis runs	20

Appendix E

Rainwater harvesting model summary calculations

This appendix describes the calculation process for the rainwater harvesting model. The steps in the process are as follows:

Step 1:

i) The volume of rainwater required every day is calculated using daily time steps for a period over 10 years.

ii) For each day the rainfall volume captured on a particular property's roof is calculated by multiplying the roof area, the rainfall depth, and the selected runoff factor

iii) The runoff is then added to the water that is already in the tank from the previous day. If the runoff volume exceeds the storage capacity of the tank, the water is assumed to have been lost as overflow.

iv) The end-use demand for rainwater is then subtracted from the water available in the tank to provide a volume of rainwater consumed per day.

v) The calculation is repeated for every day over the 10 year period.

vi) The daily results are summed up and an average yearly consumption of rainwater use is calculated for each property.

vii) i) to vi) are repeated 10 times with a different tank size used each time.

Figure E1 illustrates the procedure followed for the Step 1 calculations.

Step 2:

i) The average yearly consumption values for the ten different tank sizes are then tabulated. The lifecycle costs (capital and maintenance costs) are then factored in to provide a cost per kℓ of rainwater collected for each tank size.

ii) This cost per kℓ of rainwater collected is then compared to the municipal cost of water per kℓ of rainwater collected. The tank size that provides the highest rainwater volume whilst still remaining cheaper than the municipal supply is selected as the desired tank for that particular property.

NOTE: Steps 1 and 2 are completed for every property in the catchment. Figure E2 illustrates the procedure followed for the Step 1 calculations.

Step 3:

The final step in the rainwater harvesting model process is the determination of the impact of the incremental uptake of rainwater harvesting systems within the catchment. The model runs ten scenarios with rates of adoption ranging from 10% – 100%.

i) Excel function “RAND()” produces an evenly distributed random real number greater than or equal to zero and less than or equal to one. This number is generated for every property in the catchment.

ii) The model initially selects a 10% adoption rate for rainwater harvesting systems in the catchment. This is represented as the decimal number 0.1 in the model.

iii) Given that Excel function “RAND()” produces an evenly distributed random number between 0 and 1, there is a 10% chance that the number will be less than 0.1 If for a particular property the associated number produced by the excel function is less than 0.1 then that particular property is included into the calculation. The rainwater volume used for each property is then summed to get a value for the total catchment’s rainwater use.

iv) In order to a representative idea of the rainwater harvesting volumes for this particular level of adoption, the calculation in step ii was repeated 1000 times. With each cycle the “RAND()” function selected a different number for each property meaning that a different ‘10%’ sample of properties was included in the rainwater volume calculations.

v) After the completion of each set of 1000 cycles the results are tabulated and the minimum, mean, and maximum rainwater volumes for the catchment are extracted from the data.

This calculation process is repeated for 10% adoption increments and the results are tabulated to provide a final rainwater harvesting estimate for the 10 different rates of adoption. Figure E3 illustrates the procedure followed for the Step 1 calculations.

Daily Rainfall data (mm)							
Total Records	3651	Station number					
Date		1	2	3	4	5	6
2006-07-12		15	10,5	27,5	16	10	14

(Selected according to station number)

Rainwater harvesting input data																	
Total Records						Rainwater end-use demands (kℓ/day)											
Cycle Number	Erf No.	Annual Precipitation (mm)	Station No.	Roof Area (m^2)	Roof Type	January	February	March	April	May	June	July	August	September	October	November	December
1241	978926	1000	2	90,76	Flat Roof	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23

(Selected according to date)

Tank Size (kℓ)	0.25		Starting volume (%)		10						
Date	**Precipitation (mm)**	**Runoff (m^3)**	**Storage volume before yield (m^3)**	**Water available for Storage after yield (m^3)**	**Volume not collected (m^3)**	**Total Water Collected**	**Demand (m^3)**	**Storage after Consumption**	**Consumption of collected rainwater**	**Demand not met (m^3)**	**Demand Met? Yes: 0 or No: 1**
		Roof area x Precipitation x Runoff factor	Storage after consumption for previous day	Runoff + Vol. before yield	Water available after yield - storage volume	Water available after yield - Volume not collected		Total water collected - Demand (>0)	Total water collected - Storage after consumption	Demand - Consumption	
2006-07-12	16.88	1.30	0.02	1.32	1.07	0.25	0.23	0.02	0.23	0	0
Calculations completed with daily time steps with rainfall data from 2003-01-01 to 2012-12-31 and summed											
Sum		766,64			604,89		846,57		161,77	684,59	3110,00

Run	Tank size	Runoff	Volume not collected	Demand	Consumption	Demand not met	Periods where demand not met	% demand met	% Dry Periods	% not collected	% collected
1	0,25	766,64	604,89	846,57	161,77	684,59	3110	Consumption / Demand	Periods where demand not met / Total no. of rainfall records	Vol. not collected / Runoff	1 - % not collected

Figure E1: Calculation procedure for the volume of rainwater collected in a particular tank size

Calculated by a life cycle costing analysis developed by Fisher-Jeffes (2013)

Erf No.	Run	Tank size	Runoff	Volume not collected	Demand	Consumption	Periods where demand not met	Demand not met	% demand met	% Dry Periods	% not collected	% collected	Cost per kℓ	Cost Limit (R/kℓ)	Cost per kℓ below the cost limit?
978926	1	0,25	766,64	604,89	846,57	161,77	3110,00	684,59	0,19	0,85	0,79	0,21	33.05	30	No
	2	0,5	766,64	531,24	846,57	235,45	2816,00	610,93	0,28	0,77	0,69	0,31	24.85	30	Yes
	3	1	766,64	436,73	846,57	330,01	2406,00	516,42	0,39	0,66	0,57	0,43	19.27	30	Yes
	4	1,5	766,64	384,61	846,57	382,18	2165,00	464,31	0,45	0,59	0,50	0,50	24.76	30	Yes
	5	2,2	766,64	341,68	846,57	425,18	1955,00	421,37	0,50	0,54	0,45	0,55	24.75	30	Yes
	6	2,5	766,64	327,36	846,57	439,53	1890,00	407,04	0,52	0,52	0,43	0,57	24.98	30	Yes
	7	5	766,64	267,11	846,57	500,03	1598,00	346,54	0,59	0,44	0,35	0,65	29.55	30	Yes
	8	10	766,64	211,81	846,57	555,83	1335,00	290,74	0,66	0,37	0,28	0,72	44.45	30	No
	9	15	766,64	170,49	846,57	597,65	1141,00	248,92	0,71	0,31	0,22	0,78	54.03	30	No
	10	20	766,64	137,55	846,57	630,53	995,00	216,04	0,74	0,27	0,18	0,82	63.25	30	No

Selected tank Size

The tank size that provides the highest consumption while still falling below the cost limit is selected.

Figure E2: Calculation procedure for the tank size selection for a particular property

Excel function "RAND()" Returns an evenly distributed random real number greater than or equal to 0 and less than 1

Cycle Number	Probability	Consumption	Tank	% demand met	% Dry Periods	% not collected	% collected	Cost per kℓ
1	0,52899598	500,03	5,00	0,59	0,44	0,35	0,65	29,55

Scenario	1	2	3	4	5	6	7	8	9	10
Probability	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
Erf Included in Scenario Calculation Yes if < 0.635 No if > 0.635	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No

Erf No.		Scenario	Consumption	Tank	% demand met	% Dry Periods	% not collected	% collected	Cost per kℓ
		1	500,03	5,00	0,59	0,44	0,35	0,65	29,55
		2	500,03	5,00	0,59	0,44	0,35	0,65	29,55
		3	500,03	5,00	0,59	0,44	0,35	0,65	29,55
		4	500,03	5,00	0,59	0,44	0,35	0,65	29,55
		5	500,03	5,00	0,59	0,44	0,35	0,65	29,55
		6	500,03	5,00	0,59	0,44	0,35	0,65	29,55
		7	0	0	0	0	0	0	0
		8	0	0	0	0	0	0	0
		9	0	0	0	0	0	0	0
		10	0	0	0	0	0	0	0

Calculation completed for all Properties in the catchment and summed for all 10 scenarios

Calculation process repeated for 1000 cycles using all properties in the catchment and summed

Scenario	Min Consumption (Mℓ)	Median Consumption (Mℓ)	Max Consumption (Mℓ)
1	71	83	100
2	149	166	186
…	…	…	…
9	732	748	763
10	832	832	832

Figure E3: Calculation procedure for the allocation of rainwater harvesting systems to properties in the catchment

Appendix F

Greywater harvesting model summary calculations

This appendix describes the calculation process for the greywater harvesting model. The steps in the process are as follows:

Step 1:

i) The volume of greywater produced each day for a particular property is calculated and used as an input into the greywater harvesting model.

ii) The greywater yield is assumed to be held temporarily in a storage tank. If the runoff volume exceeds the storage capacity of the tank, the water is assumed to have been lost as overflow.

iii) The end-use demand for greywater is then subtracted from the water available in the tank to provide a volume of greywater consumed per day. If the end-use demands for a particular day are less than the greywater yield the excess greywater is emptied from the tank the same day.

iv) The calculation is repeated for every day over the 1 year period and the results are summed up and an average yearly consumption of greywater use is calculated for each property.

v) i) to iv) are repeated 10 times with a different tank size used each time.

Figure F1 illustrates the procedure followed for the Step 1 calculations.

Step 2:

vi) The average yearly consumption values for the ten different tank sizes are then tabulated. The lifecycle costs (capital and maintenance costs) are then factored in to provide a cost per kℓ of greywater collected for each tank size.

vii) This cost per kℓ of greywater collected is then compared to the municipal cost of water per kℓ of greywater collected. The tank size that provides the highest greywater volume whilst still remaining cheaper than the municipal supply is selected as the desired tank for that particular property.

NOTE: Steps 1 and 2 are completed for every property in the catchment. Figure F2 illustrates the procedure followed for the Step 1 calculations.

Step 3:

The final step in the greywater harvesting model process is the determination of the impact of the incremental uptake of greywater harvesting systems within the catchment. The model runs ten scenarios with rates of adoption ranging from 10% – 100%.

viii) Excel function "RAND()" produces an evenly distributed random real number greater than or equal to zero and less than or equal to one. This number is generated for every property in the catchment.

ix) The model initially selects a 10% adoption rate for greywater harvesting systems in the catchment. This is represented as the decimal number 0.1 in the model.

x) Given that Excel function "RAND()" produces an evenly distributed random number between 0 and 1, there is a 10% chance that the number will be less than 0.1 If for a particular property the associated number produced by the excel function is less than 0.1 then that particular property is included into the calculation. The greywater volume used for each property is then summed to get a value for the total catchment's greywater use.

xi) In order to a representative idea of the greywater harvesting volumes for this particular level of adoption, the calculation in step ii was repeated 1000 times. With each cycle the "RAND()" function selected a different number for each property meaning that a different '10%' sample of properties was included in the greywater volume calculations.

xii) After the completion of each set of 1000 cycles the results are tabulated and the minimum, mean, and maximum greywater volumes for the catchment are extracted from the data.

This calculation process is repeated for 10% adoption increments and the results are tabulated to provide a final greywater harvesting estimate for the 10 different rates of adoption. Figure F3 illustrates the procedure followed for the Step 1 calculations.

Greywater harvesting input data																	
Total Records						Greywater end-use demands (kℓ/day)											
Cycle Number	Erf No.	Greywater supply (kℓ)	Station No.	Roof Area (m²)	Roof Type	January	February	March	April	May	June	July	August	September	October	November	December
301	34367	0.27	NA	NA	NA	0,43	0,36	0,30	0,14	0,11	0,11	0,11	0,11	0,11	0,23	0,30	0,39

(Selected according to date)

Tank Size (kℓ)	0.25	Starting volume (%)		10						
Date	**Runoff (m^3)**	**Storage volume before yield (m^3)**	**Water available for Storage after yield (m^3)**	**Volume not collected (m^3)**	**Total Water Collected**	**Demand (m^3)**	**Storage after Consumption**	**Consumption of collected greywater**	**Demand not met (m^3)**	**Demand Met? Yes: 0 or No: 1**
	Greywater supply (kℓ)	Storage after consumption for previous day	Runoff + Vol. before yield	Water available after yield - storage volume	Water available after yield - Volume not collected		Total water collected - Demand (>0)	Total water collected - Storage after consumption	Demand - Consumption	
2003-12-27	0.27	0	0.27	0.02	0.25	0.39	0	0.25	0.14	1
Calculations completed with daily time steps from 2003-01-01 to 2012-12-31 and summed										
Sum	988,59			329,92		821,99		658,69	163,11	1511,00

Run	Tank size	Runoff	Volume not collected	Demand	Consumption	Demand not met	Periods where demand not met	% demand met	% Dry Periods	% not collected	% collected
1	0,25	988,59	329,92	821,99	658,69	163,11	1511,00	Consumption / Demand	Periods where demand not met / Total no. of days	Vol. not collected / Runoff	1 - % not collected

Figure F1: Calculation procedure for the volume of greywater temporarily collected in a particular tank size

Calculated by a life cycle costing analysis developed by Fisher-Jeffes (2013)

Erf No.	Run	Tank size	Runoff	Volume not collected	Demand	Consumption	Periods where demand not met	Demand not met	% demand met	% Dry Periods	% not collected	% collected	Cost per kℓ	Cost Limit (R/kℓ)	Cost per kℓ below the cost limit?
978926	1	0,25	988,59	329,92	821,99	658,69	1511,00	163,11	0,80	0,41	0,33	0,67	8.12	30	Yes
	2	0,50	988,59	296,22	821,99	692,42	1431,00	129,45	0,84	0,39	0,30	0,70	8.45	30	Yes
	3	1,00	988,59	291,22	821,99	697,47	1241,00	124,45	0,85	0,34	0,29	0,71	9.12	30	Yes
	4	1,50	988,59	286,22	821,99	702,52	1181,00	119,45	0,85	0,32	0,29	0,71	13.47	30	Yes
	5	2,20	988,59	279,22	821,99	709,59	1120,00	112,40	0,86	0,31	0,28	0,72	14.83	30	Yes
	6	2,50	988,59	276,22	821,99	712,62	1090,00	109,37	0,87	0,30	0,28	0,72	15.41	30	Yes
	7	5,00	988,59	251,22	821,99	737,40	891,00	84,59	0,90	0,24	0,25	0,75	20.04	30	Yes
	8	10,00	988,59	201,22	821,99	782,90	609,00	39,09	0,95	0,17	0,20	0,80	31.56	30	No
	9	15,00	988,59	164,82	821,99	814,80	81,00	7,19	0,99	0,02	0,17	0,83	39.63	30	No
	10	20,00	988,59	159,82	821,99	815,30	78,00	6,69	0,99	0,02	0,16	0,84	48.92	30	No

Selected tank Size

The tank size that provides the highest consumption while still falling below the cost limit is selected.

Figure F2: Calculation procedure for the tank size selection for a particular property

Excel function "RAND()" Returns an evenly distributed random real number greater than or equal to 0 and less than 1

Cycle Number	Probability	Erf No.	Consumption	Tank	% demand met	% Dry Periods	% not collected	% collected	Cost per kℓ
1	0,22	34367	737,40	5,00	0,90	0,24	0,25	0,75	20,04

Scenario	1	2	3	4	5	6	7	8	9	10
Probability	**0,1**	**0,2**	**0,3**	**0,4**	**0,5**	**0,6**	**0,7**	**0,8**	**0,9**	**1**
Erf Included in Scenario Calculation Yes if < 0.635 No if > 0.635	Yes	Yes	No	No	No	No	No	No	No	No

Erf No.		Scenario	Consumption	Tank	% demand met	% Dry Periods	% not collected	% collected	Cost per kℓ
		1	737.40	5,00	0,9	0,24	0,25	0,75	20.04
		2	737.40	5,00	0,9	0,24	0,25	0,75	20.04
		3	0	0	0	0	0	0	0
		4	0	0	0	0	0	0	0
		5	0	0	0	0	0	0	0
		6	0	0	0	0	0	0	0
		7	0	0	0	0	0	0	0
		8	0	0	0	0	0	0	0
		9	0	0	0	0	0	0	0
		10	0	0	0	0	0	0	0

Calculation completed for all Properties in the catchment and summed for all 10 scenarios

Calculation process repeated for 1000 cycles using all properties in the catchment and summed

Scenario	Min Consumption (Mℓ)	Median Consumption (Mℓ)	Max Consumption (Mℓ)
1	22	57	108
2	70	116	182
…	…	…	…
9	486	530	562
10	587	587	587

Figure F3: Calculation procedure for the allocation of greywater harvesting systems to properties in the catchment

Appendix G

Water efficient devices model summary calculations

This appendix describes the calculation process for the water efficient devices model. The model aims to determine the impact of the incremental uptake of water efficient devices within the catchment with rates of adoption ranging from 20% – 100%. The steps in the process are as follows:

i) Water savings factors for medium saving and high saving devices are used as inputs into the water efficient devices model.

ii) Excel function “RAND()” produces an evenly distributed random real number greater than or equal to zero and less than or equal to one. This number is generated for every property in the catchment.

iii) The model initially selects a 10% adoption rate for medium savings devices, a 10% adoption rate for high savings devices, and 80% use of typical devices in the catchment. These are represented as the decimal number 0.1 in the model.

iv) Given that Excel function “RAND()” produces an evenly distributed random number between 0 and 1, there is a 80% chance that the number will be less than 0.8. If for a particular property the associated number produced by the excel function is less than 0.8 then that particular property is included into the typical devices category. If for a particular property the associated number produced by the excel function is greater than 0.8 but less than or equal to 0.9 then that particular property is included into the medium savings devices category. If for a particular property the associated number produced by the excel function is greater than 0.9 then that particular property is included into the medium savings devices category. The water savings factors linked to each water savings category are assigned to each property. The final water use of each property is then summed to get a value for the total catchment’s water use.

v) In order to a representative idea of the water savings for this particular level of adoption of water savings devices, the calculation in ii) was repeated 1000 times. With each cycle the “RAND()” function selected a different number for each property meaning that a different sample of properties was included in each water savings category.

vi) After the completion of each set of 1000 cycles the results are tabulated and the minimum, mean, and maximum volumes of water use for the catchment are extracted from the data.

This calculation process is repeated for the different adoption increments specified and the results are tabulated to provide a final water savings estimate for the 5 different rates of adoption. Figure G1 illustrates the procedure followed for the calculations.

		AADD Current	High savings	Medium Savings
1	Domestic	1	0,42	0,59
2	Hospitals	1	0,79	0,88
3	Commercial	1	0,78	0,87
4	Education	1	0,73	0,84
5	Community	1	0,70	0,82

Factors selected according to land-use

Excel function "RAND()" Returns an evenly distributed random real number greater than or equal to 0 and less than 1

Cycle Number	Erf Number	Land use	Probability	Standard water use (ℓ/day)	Medium	High	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
					Med Factor x Standard water use	High Factor x Standard water use	Calculated for each scenario using Excel function "IF()" as shown				
1	18606	3	0,54	257,83	224,25	200,19	257,83	257,83	224,25	224,25	200,19
Calculation completed for all properties in the catchment and Summed											
Sum							4756896	4471872	4320450	3827743	3398334

If	Then
Probability ≤ (Current)	Use Current Selection
(Current) < **Probability** ≤ (Current + Medium)	Use Medium Selection
Probability > (Current + Medium)	Use Low Selection

Scenario 1			Scenario 2			Scenario 3			Scenario 4			Scenario 5		
Current	Medium	Low	Current	Medium	Low	Current	Medium	Low	Current	Medium	Low	Current	Medium	Low
0,8	0,1	0,1	0,6	0,2	0,2	0,5	0,25	0,25	0,25	0,4	0,35	0	0,5	0,5

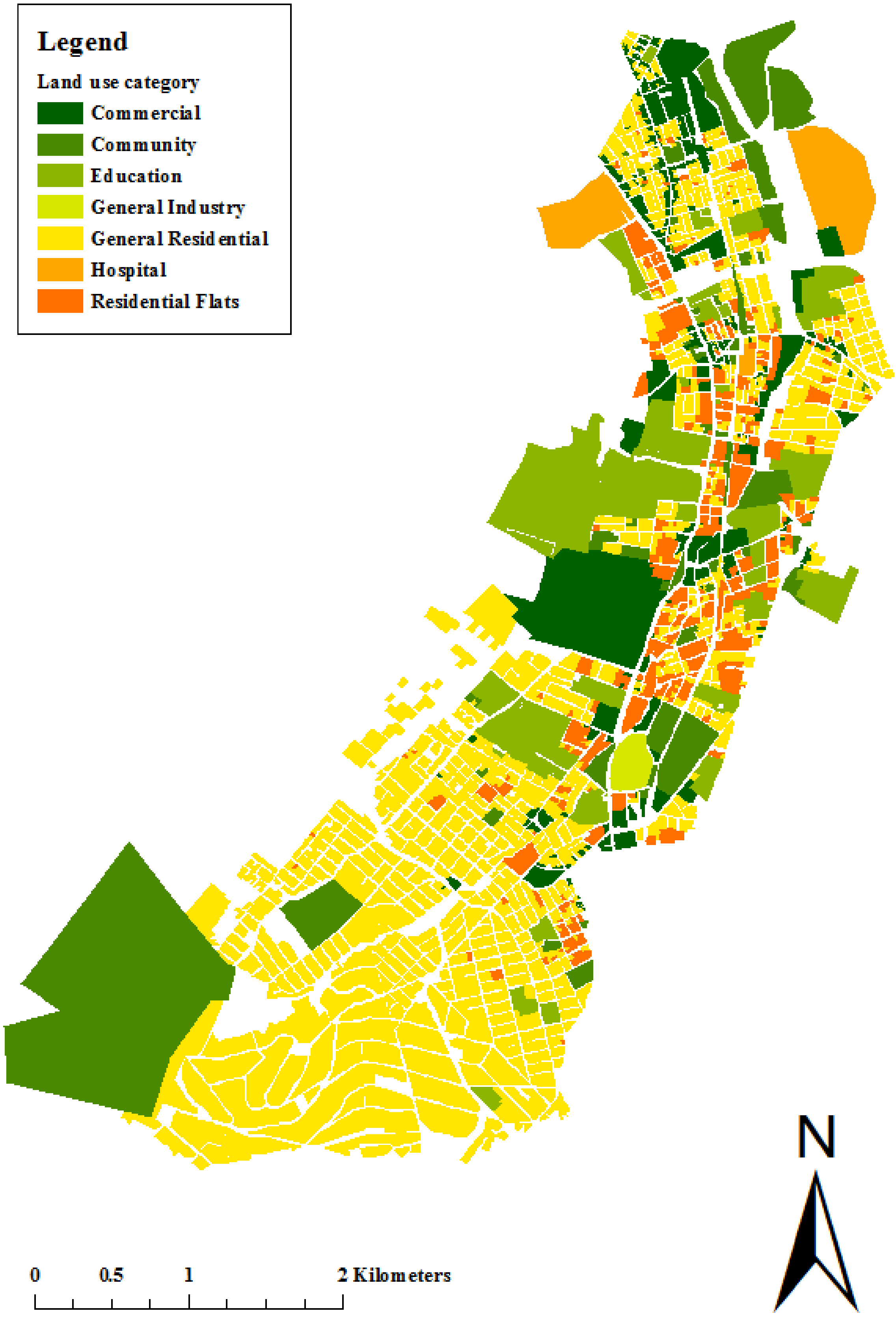
Calculation Process repeated for 1000 cycles

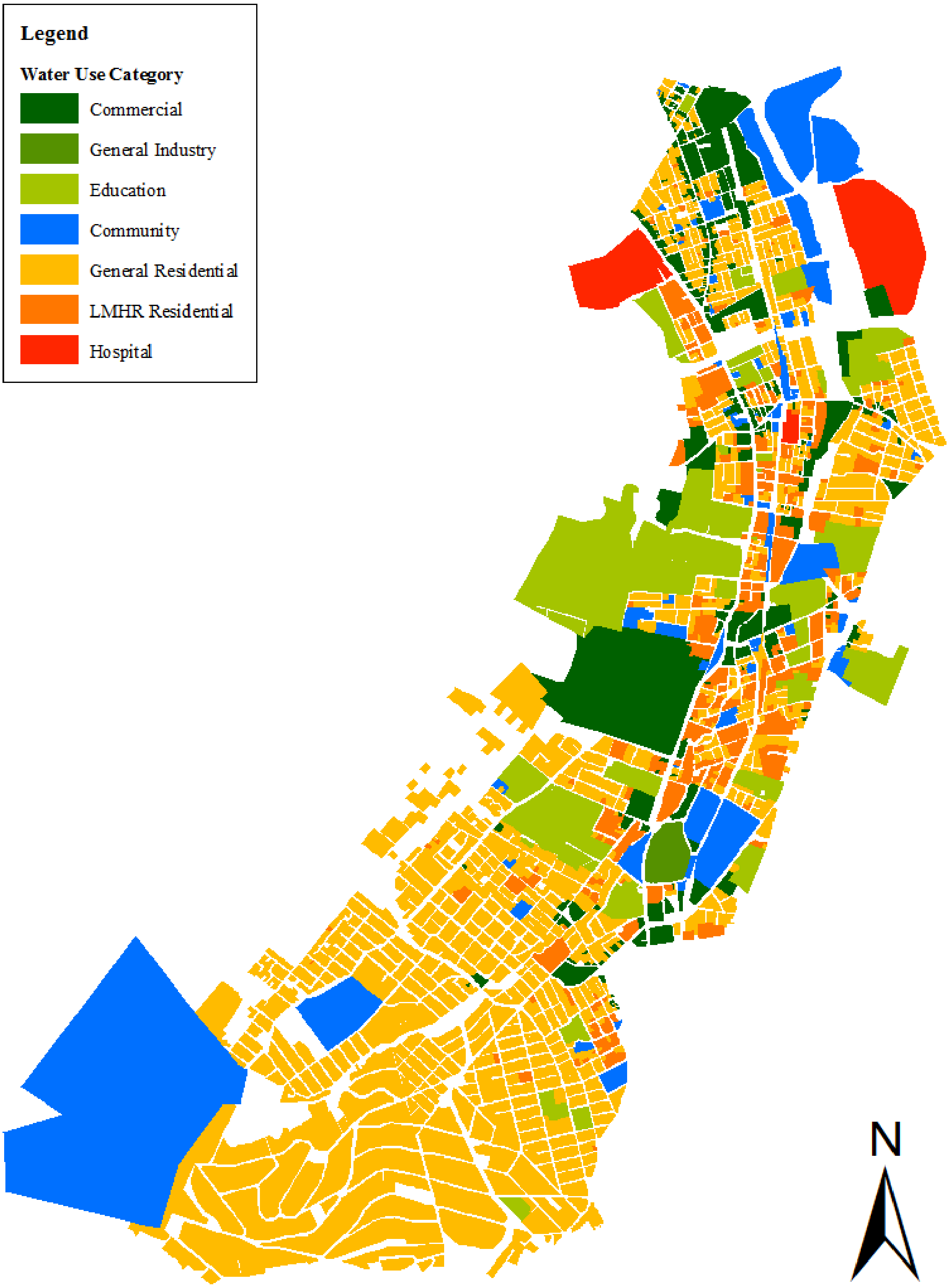
	Current Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 3	Scenario 4
Min Consumption (kℓ)	5130	4516	4157	4001	3615	3249
Median Consumption (kℓ)	5130	4787	4417	4238	3807	3346
Max Consumption (kℓ)	5130	4884	4599	4444	4047	3445

Figure G1: Calculation procedure for the allocation of water efficient devices to properties in the catchment

Appendix H

GIS Land use distribution maps

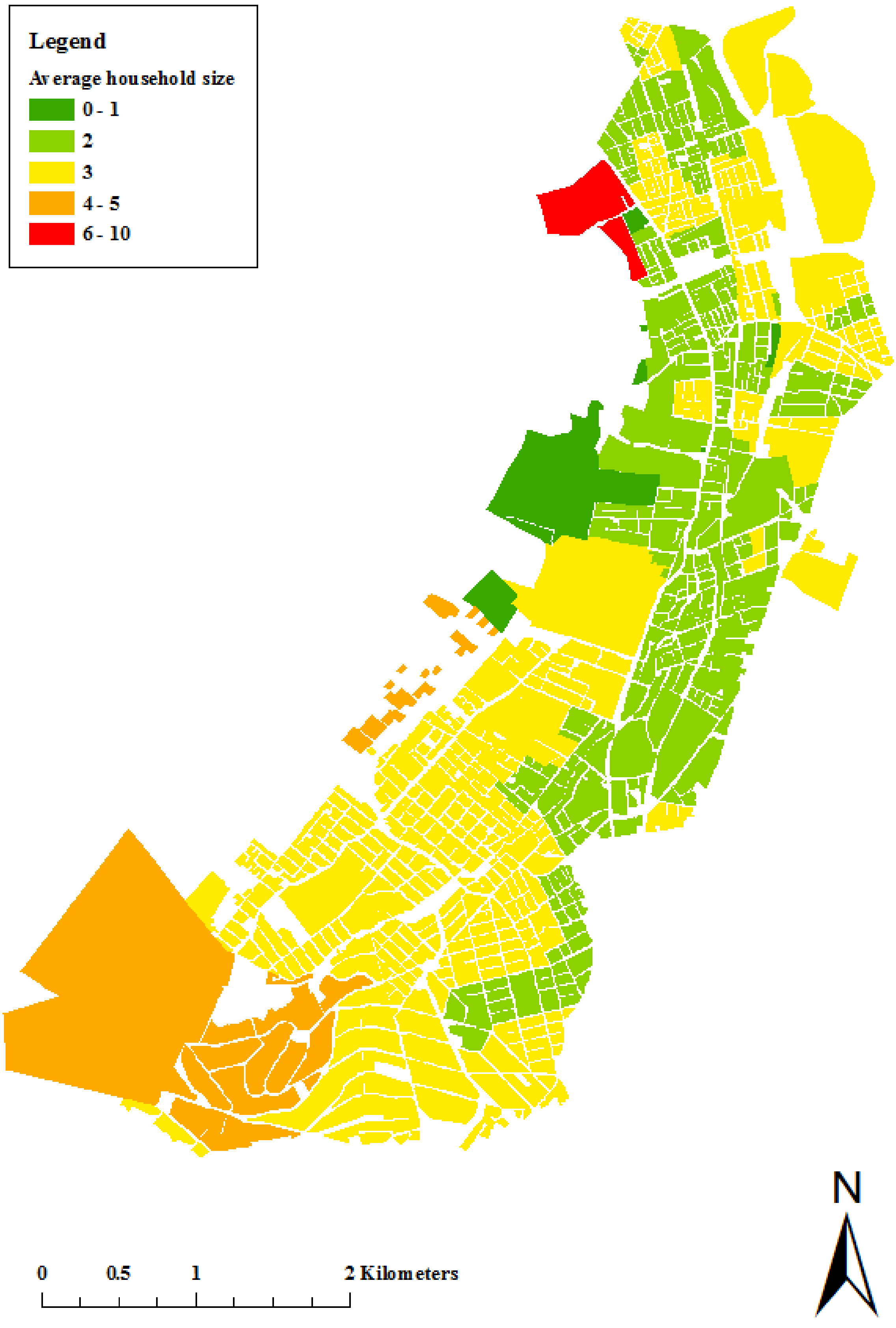

Legend
Land use category
Commercial
Community
Education
General Industry
General Residential
Hospital
Residential Flats
0
0.5
1
2 Kilometers
N



Legend
Water Use Category
Commercial
General Industry
Education
Community
General Residential
LMHR Residential
Hospital
N
0
0.5
1 Kilometers

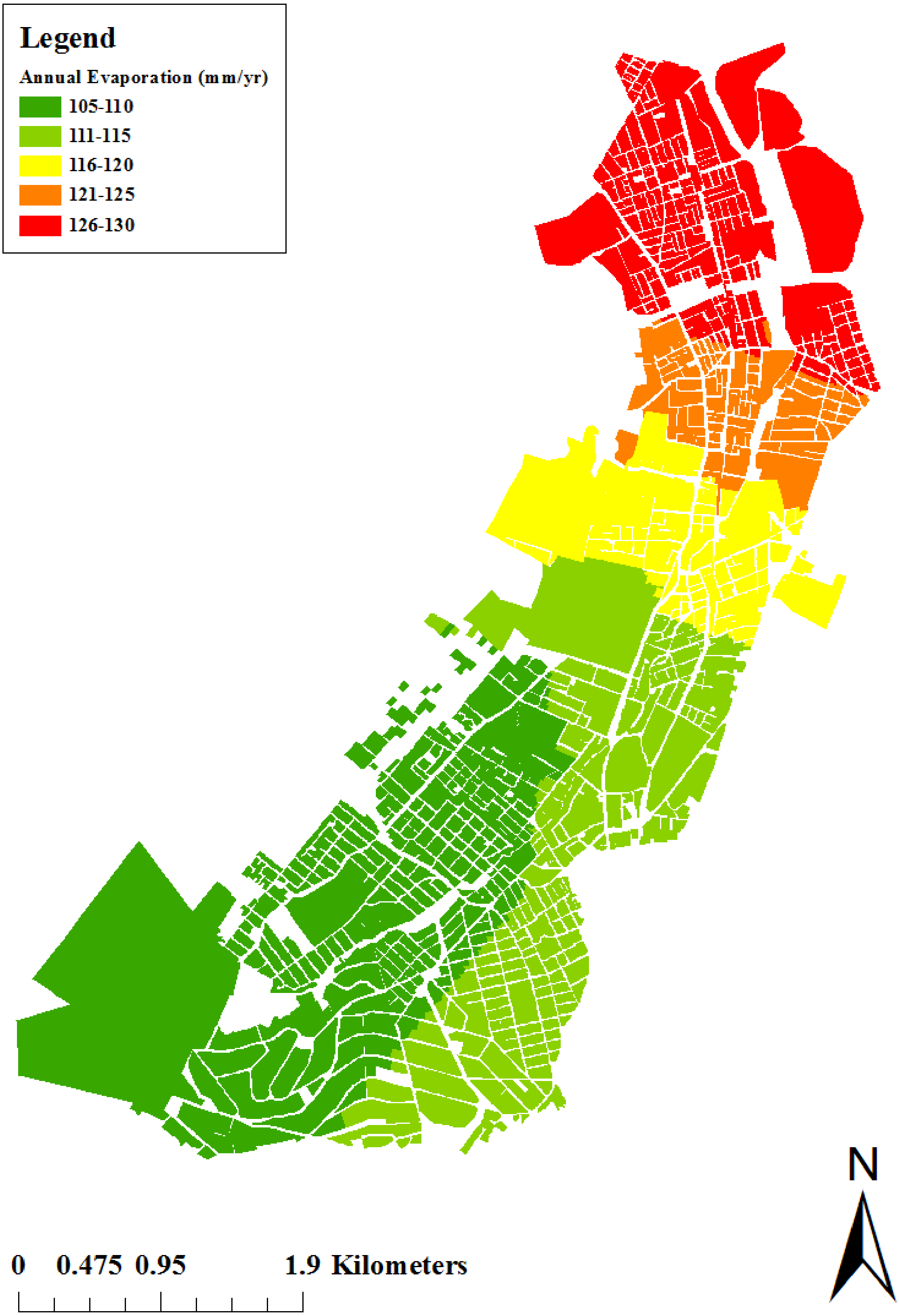
Appendix I

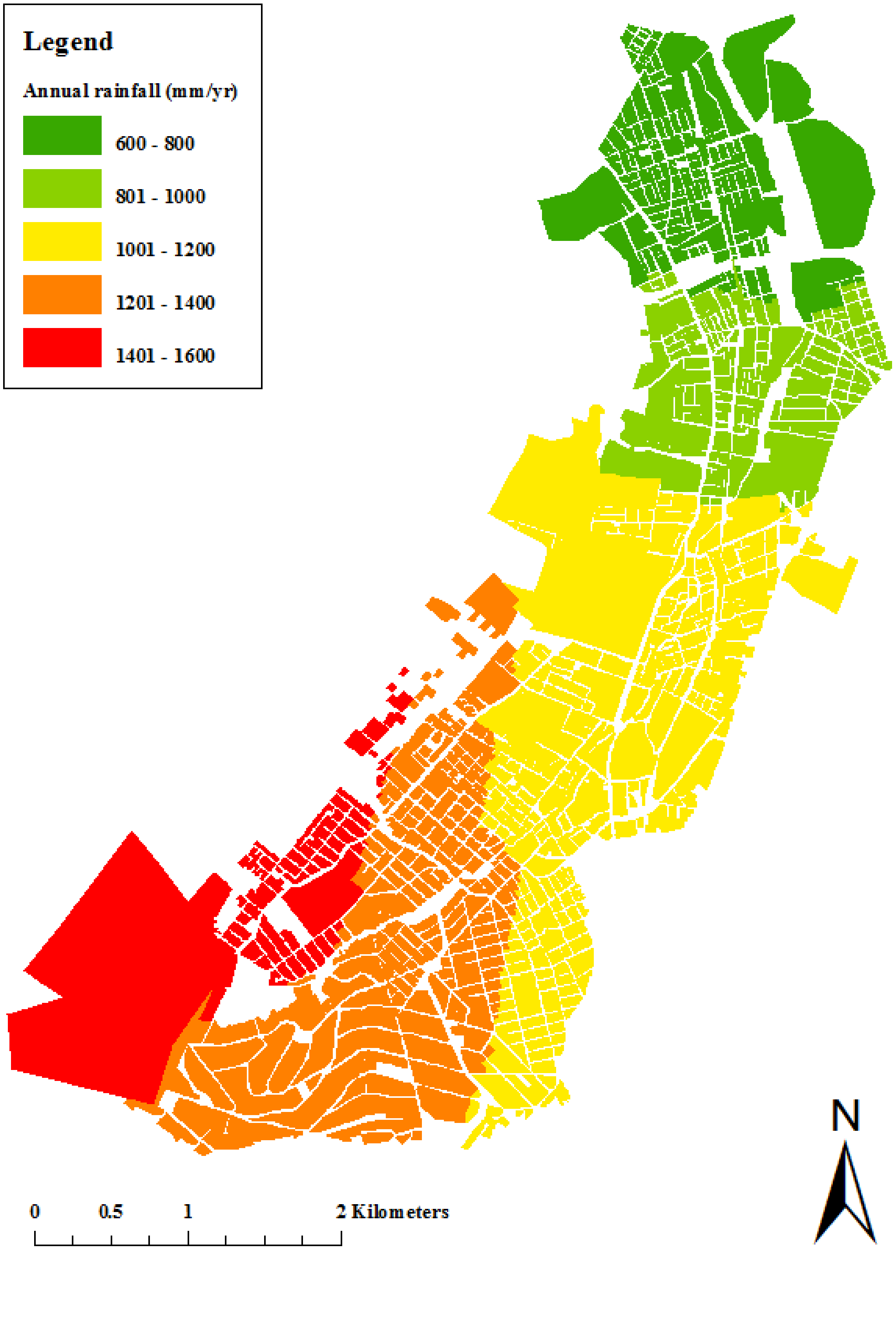
GIS household size distribution


Legend
Average household size
0 - 1
2
3
4 - 5
6 - 10
0
0.5
1
2 Kilometers
N

Appendix J

GIS rainfall and evaporation distribution


Legend
Annual Evaporation (mm/yr)
105-110
111-115
116-120
121-125
126-130
0 0.475 0.95 1.9 Kilometers
N

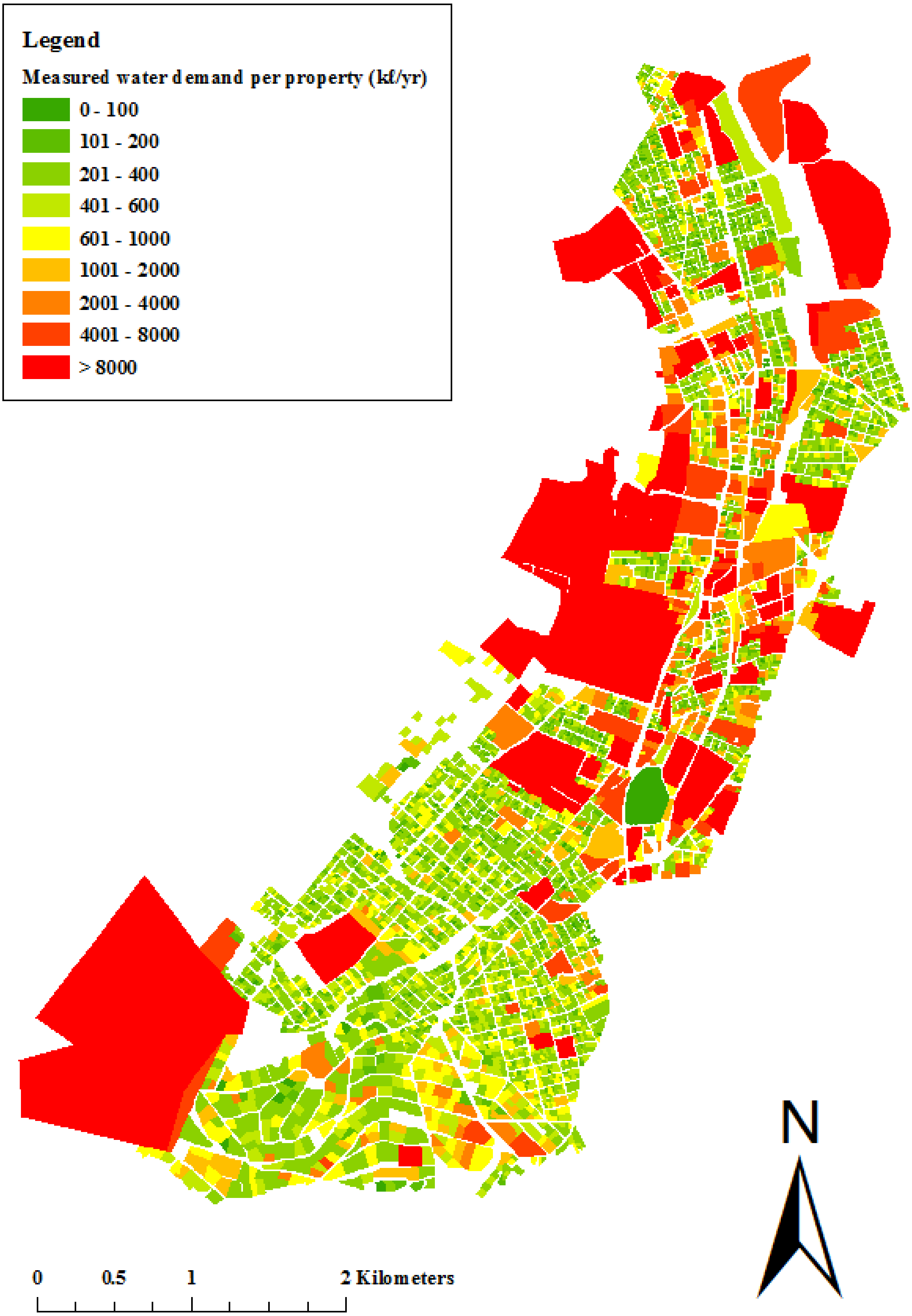

Legend
Annual rainfall (mm/yr)
600 - 800
801 - 1000
1001 - 1200
1201 - 1400
1401 - 1600
0
0.5
1
2 Kilometers
N

Appendix K

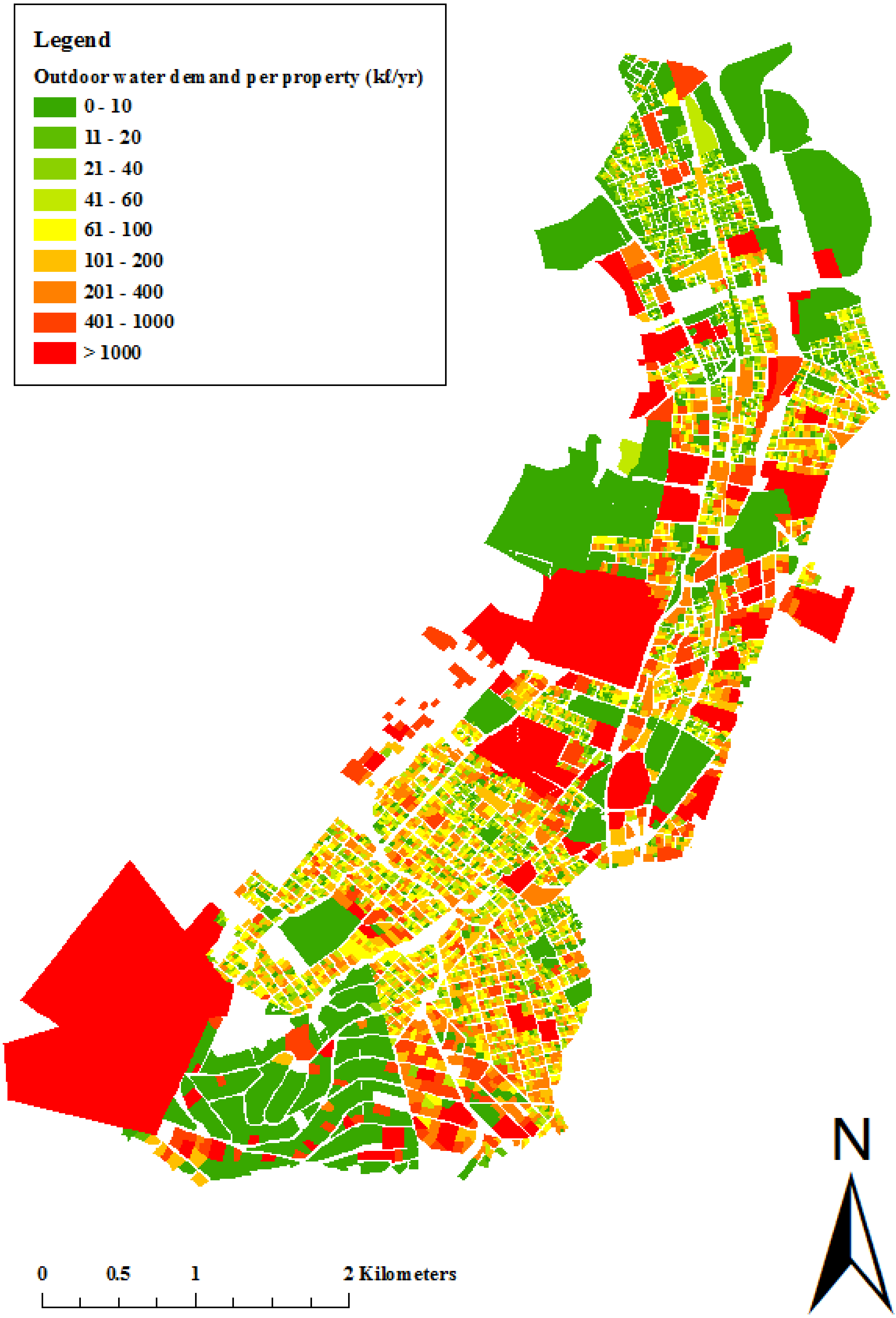
GIS Measured water demand

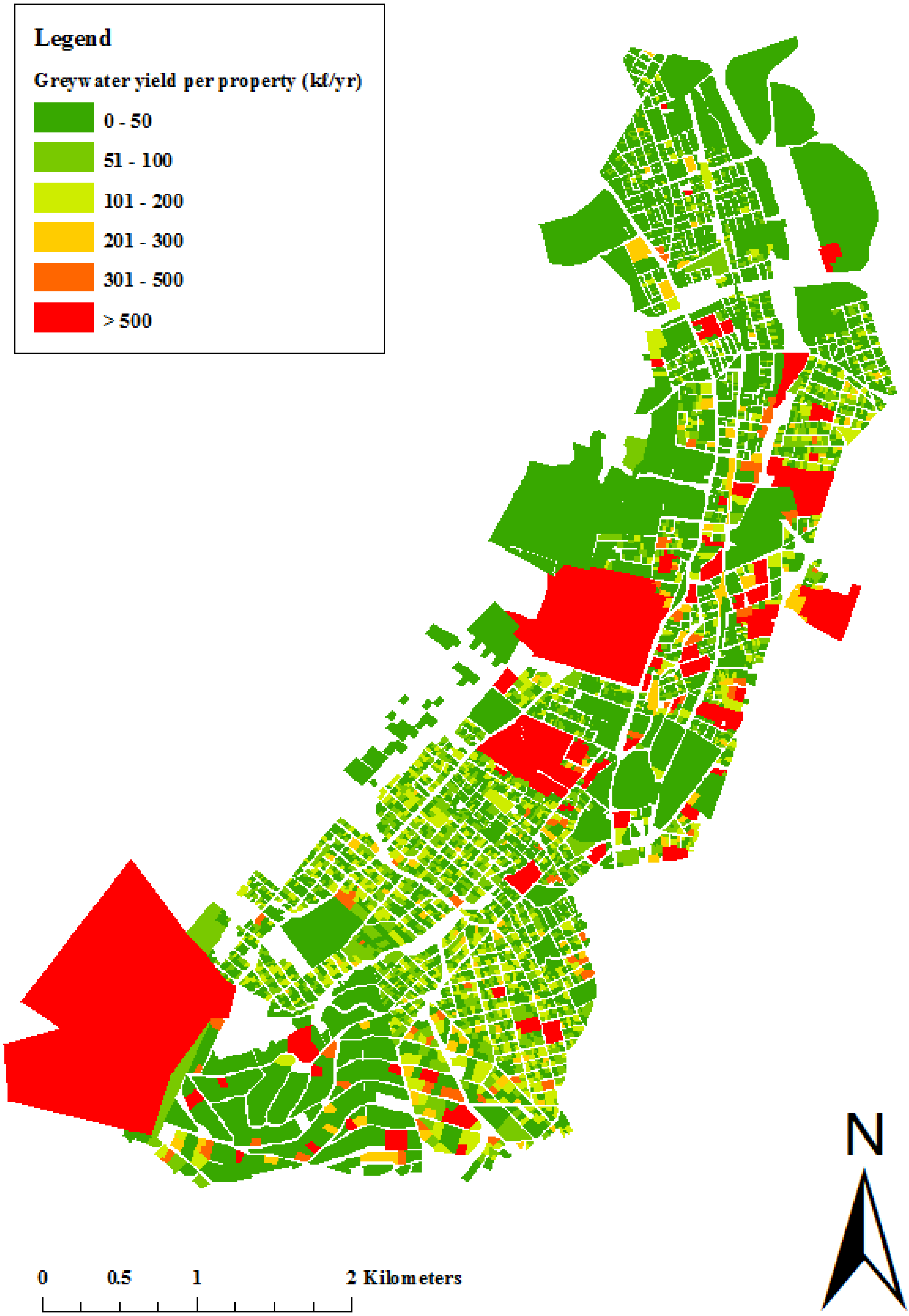
Outdoor water demand

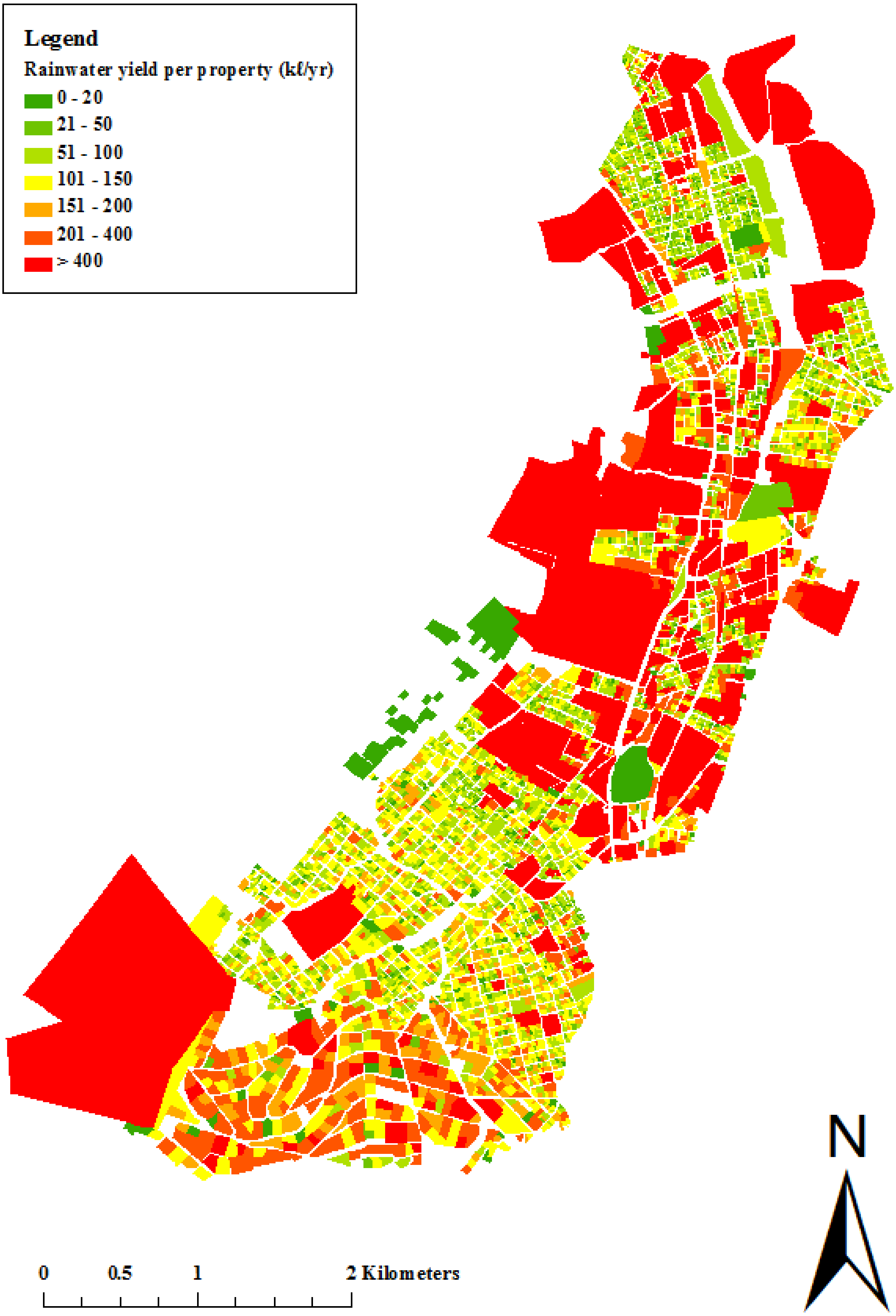
Greywater and greywater harvesting yields



Legend
Measured water demand per property (kℓ/yr)
0 - 100
101 - 200
201 - 400
401 - 600
601 - 1000
1001 - 2000
2001 - 4000
4001 - 8000
> 8000
0
0.5
1
2 Kilometers
N


Legend
Outdoor water demand per property (kl/yr)
0 - 10
11 - 20
21 - 40
41 - 60
61 - 100
101 - 200
201 - 400
401 - 1000
> 1000
0
0.5
1
2 Kilometers
N


Legend
Greywater yield per property (kℓ/yr)
0 - 50
51 - 100
101 - 200
201 - 300
301 - 500
> 500
0
0.5
1
2 Kilometers
N


Legend
Rainwater yield per property (kℓ/yr)
0 - 20
21 - 50
51 - 100
101 - 150
151 - 200
201 - 400
> 400
0
0.5
1
2 Kilometers
N