Challenges and opportunities for implementing Water Sensitive Design in South Africa

Report to the

Water Research Commission

by

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WRC Report No. 2412/1/18
ISBN 978-0-6392-0015-6

June 2018

Obtainable from
Water Research Commission
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GEZINA 0031

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Printed in the Republic of South Africa

Preamble

This report is a compilation of several research projects that were undertaken in an attempt to start ‘building a case’ for the implementation of WSD on a broad scale in South Africa – in recognition of the fact that a new approach to the management of water is required. It therefore simply provides an overview of what might (and might not) work in this regard, rather than being a prescriptive manual on WSD implementation in South Africa. In this regard it represents a ‘work in progress’, aimed at demonstrating the various research contributions and at showing that there is potential to change the way water is managed in this country.

The document should be read in conjunction with WRC Report TT 588/14: “*Water Sensitive Urban Design (WSUD) for South Africa: Framework and guidelines*” (Armitage *et al*., 2014) and WRC Report TT 558/13: *The South African Guidelines for Sustainable Drainage Systems* (Armitage *et al*., 2013).

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Executive summary

Introduction

One of the most pressing issues of concern in South Africa is the availability and quality of water, both as a natural resource critical for human development, as well as a commodity that contributes significantly to the country's economic growth. Worldwide, evidence suggests that the philosophy of Water Sensitive Urban Design (WSUD) – an approach to urban planning and design that integrates the management of the entire urban water cycle into land use and development processes – offers a wider variety of choices in the management of scarce and often deteriorating water resources, and that it adds general economic and environmental value to cities. In the South African context, the WSUD approach can additionally be seen to transform urban areas, potentially connecting spatial divisions through the development of 'blue-green corridors', and ensuring greater equity in terms of the availability of a wider variety of water services – as well as through the adoption of alternative technologies and enterprise innovations that ensure water security.

The importance of an approach such as this was acknowledged in WRC study K5/2071 (Armitage *et al.*, 2014), which provided a framework and guidelines for WSUD in South Africa. However, outside of a relatively small number of professionals, there is a lack of information on the potential benefits that could result from implementing WSUD on a large scale in this country. A business case needs to be developed to show that it is a viable approach, and to encourage national / local authorities, developers and citizens to change their behaviour accordingly – specifically in a developing country such as South Africa which is committed to addressing the effects of rapid urbanisation, and achieving universal access to basic services in a manner that is resource-efficient whilst minimising environmental impact and improving affordability. It is not only urban and peri-urban environments that could benefit from such an approach; the integration of water cycle management into planning and design for the growth of communities needs to include rural settlements as well. For this reason, reference to the word 'urban' has been removed from the term WSUD; thus **Water Sensitive Design (WSD)** is envisioned as the enabler for ensuring that local authorities move closer to meeting developmental goals in all settlements where people dwell, irrespective of scale and locality.

The study has explored the challenges to and opportunities for the implementation of WSD in South Africa, mainly from a technical perspective – as highlighted through detailed catchment studies. The future development of policy on WSD in South Africa will likely be informed by the various different components of the project aimed at identifying opportunities for implementing the various WSD tools and techniques in selected urban catchments – including rainwater harvesting (RWH) and stormwater harvesting (SWH); sustainable (urban) drainage systems (SuDS), Water Conservation and Water Demand Management (WCWDM), water efficient devices, greywater harvesting, and groundwater use linked to managed aquifer recharge (MAR). WSD elements have been assessed in the design / redesign of precincts of the selected catchments to demonstrate how WSD could potentially improve water quality, water quantity, biodiversity and amenity value – thus creating liveable, sustainable and resilient outcomes for urban areas.

Background and rationale

As South Africa continues to face the challenges of water scarcity and declining water quality, the relevance of WSD will increase and the need to start considering cities in a different way will become more urgent. Climate change has the potential to further complicate these challenges by decreasing the availability of water while simultaneously increasing demand. Changes in storm intensities can also result in extensive flooding in areas where stormwater systems are either inadequate in terms of safely removing runoff, or have not been properly maintained. Locally-relevant information on the individual technologies associated with WSD is generally available and well-documented; what is not so apparent in the South African context however, is the way in which the notion of water sensitivity links with urban design and planning, and how the concept of WSD can be used to transform towns and cities through policy development; institutional structures; community participation; integration of operation and maintenance processes, job creation, etc. The use of modelling tools is seen as an effective approach for developing information to illustrate the benefits and feasibility of sustainable water management interventions, and one of the most useful of these modelling approaches is the development of a water balance which performs an analysis of the inputs and outputs of water for a given catchment.

Recent approaches towards achieving resilience-based water management recognise the value of water in all its competing uses. There has been growing interest in both the notion of reducing system inefficiencies, as well as in the idea of resource capture and use through sustainable water supply options such rainwater / stormwater, and the use of groundwater, greywater and treated wastewater. As an example of water system inefficiencies, the average per capita demand for potable water in South Africa is 235 ℓ/c/d, increasing to 290 ℓ/c/d in metropolitan areas – compared to the international average of 173 ℓ/c/d (McKenzie *et al.*, 2009). There is thus significant scope to reduce unit consumption of water in this country and proactively curtail water losses.

The impacts of urban domestic RWH, including the related costs, stormwater management impacts, and water demand benefits are not well established. Additionally, whilst SWH is increasingly being considered in water management planning internationally, there has been little experience in South Africa of its viability and benefits, and very few studies have considered the impacts of RWH and SWH in combination. Further attention is being focused on the strong interactions between groundwater and these other water flows, and the fact that groundwater is becoming an increasingly important resource in urban areas worldwide. The most established role of groundwater within WSD is directly or indirectly linked to various forms of MAR, which fulfils a number of WSD objectives, such as stormwater management, stormwater / wastewater reuse, and reducing demand for potable water by providing alternative sources of water that can be used for a number of 'fit-for-purpose' applications.

Research approach

The overall aim of this study was to test the WSD concept and framework that was developed as part of WRC Project K5/2071 within selected catchments and/or municipalities in South Africa. This was achieved by way of an intensive, multidisciplinary study of an urban catchment in Cape Town, the Liesbeek River catchment – including aspects such as: developing a total water balance; investigating the viability of water (re)use options (RWH, SWH, greywater harvesting, and water efficient devices); assessing property value capture opportunities; exploring architectural influences in WSD; and determining environmental and socio-economic externalities (for example, public knowledge related to stormwater quality, societal perceptions, and amenity value of WSD). A range of other sites in and around Cape Town which demonstrate various aspects of WSD and which offer a means of developing a practice for WSD, were also explored.

In addition to this, an investigation of the potential for using MAR in the Cape Flats Aquifer (CFA) was undertaken – in particular to determine whether there is potential to infiltrate winter rainfall into the aquifer and to enhance the storage capacity through controlled summer abstractions, as well as reducing groundwater related flooding through artificially lowering the water table. The results of the regional-scale *MIKE SHE* model for the CFA provided insights into the relevant hydrogeological processes, including mean groundwater level, groundwater head elevation and recharge. Based on this, the Philippi and Mitchells Plain areas in the southern region of the CFA were deemed to be most appropriate for MAR (see Figure 4.8). A more detailed local-scale MIKE SHE model was used to perform a scenario analysis of the MAR options available that attempt to reduce winter flooding while supplementing the demand for water during summer.

Owing to the fact that the feasibility assessment process was dominated by intensive catchment studies, less attention was paid in this study to the ways in which WSD will be championed and/or will find traction in a country like South Africa; i.e. through city planning policy and investment; national water resource strategies and other legislation; human and financial capacity development. However, an ongoing parallel project – the Water Sensitive Design Community of Practice programme (WRC Project K5/2413) – aims to advance the WSD vision in South Africa, and is attempting to address the notion of managing the complexity inherent in an approach such as WSD, to ensure that it can influence planning and the alignment of governance aspects at a high level.

Implementing WSD – results of feasibility studies

WSD is based on the premise that any development or redevelopment must address the sustainability of water, with the focus not only on the design of the individual elements or technology/ies, but also on how the system is managed as a whole. In other words, the innovation in WSD arises from the systems approach that it demands. A key finding of WSD-related research in South Africa is that while much can be gained from international experience, there is a need to test technologies within the local context. Much of the focus to date on WSD technology options has, however, been on alternative water sources, with limited research on issues such as: stormwater, treated effluent and groundwater / MAR management activities associated with WSD; and the development of appropriate systems that promote amenity and biodiversity as part of WSD implementation projects in South Africa.

Conceptualising the implementation of WSD requires an interdisciplinary perspective of a range of factors (technical; environmental / climatic; social; economic), many of which will be site specific. This project investigated the feasibility of implementing a range of different WSD technologies – specifically in respect of the potential benefits each of the technologies can potentially provide (see Table 5.1). The research also indicated that while different WSD technologies may provide certain benefits in isolation, these benefits can either be substantially increased (e.g. where a treatment train is used for stormwater quality management), or decreased (e.g. where multiple alternative water sources are being used to supply water for only one end use).

Table 5.1: Technology-specific findings from WSD feasibility studies

WSD technology	Potential benefits of WSD technology implementation
Rainwater harvesting	Rainwater harvesting primarily offers a means of reducing municipal water demand, but with negligible stormwater management benefits. Currently it is only financially viable for a minority of the (more affluent) property owners (8% and 9.5%) in the Liesbeek catchment, and only if runoff is harvested from the majority of their roof areas and used for a diversity of end uses – equating to approximately 7% of total residential water demand.
Stormwater harvesting	Stormwater harvesting offers a means of reducing municipal potable water demand (potentially up to 20% in the Liesbeek River catchment), decreasing total runoff volumes, offering amenity benefits and, if actively managed, also a means of attenuating peak flows. In certain areas, it offers a means of financially and economically providing water that is less expensive than the currently supplied potable water.
Water efficient devices	Water efficient devices could have a significant impact on reducing water demand. The results from the Liesbeek catchment study showed that the implementation of water efficient devices had the greatest impact on the domestic sector. Installing water efficient devices in domestic properties could potentially reduce indoor water use by nearly 50%.
Greywater harvesting	Greywater could be used to significantly reduce the demand for potable water – by meeting outdoor water requirements – in the Liesbeek River catchment (whilst acknowledging potential health risks). The one main advantage of greywater reuse over RWH / SWH is that the supply of greywater is constant throughout the year, meaning that the seasonal variation of outdoor water demand can be catered for. Managed greywater reuse is considered most feasible for commercial and institutional purposes – and could contribute nearly 12% of the total water demand in the Liesbeek catchment.
Sustainable Drainage Systems (SuDS) – e.g. Permeable Pavement Systems (PPS)	SuDS such as PPS offer a means of not only improving the quality of polluted stormwater run-off in urban areas, but also offer potential for storing water for a range of fit-for-purpose uses. Proper design, installation, maintenance and operation of these systems is however crucial.
Managed Aquifer Recharge (MAR) – linked to stormwater harvesting	MAR could provide a viable water supply option for the city of Cape Town by facilitating the reuse or recycling of stormwater or treated wastewater, potentially contributing between 18 Mm^3 to 40 Mm^3 per year (5 to 11% of the average potable demand) towards the city's water supply. MAR is a tool for application of WSD in Cape Town, offering value for both water supply and stormwater management / reducing flooding. Additionally, WSD and its application in MAR offers valuable benefits including pre-treatment, enhanced public amenity and improved biodiversity.

One of the key economic factors for widespread implementation of WSD is the 'level of adoption' as this is a critical driver of cost. Ultimately, however, adoption is driven predominantly by social perceptions – especially those around what are 'acceptable' water resources – although these may change over time, especially during times of drought or floods. In this regard, community involvement in the implementation process is important, as WSD is an opportunity to educate people on the value of water in the urban environment. Additionally, six drivers have been identified for encouraging South African developers to incorporate WSD approaches, including: Approval / legislative mechanisms (development approval processes, local government policy and by-laws); Institutional champions; Economic incentives (particularly in respect of perceived benefit provided to return on investments); Green Building ratings; Physical constraints (such as infrastructure capacity limitations, stringent water quality standards, pre-existing and protected buildings, zoning restrictions and/or difficult sites); and Sensitive environments (e.g. wetlands, dry coastal forests, estuaries). However, it appears that the potential value capture from WSD is not yet being emphasised in spatial planning decisions, nor are planners sufficiently aware of the positive role of sustainably-managed stormwater and river systems – although there are examples of property owners funding the SuDS maintenance required because they want high levels of service in their area and recognise the value of these assets.

Conclusions

The use of catchment-based modelling studies – including the calculation of water balances – is critical in terms of supporting a transition to water sensitive towns and cities, and emphasises the importance of monitoring information and data availability. The studies undertaken as part of this research provided useful lessons and evidence in terms of the opportunities for using stormwater and groundwater storage infrastructure to deal with water scarcity. If these options are considered sufficiently early on in any design process – in association with the planning for potable water and sewage treatment systems – WSD could potentially provide urban areas in South Africa with supplementary sources of non-potable ('fit-for-purpose') water, thereby reducing the demand for potable water. This, in turn, may assist in ensuring that all South Africans have access to sufficient water and could contribute to improved health outcomes as a result of providing water at determined service levels. Conversely, due consideration must be taken of the potential health risks associated with alternative water resource use; although this can be countered with the proposed / desired 'fit-for-purpose' uses of the water, and the fact that further treatment processes can be put in place if necessary. Taking this a step further, WSD could be implemented as a means of ultimately taking urban areas 'off the water grid' and for towns and cities to start operating within the limits of their existing water resources. In Cape Town, for example, the average annual amount of rain that falls on the city equates to almost three times that of its potable water demand; however, innovative ways of storing this rainwater will need to be found if it is to be used as resource. Also, the management of water has to encompass all aspects of the urban water cycle, including water supply, sewerage and stormwater management, so that water of different levels of quality can be made available for a range of 'fit-for-purpose' uses and the demand for potable water is thus reduced. In this regard, the new element of sanitation as a resource ('waste to wealth') also needs to be considered as a lever for WSD. This is not only in terms of reducing water use through dry sanitation or low-flush options for waterborne sanitation , but also in terms of other resource capture options such as nutrients, energy, etc.

The implementation of WSD at local, site or city-scale, requires much more than just the careful design, operation and management (including monitoring) of separate WSD infrastructure elements. It also requires the involvement of and consultation with relevant stakeholders and officials (e.g. through the development of Communities of Practice and the setting up of Learning Alliances), so as to explore new ways of thinking based on the knowledge and experiences of a wide range of participants, and to deal with any potential conflicts of interest that may arise specifically from a lack of understanding and ability to interpret WSD systems as a whole.

In order for WSD to become entrenched in water services planning in the country, the institutional and technical linkages that have been highlighted by way of the research will need to be translated into policy and organisational structures. This is especially important when considering the trade-offs between managing water as a resource (the central tenet of WSD), and protecting biodiversity and human health; for example, including more SuDS features will necessarily change the form and maintenance requirements of stormwater ponds and other drainage infrastructure, thus necessitating changes with respect to the way these features are operated and maintained. Institutional acceptance is thus critical, as the more landscaping that is involved, the less it appears as an ‘engineered solution’ (even though there is often very precise engineering involved), and the less effort is put into maintaining it by the municipality. SuDS features must form part of the municipal engineering maintenance schedule, and be budgeted for accordingly. There is also the issue of different perception of green space and open bodies of water, particularly amongst low-income groups who may find these areas undesirable (from a safety / health risk point of view). Trade-offs may thus also be required when determining the best use of resources either for addressing development and equity issues, or for developing multi-functional urban areas that are resilient and adaptable to change. It is important to note that by including ecological infrastructure in the design of urban spaces, natural ecosystems can assist in recreating catchment (i.e. water capture and storage) conditions and improving water quality, as well as enhancing and improving the liveability of towns and cities (e.g. through reducing urban heat island effects and mitigating storm intensities).

The challenges with WSD implementation in the context of municipal planning are mainly as a result of: institutional and planning fragmentation and power dynamics within local authorities; a mindset of lack of resources and time constraints; the traditional planning and engineering paradigm not being suited to current complex water issues (for example, the fact that stormwater is viewed as a threat to roads infrastructure); and an overall resistance to change. This study has shown that Water Sensitive Design has the potential – through relatively modest interventions – to change the way in which water is managed in South Africa so as to increase sustainability and develop resilience within water systems. It is acknowledged, however, that embedding a new paradigm such as this will take time, and will be dependent on local-level knowledge and the appropriate ‘champions’ with some level of recognition and political acceptance to take it forward.

Recommendations

The following key actions are suggested as central to speeding up implementation and ensuring the feasibility of WSD in South Africa:

- Establishing clear and consistent objectives and targets for WSD with regard to new urban developments and infrastructure;
- Ensuring stronger linkages between the urban development and planning system and urban water management;
- Ensuring a consistent approach to WSD across all relevant government policy areas;
- Establishing processes for national and local government leadership in adopting WSD principles in its own developments;
- Providing local government and private sector support by building capacity and skills through an ongoing capacity building initiative;
- Supporting ongoing research into WSD approaches and impediments;
- Establishing arrangements for ongoing monitoring and assessment to demonstrate the benefits of WSD are achieved and sustained over the long term.

Based on these recommended actions, the following is recommended as a way forward for implementing Water Sensitive Design more broadly in South Africa:

- WSD should be incorporated into the overall regulatory structures of local authorities, including future Integrated Development Plans (IDPs), Spatial Development Plans (SDPs), Water Services Development Plans (WSDPs), bylaws and policies – and taking into account oversight and accountability mechanisms.
- An integrated 'Water Sensitive' strategy and/or Plan and associated targets – with resilience as the main focus – should be developed for all towns and cities, and should link to the WSD framework and guidelines (Armitage *et al.*, 2014). This plan should include all aspects of WSD, with a specific focus on Water Conservation and Water Demand Management strategies.
- The concepts of WSD / SuDS (and their focus on resilience) should be included in the Guidelines for Human Settlement Planning and Design, the 'Red Book' (CSIR, 2001) currently under review.
- The integration of departments dealing with water and spatial planning – at both site and regional scale within local areas – is critical to ensure that planning support for WSD options is secured, particularly in respect of greenfield development.
- WSD / SuDS and other green infrastructure elements within urban areas should be included in local authority asset registers, and provision made for suitable design, installation, operation and maintenance of these elements (in terms of budget allowance as well as available capacity).

- The implementation of all new WSD / SuDS systems should make provision for the monitoring (and benchmarking where appropriate) of these systems, – so that a better understanding is created of the way in which they perform.
- One of the key challenges to urban water reform is the disconnect between water systems and the people served by them – engaging residents / communities is therefore crucial in order to effect the behaviour change needed to implement WSD.
- Use the existing WSD Community of Practice (CoP) programme to generate increased understanding about innovative practices and reflexive learning within WSD in South Africa, and to develop knowledge connected to policy development and change to influence planning and design towards water sensitive cities.

Acknowledgements

The authors would like to acknowledge the following contributions to WRC Project K5/2412:

i) The Water Research Commission (WRC) for the financial and technical support of this study, and particularly to the two Project Managers (Dr V Naidoo and Mr J Bhagwan) who were responsible at different stages for overseeing this project.

ii) The project Reference group who provided enthusiastic support and advice throughout. In particular, thanks are due to those members of the Committee who generously made themselves available for consultation outside the formal meetings of the Reference Group:

- City of Cape Town: Mr B Wood, Mr R Arnold (retired), Ms C Haskins;
- City of Johannesburg: Ms J Eagle;
- City of Tshwane: Mr G Jansen van Vuuren;
- eThekwini Municipality: Mr G Tooley and Mr J Harrison (retired);
- Freshwater Consulting Group: Dr E Day
- SRK Consulting: Ms J Burke;
- University of Pretoria: Mr M van Dijk, Ms I Loots
- University of Stellenbosch: Dr J Barnes;

iii) The many undergraduate and postgraduate students from the University of Cape Town (UCT) and the University of the Western Cape (UWC) who contributed to the research effort in various ways. This project was particularly successful in terms of the capacity building it promoted, with no fewer than 22 students involved in various aspects of the research across six different departments / disciplines. The table below provides details of the main student involvement and gives an indication of their project contributions. Should further information be required please refer to the website, www.wsud.co.za – all completed reports, dissertations and theses will be uploaded as they become available.

Selected student research projects associated with WRC Project K5/2412

Name	Degree	Department / Institution	Title of research study	Link to completed thesis / dissertation / project report if available
Lloyd Fisher-Jeffes	PhD	Civil Engineering (UCT)	The viability of rainwater and stormwater harvesting in the residential areas of the Liesbeek River catchment, Cape Town	http://open.uct.ac.za/handle/11427/16523
Ben Mauck	PhD	EGS (UCT)	Managed Aquifer Recharge (MAR) for the management of stormwater on the Cape Flats	Under examination
Daniel Coulson	MSc	Civil Engineering (UCT)	Quantifying the potential for potable water savings in the Liesbeek River catchment	http://open.uct.ac.za/handle/11427/13197
Monica Giermek	MSc	EGS (UCT)	Analysing peak flow attenuation in an urban wetland	http://open.uct.ac.za/handle/11427/19960
Elizabeth Ward	MSc	EGS (UCT)	Public knowledge and stormwater quality in Cape Town, South Africa: a case study of the Liesbeek River	http://open.uct.ac.za/handle/11427/9101
Annesley Crisp	MSc	EGS (UCT)	Analysing stormwater temperature at site-specific discharge points along the Liesbeek River, South Africa	http://open.uct.ac.za/handle/11427/22883
Alastair Rohrer	MSc	Civil Engineering (UCT)	The viability of using the stormwater ponds on the Diep River in the Constantia Valley for stormwater harvesting	Awaiting graduation
Greg Mallett	MSc	CEM (UCT)	An investigation into how value is created through WSUD, using the V&A Waterfront and Century City as Case Studies	Under examination
Siyamthanda Gxokwe	MSc	Geohydrology (UWC)	Local groundwater flow simulation using site specific conceptual and numerical model, Cape Flats Aquifer, Cape Town, South Africa	Draft under review
Christoph de Chavonnes Vrugt	MA	Anthropology (UCT)	Amenity function and social perceptions of stormwater ponds	Not yet completed
Preetya Bhikha	MPhil	Architecture (UCT)	Exploring architectural knowledge in Water Sensitive Design	Draft under review

Selected student research projects associated with WRC Project K5/2412 (cont.)

Name	Degree	Department / Institution	Title of research study	Link to completed thesis / dissertation / project report if available
Frances A'bear	BScEng	Civil Engineering (UCT)	Feasibility study of implementing Water Sensitive Urban Design in Sir Lowry’s Pass Village	Hardcopy only / pdf available on www.wsud.co.za
Aumashvini Gobin	BScEng	Civil Engineering (UCT)	Evaluating the potential of selected WSUD measures in a generic middle income urban catchment in South Africa	Hardcopy only / pdf available on www.wsud.co.za
Alastair Rohrer	BScEng	Civil Engineering (UCT)	Cape Town’s ponds	Hardcopy only / pdf available on www.wsud.co.za
Caitlin Wale	BScEng	Civil Engineering (UCT)	Investigation into the viability of implementing an integrated water management system within a WSUD framework for the proposed Two Rivers Urban Park (TRUP) development in Cape Town	Hardcopy only / pdf available on www.wsud.co.za
Tieho Sekonyela	BScEng	Civil Engineering (UCT)	Investigating solutions for Cape Town to ensure water security until 2040	Hardcopy only / pdf available on www.wsud.co.za
Lucky Mbengwa	BScEng	Civil Engineering (UCT)	Review of Cape Town’s recreational water (‘spray’) parks	Hardcopy only / pdf available on www.wsud.co.za
William van der Byl	BScEng	Civil Engineering (UCT)	Evaluation of the filter drain at the MyCiti bus depot	Hardcopy only / pdf available on www.wsud.co.za
Lauren Brooks	BScEng	Civil Engineering (UCT)	Development of a decision support system to provide direction with Sustainable Drainage Systems selection	Hardcopy only / pdf available on www.wsud.co.za
Anthony Fry	BScEng	Civil Engineering (UCT)	Opportunities for using WSUD to reduce the negative impacts of the developing industries in Saldanha Bay Municipality	Hardcopy only / pdf available on www.wsud.co.za
Catherine Atkinson	BScEng	Civil Engineering (UCT)	Water Sensitive Urban Design case study in East London	Hardcopy only / pdf available on www.wsud.co.za
Raadhiya Perin	BScEng	Civil Engineering (UCT)	Investigation of current decentralised groundwater usage in the City of Cape Town	Hardcopy only / pdf available on www.wsud.co.za

Table of contents

Appendix A: Catchment study – Liesbeek River, Cape Town

Appendix B: Testing Managed Aquifer Recharge on the CFA

Appendix C: 'Liesbeek Life Plan'

List of tables

List of figures

List of Abbreviations

AADD	Annual average daily demand
ASR	Aquifer Storage and Recovery
ASTR	Aquifer Storage, Transfer and Recovery
AWRMS	Atlantis Water Resource management Scheme
BMP	Best Management Practice
CFA	Cape Flats Aquifer
CoCT	City of Cape Town
CoP	Community of Practice
CRCWSC	Cooperative Research Centre for Water Sensitive Cities
CSI	Corporate Social Responsibility
CTSDF	Cape Town Spatial Development Framework
DSS	Decision Support System
EC	Electrical Conductivity
ESG	Environmental, Social & Governance
FM	Facilities Management
GBCSA	Green Building Council of South Africa
GBI	Green Building Industry
GBRT	Green Building Rating Tool
GI	Green Infrastructure
GWH	Greywater Harvesting
ha	Hectare
ICBD	Inner City Bus Depot
IUDF	Integrated Urban Development policy Framework
IUWM	Integrated Urban Water Management
IWRM	Integrated Water Resource Management
kℓ	Kilolitre
ℓ/c.d	Litres per capita per day
LA	Learning Alliance
LEED	Leadership in Energy and Environmental Design
LID	Low Impact Development
MAR	Managed Aquifer Recharge
Mℓ	Megalitre
MOSS	Metropolitan Open Space System
NGO	Non-governmental Organisation
NRW	Non-Revenue Water
NWA	National Water Act
NWRS	National Water Resource Strategy
O&M	Operation and Maintenance
PPS	Permeable Pavement System
RoI	Return on Investment
RSA	(Republic of) South Africa
RTC	Real-time Control

RWH	Rainwater Harvesting
SBM	Saldanha Bay Municipality
SES	Socio-ecological Systems
SRI	Socially Responsible Investment
SuDS	Sustainable (urban) Drainage Systems
SWH	Stormwater Harvesting
TDS	Total Dissolved Solids
TP	Total Phosphorous
TRUP	Two Rivers Urban Park
TSS	Total Suspended Solids
UCT	University of Cape Town
USGBC	United States Green Building Council
WC/WDM	Water Conservation / Water Demand Management
WED	Water Efficient Device
WRC	South African Water Research Commission
WSC	Water Sensitive City
WSD	Water Sensitive Design
WSUD	Water Sensitive Urban Design
YAS	Yield After Spillage
YBS	Yield Before Spillage

Glossary of terms

Please note that these definitions apply to the use of terms in this document only.

Aquifer is a porous, water-logged sub-surface geological formation. The description is generally restricted to media capable of yielding a substantial supply of water.

Attenuation means the reduction of peak stormwater flow.

Bio-retention area here refers to a depressed landscaped area that collects stormwater runoff and infiltrates it into the soil below through the root zone thus prompting pollutant removal.

Brownfield here refers to a site that is or was occupied by a permanent structure which is now being considered for redevelopment.

Catchment here refers to the area contributing runoff to any specific point on a watercourse or wetland.

Channel here refers to any natural or artificial watercourse.

Climate change is a continuous phenomenon and refers to the change in global climatic conditions, e.g. as a result of temperature increases due to anthropogenic emissions.

Contamination here refers to the introduction of microorganisms, factory produced chemicals or wastewater in concentrations that render water unsuitable for most uses.

Detention pond here refers to a pond that is normally dry except following large storm events when it temporarily stores stormwater to attenuate flows. It may also allow infiltration of stormwater into the ground.

Drainage may refer to: (1) the removal of excess ground-water or surface water by gravity or pumping; (2) the area from which water bodies are removed; or (3) the general flow of all liquids under the force of gravity.

Drainage area is that part of a catchment that contributes to the runoff at a specified point.

Drainage system refers to the network of channels, drains, hydraulic control structures, levees, and pumping mechanisms that drain land or protect it from potential flooding.

Dry pond is a detention pond that remains dry during dry weather flow conditions.

Dry weather flow means flow occurring in a water course not attributable to a storm rainfall event. Dry weather flows do not fluctuate rapidly.

Effluent here refers to wastewater that flows from a process or confined space that has been partially or completely treated.

Evapotranspiration means the evaporation from all water, soil, snow, ice, vegetation and other surfaces plus transpiration of moisture from the surface membranes of leaves and other plant surfaces.

Filtration, also referred to as **biofiltration**, means the filtering out of stormwater runoff pollutants that are conveyed with sediment by trapping these constituents on vegetative species in the soil matrix or on geotextiles.

Flood means a temporary rise in water level, including ground water or overflow of water, onto land not normally covered by water.

Floodplain means the area susceptible to inundation by floods.

Greenfield here refers to any site including parkland, open space and agricultural land which has not previously been used for buildings and other major structures.

Green roof is a roof on which plants and vegetation can grow. The vegetated surface provides a degree of retention, attenuation, temperature insulation and treatment of rainwater.

Hydrology refers to the physical, chemical and physiological sciences of the water bodies of the earth including: occurrence, distribution, circulation, precipitation, surface runoff, stream-flow, infiltration, storage and evaporation.

Impervious surface here refers to surfaces which prevent the infiltration of water. Roads, parking lots, sidewalks and rooftops are typical examples of impervious surfaces in urban areas.

Infiltration here refers to the process of penetration of rainwater into the ground.

Infiltration device is a SuDS element designed to aid the infiltration of surface water into the ground.

Non-revenue water refers to all water lost through physical leakage or commercial losses(meter under-reghistration, billing errors, theft, etc.) as well as any unbilled autorised consumption (fire-fighting, mains flushing, etc.).

Peak discharge (also known as ‘peak flow’) is the maximum rate of flow of water passing a given point during or immediately after a rainfall event.

Permeability refers to the ability of a material to allow water to flow through when fully saturated and subjected to an unbalanced pressure.

Precipitation is the water received from atmospheric moisture as rainfall, hail, snow or sleet, normally measured in millimetres depth.

Rainwater harvesting is the direct capture of stormwater runoff, typically from roof-tops, for supplementary water uses on-site.

Receiving waters are natural or man-made aquatic systems which receive stormwater runoff, e.g. watercourses, wetlands, canals, estuaries, groundwater and coastal areas.

Resilience refers to the preservation or enhancement of adaptive capacity, i.e. the capacity of a system to preserve core functioning in the presence of shocks and long-term changes.

Retrofitting here refers to the modification or installation of additional or alternative stormwater management devices or approaches in an existing developed area in order to achieve better management of stormwater.

Runoff generally refers to the excess water that flows after precipitation.

Sedimentation is the deposition of soil particles that have been carried by flowing waters, typically during flood peaks as a consequence of a decrease in the velocity of flow below the minimum transportation velocity.

Soakaway is a subsurface structure that is designed to promote infiltration into the ground.

Source controls are non-structural or structural best management practices to minimise the generation of excessive strormwater runoff and/or pollution of stormwater at or near the source.

Stormwater is water resulting from natural precipitation and/or accumulation and includes rainwater, groundwater and spring water.

Stormwater runoff refers to the portion of rainfall which flows to the surface drainage system.

Stormwater system is constituted by both constructed and natural facilities including: stormwater pipes, canals, culverts, overland escape routes, ‘vleis’, wetlands, dams, lakes, and other watercourses, whether over or under public or privately owned land, used or required for the management, collection, conveyance, temporary storage, control, monitoring, treatment, use and disposal of stormwater.

SuDS is the abbreviation for sustainable drainage systems or sustainable urban drainage systems, which are a sequence of management practices and/or control structures or technologies designed to drain surface water in a more sustainable manner than conventional techniques.

Surface runoff is that part of the runoff that travels over the ground surface and in channels to reach the receiving streams or bodies of water.

Sustainable development can be considered as “*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” (WCED, 1987).

Swale is a shallow vegetated channel designed to convey stormwater, but may also permit infiltration. The vegetation assists in filtering particulate matter.

Treatment train is a combination of different methods implemented in sequence or concurrently to achieve best management of stormwater. These methods include both structural and non-structural measures.

Unconfined aquifer is an aquifer that is open to receive water from the surface.

Water table is the upper most level of the zone of saturation below the Earth’s surface, except where this surface is formed by an impermeable body.

Watercourse means any river, stream, channel, canal or other visible topographic feature, whether natural or constructed, in which water flows regularly or intermittently including any associated storage and/or stormwater attenuation dams, natural ‘vleis’ or wetland areas.

Watershed is the upper boundary of a specified catchment area for rainfall that contributes to a given drainage area.

Wetland refers to any land translational between terrestrial and aquatic systems where the water table is usually at or near the surface, or is periodically covered with shallow water, and which in normal circumstances supports or would support vegetation typically adapted to life in saturated soil. This includes water bodies such as lakes, salt marshes, coastal lakes, estuaries, marshes, swamps, ‘vleis’, pools, ponds, pans and artificial impoundments.

1. Introduction

One of the most pressing issues of concern in South Africa is the availability and quality of water, both as a natural resource critical for human development, as well as a commodity that contributes significantly to the country's economic growth. Annual water demand in the country is expected to exceed the available supply by an average of 17% by 2030 (Barilla Group *et al.*, 2009), largely due to increasing rates of urbanisation and population growth. The World Wide Fund for Nature (WWF-SA, 2017) recently proposed four main goals for addressing the future water risks in South Africa, including: building sufficient knowledge and skills to become a water-conscious country; implementing strong water governance to achieve water security under climate change; managing water supply and demand; and becoming a water-smart economy. Worldwide, the evidence suggests that the philosophy of Water Sensitive Urban Design[1] (WSUD) – an approach to urban planning and design that integrates the management of the entire urban water cycle into land use and development processes – offers a wider variety of choices in the management of scarce and often deteriorating water resources, and that it adds general economic and environmental value to cities (Wong & Eadie, 2000). In the South African context, the WSUD approach can additionally be seen to transform urban areas, potentially connecting spatial divisions through the development of 'blue-green corridors', and ensuring greater equity in terms of the availability of a wider variety of water services – as well as through the adoption of alternative technologies and enterprise innovations that ensure water security.

The importance of an approach such as this was acknowledged in WRC study K5/2071 (see Armitage *et al.*, 2014), which was aimed at developing a framework and guidelines for Water Sensitive Urban Design (WSUD) in South Africa (referred to as 'the Framework'). The primary goal of that study was to provide an overview of WSUD through literature in an attempt to address four main aims:

i) To provide a comprehensive summary of the WSUD concept including its principles, strategies and application to water management and urban design through the development of a strategic framework for sustainable urban water management / WSUD;

ii) To carry out an institutional, legal and policy issue review with a view to identifying obstacles to WSUD implementation in a South African context and providing recommendations on how they may be overcome;

iii) To develop WSUD guidelines for South Africa; and

iv) To identify appropriate modelling tools for WSUD in South Africa.

In South Africa, there is currently little knowledge or support for WSUD outside of a relatively small number of professionals, and there is a complete lack of information on the potential benefits that could result from implementing WSUD on a large scale in this country. In other

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[1] *"in its broadest context, WSUD encompasses all aspects of integrated urban water cycle management, including water supply, sewerage and stormwater management. It represents a significant shift in the way water and related environmental resources and water infrastructure are considered in the planning and design of cities and towns, at all scales and densities"* (Fletcher *et al.*, 2014).

words, a business case needs to be developed to show that a holistic design process like WSUD is a viable approach, and to encourage national and local authorities, developers, industrialists and citizens to change their behaviour accordingly. Owing to the fact that WSUD is about creating places to live that are sensitive to the needs of the natural water cycle and which are also attractive, functional and valued (Abbott *et al.*, 2013), there are many approaches and benefits around which a baseline business case could be developed, including:

- Optimising the cost-benefit of infrastructure and built form (green infrastructure; job creation; cost savings and efficiencies);
- Providing resource security and resilience[2] in the future (reduction of flood risk; greater security of water supply);
- Celebrating local character, environment and community (improvement of water quality in watercourses; improvement of ecosystem health); and
- Improving flexibility for communities (local food production; community engagement in water management).

The logic of these objectives is not in question, but rather the feasibility of implementing WSUD against other competing considerations such as cost-benefit factors; betterment of society and the environment – specifically in a developing country such as South Africa which is committed, *inter alia*, to adopting an integrated urban development policy framework (IUDF) to assist local authorities in managing the effects of rapid urbanisation (COGTA, 2013). The IUDF is aimed at improving planning and resource efficiencies so that better returns on investment can be achieved for every Rand spent on infrastructure in urban environments. It is emphasised however, that environmental concerns do not take priority over social concerns – the focus is rather on achieving universal access to basic services in a manner that is resource-efficient so as to minimise environmental impact and improve affordability in the longer term. It is also recognised that it is not only urban and peri-urban environments that could benefit from such an approach; the integration of water cycle management into planning and design for the growth of communities needs to include rural settlements as well. For this reason, it has been suggested that reference to the word ‘urban’ be removed from the term WSUD; thus **Water Sensitive Design (WSD)** is envisioned as the enabler for ensuring that local authorities move closer to meeting developmental goals in <u>all</u> settlements where people dwell, irrespective of scale and locality (note that the terms WSUD and WSD are used interchangeably throughout this report). The question therefore arises as to how WSD is likely to gain credibility in SA – what are the drivers; how should it be promoted and implemented, and whether it makes economic, social, institutional and environmental sense? Simply put: “*Is it feasible in a South African context to adopt WSD principles over conventional means of urban development?*”

This study has thus attempted to determine what it will take to implement WSD in South Africa, by exploring the limitations and challenges to its implementation, mainly from a technical perspective – as highlighted through the detailed catchment studies. The future

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[2] Resilience refers to the preservation or enhancement of adaptive capacity, i.e. the capacity of a system to preserve core functioning in the presence of shocks and long-term changes.

development of policy on WSD in South Africa will likely be informed by the various different components of the project aimed at identifying opportunities for implementing the various WSD tools and techniques in selected urban catchments – including rainwater and stormwater harvesting; sustainable (urban) drainage systems, water efficient devices, greywater harvesting, and groundwater harvesting linked to managed aquifer recharge. WSD elements have been assessed in the design / redesign of precincts of the selected catchments to demonstrate how WSD could potentially improve water quality, water quantity, biodiversity and amenity value – thus creating liveable, sustainable and resilient outcomes for urban areas.

1.1 Study aims

The overall aim of this study was to test the WSD concept and framework developed in WRC Project K5/2071 (Armitage *et al.*, 2014) within selected catchments and/or municipalities in South Africa. Specific research aims (as per the original WRC proposal, no. 1003720) were as follows; and were achieved either by way of this project or through complementary projects aligned with the suite of projects being undertaken as part of the WRC Lighthouse on Water Sensitive Design:

i) Conduct a scoping exercise to evaluate suitable sites for a feasibility assessment study. This exercise should also evaluate the vision, strategy, organisational structure (i.e. planning divisions), resources, budgets and implementation strength of the institutions that may be involved in adopting WSD.

ii) Engage and share the water sensitive design concept, framework and guidelines with relevant stakeholders and ensure buy-in of stakeholders through project cycle.

iii) Provide a baseline assessment of the selected catchment/s (with relevant implementation partner/s).

iv) Set specific WSD objectives for the selected catchment with realistic design and performance objectives. A comparative analysis between conventional design objectives and WSD objectives should be done.

v) Screen and evaluate feasibility of the WSD options within current best planning and management practices, including the selection of appropriate technology options to meet design, cost and performance objectives.

vi) Where possible, develop suitable templates for the various activities and recommend development of new tools or guidelines where gaps in knowledge exist.

vii) Present options to key stakeholders and evaluate the feasibility of the options and the barriers to implementation and document opportunities for future potential demonstration partnerships.

viii) Link knowledge and partnerships to the WRC Water Sensitive Design Community of Practice Programme.

Owing to the fact that the feasibility assessment process was dominated by intensive catchment studies, less attention was paid in this study to the ways in which WSD will be championed and/or will find traction in a country like South Africa; i.e. through city planning policy and investment; national water resource strategies and other legislation; human and financial capacity development. These will be discussed further in the concluding sections to this report.

1.2 Report outline

Chapter 2 provides some background to the concept of Water Sensitive Design (WSD) and the necessity for resilience-based approaches to water management. It also introduces some of the WSD interventions that have been considered as part of this research, and a short discussion on how they fit into the WSD approach as a whole. Some literature on stakeholder engagement related to the implementation of a new approach such as this, is also presented, as well as a review of some of the drivers and barriers to the uptake of WSD. An overview of the research process that was followed is given in **Chapter 3**, which also outlines the various postgraduate research studies that have contributed to this report. Chapter 3 also provides some detail of the complementary project on the development of a WSD Community of Practice programme (WRC Project K5/2413). The findings from the Liesbeek River catchment-based study are highlighted in **Chapter 4**, which also details some of the findings from the study of Managed Aquifer Recharge on the Cape Flats Aquifer. The results of the various different feasibility studies are presented in **Chapter 5**, which begins to describe how WSD should be conceptualised and implemented, as well as providing details on the various different infrastructure options. **Chapter 6** presents the overall conclusions and recommendations emanating from the research. The Appendices provide further specific detail on the various studies that were undertaken.

2. Background literature

The WSUD approach proposed by Brown *et al*. (2008) is defined as "*an approach to urban planning and design that integrates land and water planning and management into urban design. WSUD is based on the premise that urban development and redevelopment must address the sustainability of water"* (Engineers Australia, 2006). As South Africa continues to face the challenges of water scarcity and declining water quality, the relevance of WSD will increase and the need to start considering cities in a different way will become more urgent. Climate change has the potential to further complicate these challenges by decreasing the availability of water while simultaneously increasing demand. Changes in storm intensities can also result in extensive flooding in areas where stormwater systems are either inadequate in terms of safely removing runoff, or have not been properly maintained. Locally-relevant information on the individual technologies associated with WSD is generally available and well-documented. What is not so apparent in the South African context however, is the way in which the notion of water sensitivity links with urban design and planning, and how the concept of WSD can be used to transform towns and cities in this country. Engineers and technologists can only take the notion of WSD so far – social aspects must also be included, as well as the way in which the WSD message is conveyed, and indeed, regulated. It is postulated that if the required planning is achieved at an overarching level, then WSD will automatically be incorporated. The use of modelling tools is seen as an effective approach for developing information to illustrate the benefits and feasibility of sustainable water management interventions; one of the most useful of these modelling approaches is the development of a water balance which performs an analysis of the inputs and outputs of water for a given catchment. The following chapter provides a brief overview of some of the background literature which has informed the modelling (and other) processes which have been adopted for this research.

2.1 Resilience-based water management

Water is a prerequisite for human health, food production and the generation of all other ecosystem services, from biodiversity to temperature regulation, and is thus critical to the resilience of landscapes and communities (Rockström *et al.*, 2014). Water resilience is a prerequisite for global sustainability, and global sustainability is required to safeguard water availability from local to global scales. Stronger emphasis needs to be placed on managing water for social-ecological resilience and sustainability in order to be able to understand the inter-linkages between societies and ecosystems required to secure future water supply (*ibid*). Figure 2.1 (adapted from Rockström *et al., 2014)* shows how this shift in thinking and practice has occurred over the last three decades to reach a position in which the interactions of blue (liquid) and green (infiltrated rain)[3] water are closely linked to social-ecological systems. Bringing social ecology into water management might be what is needed to conceptualise

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[3] Blue water is water that is used in its liquid form and is abstracted from rivers, dams or groundwater. Green water is water that is used by plants and is abstracted from soil water. There is thus also a distinction between infiltrated water that becomes blue water (groundwater) and that which becomes green water (soil water or water available for plants)

boundaries around the feasibility of implementing WSD in a country such as South Africa; i.e. to envisage a "*shift away from yesterday's focus on how to reduce environmental impacts of human activities, towards reconnecting our societies with the biosphere and transition towards development within the safe and just operating space of a stable and resilient Earth system" (*Rockström *et al.,* 2014).

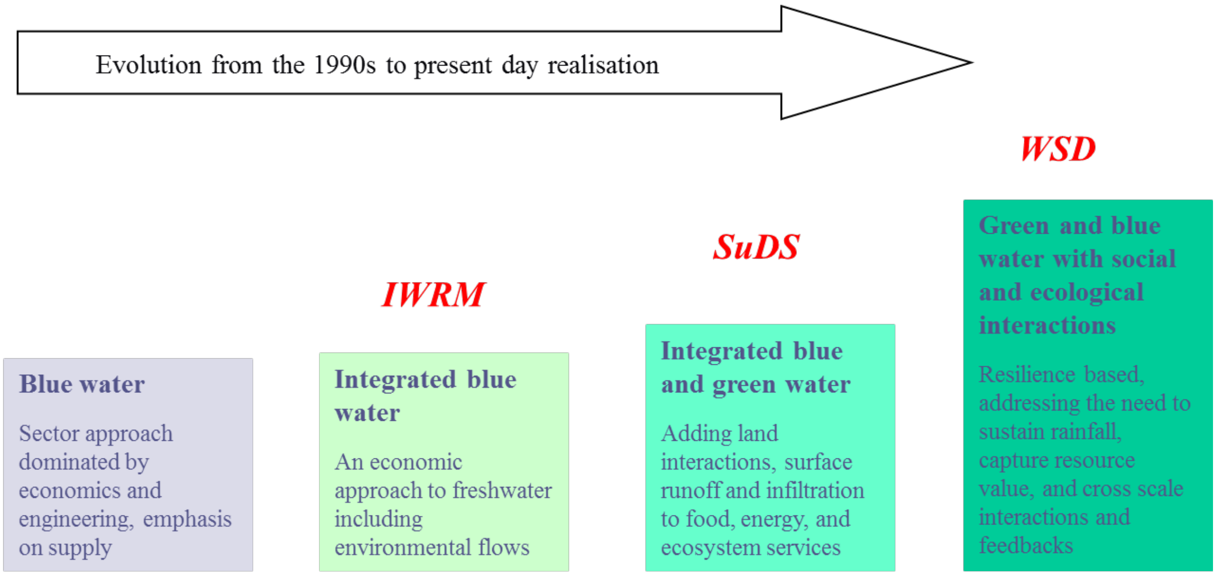

Figure 2.1: Resilience-based water management (adapted from Rockström *et al.*, 2014)

Water sensitivity in South Africa is defined as the management of the country's urban water resources through the integration of the various disciplines of engineering, social and environmental sciences – whilst acknowledging that: South Africa is a water scarce country; access to adequate potable water is a basic human right; the management of water should be based on a participatory approach; water should be recognised as an economic good; and water is a finite and vulnerable resource, essential to sustaining all life and supporting development and the environment at large (Armitage *et al*., 2014). Historically, water systems have been developed using a linear design approach, i.e. source, treat, transport, distribute, collect, treat and dispose. This technologically-driven and resource-intensive approach is removed from the citizens it serves, resulting in technocratic solutions and the fragmentation of the management of the urban water cycle.

WSD has the potential to: mitigate the negative effects of water scarcity; manage and reverse water pollution; develop social and intergenerational equity; increase sustainability; and develop resilience within water systems in South Africa. In order for this to happen, however, the various existing development plans and strategies within the different sectors related to urban water need to be aligned to ensure that they are aimed towards a common goal of decoupling future economic growth from resource consumption. The most relevant documents in this regard are the National Development Plan (NDP), issued by the National Planning Commission (RSA, 2011) with the aim of setting an overarching plan to eliminate poverty and reduce inequality, and the National Water Resource Strategy 2 (NWRS-2), published by the Department of Water Affairs (DWA, 2013).

Both the NWRS-2 and the NDP propose the adoption of ‘developmental water management’, where water plays a critical role in equitable social and economic development and where Government has a critical role in ensuring that this takes place (DWA, 2013). Despite these documents having similar visions and acknowledging that South Africa is a water stressed country, water resources are still not receiving the priority status and attention they deserve, and do not provide an adequately comprehensive approach to managing the total water cycle (including, for example the significant impacts and consequences of urban runoff / stormwater and the potential to use strategies such as Sustainable Drainage Systems, SuDS. A much broader definition of water resources is required within these strategy documents, to account for the following:

- *Water resources & Total Water Cycle Managemen*t – it is recognised that traditional water management approaches are insufficient to deal with growing water demand and an increasingly complex water sector (DWA, 2013). The holistic consideration of water use efficiency, demand management, improved water governance, optimisation of existing water resources including groundwater, seawater, rainwater harvesting, re-use of water, and resource protection and groundwater recharge is required if South Africa is to have adequate water resource potential to meet its requirements. The WSD approach encourages water management authorities to find ‘fit for purpose’ solutions that recognise the importance of the total water cycle and its impacts on other sectors.
- *Economics* – including an economic assessment of the provision of water services, and an evaluation of the secondary economic benefits (including ecosystems services) that could accrue from the implementation of such an approach.
- *Water-Energy-Food Nexus* – the ‘fit for purpose’ approach to water management that is central to WSD could balance the need to ensure water, food and energy security with the need for social development – whilst acknowledging the potential health risks. WSD also aims to take advantage of ecosystem goods and services by ‘greening’ cities, which provides the additional advantage of reducing the heat island effect, resulting in a reduction in energy consumption for cooling.
- *Climate change / resilience* – a WSD approach encompassing integrated planning at a macro-level will ensure that the risks associated with climate change impacts are better understood and the necessary institutional responses can then be put forward. Municipal authorities need to go beyond the delivery of basic services to ensure urban resilience by, *inter alia*, reconfiguring cities by way of strategic planning and investment to address future uncertainties like resource shortages, flood risks and climate change impacts.
- *Capacity building* – the successful implementation of WSD will depend on, *inter alia*, gathering adequate and reliable information; adhering to adopted policies and procedures; and the deployment of appropriately skilled people.

2.2 Transitioning to WSD in South Africa

Whilst the various terminologies might have varied over time and between nations (see for example Fletcher *et al.*, 2014), it is apparent that recent approaches towards achieving resilience-based water management recognise the value of water in all its competing uses. As a result, there has been growing interest in both the notion of reducing system inefficiencies, as well as in the idea of resource capture and use through concepts such as rainwater harvesting (RWH), stormwater harvesting (SWH) and greywater / wastewater use. These concepts are exemplified in Figure 2.2, which highlights the impact of a WSD approach on the urban water cycle.

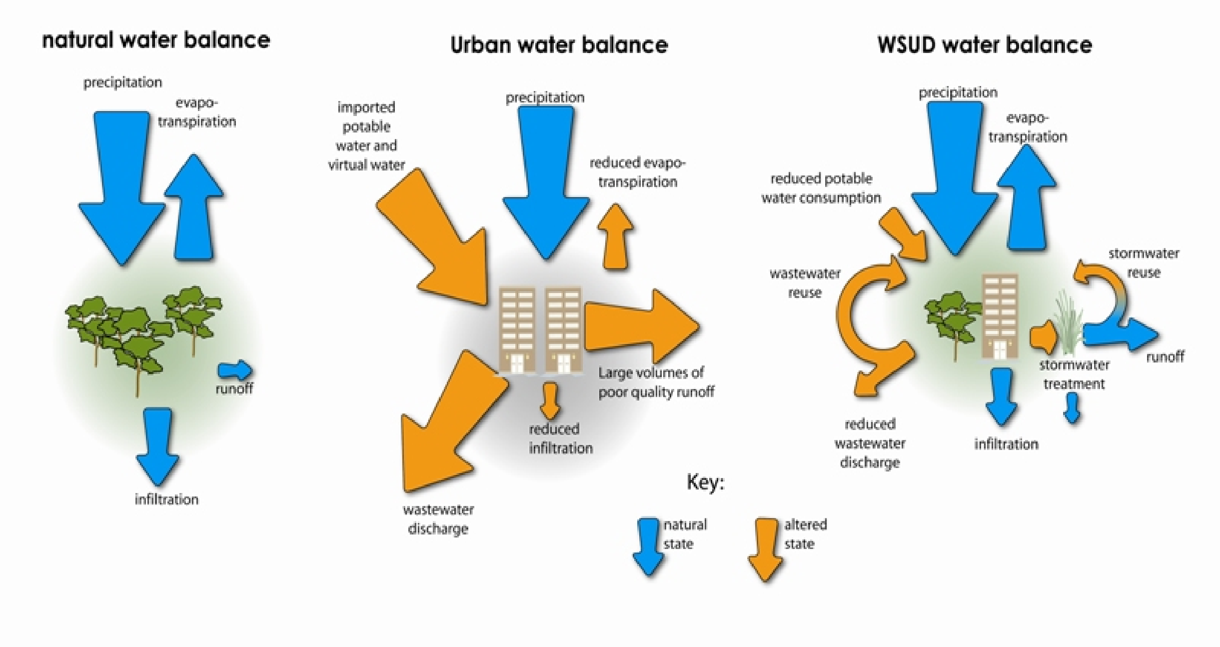

Figure 2.2: Impact of WSD on the urban water cycle (from Hoban & Wong, 2006)

As an example of water system inefficiencies, the average per capita demand for potable water in all municipalities in South Africa is 235 ℓ/c/d. This figure increases to 290 ℓ/c/d in metropolitan areas – which is high compared to the international average water use of 173 ℓ/c/d (McKenzie *et al.*, 2009), and suggests that there is significant scope to reduce unit consumption of water in this country. Additionally, owing to the fact that reported water use figures are based on the total water supplied for the total population served within these municipal systems, another key issue in terms of reducing demand relates to the need to proactively curtail water losses. A study on the state of non-revenue water[4] (NRW) in South Africa (McKenzie *et al.*, 2012) indicated levels of the order of 37% – which equates to a volume of around 1,580 million m^3 per annum, with an estimated financial value of R7.2 billion per year. These figures represent a considerable risk to the achievement of resilience-based water management in the

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[4] Defined as the sum of the total water losses (physical and commercial) and estimated un-billed consumption (McKenzie *et al.*, 2009)

country and emphasise the need for comprehensive Water Conservation and Water Demand Management (WC/WDM) strategies to be put in place.

Added to the largely 'technological' or infrastructure approach related to water demand, however, are the various other aspects which will allow a transition to water sensitivity within South African settlements; i.e. policy development; institutional structures; community participation; integration of operation and maintenance processes, job creation, etc. – most of which are captured in the proposed WSD transitions framework for the country (Armitage *et al*., 2014) shown in Figure 2.3.

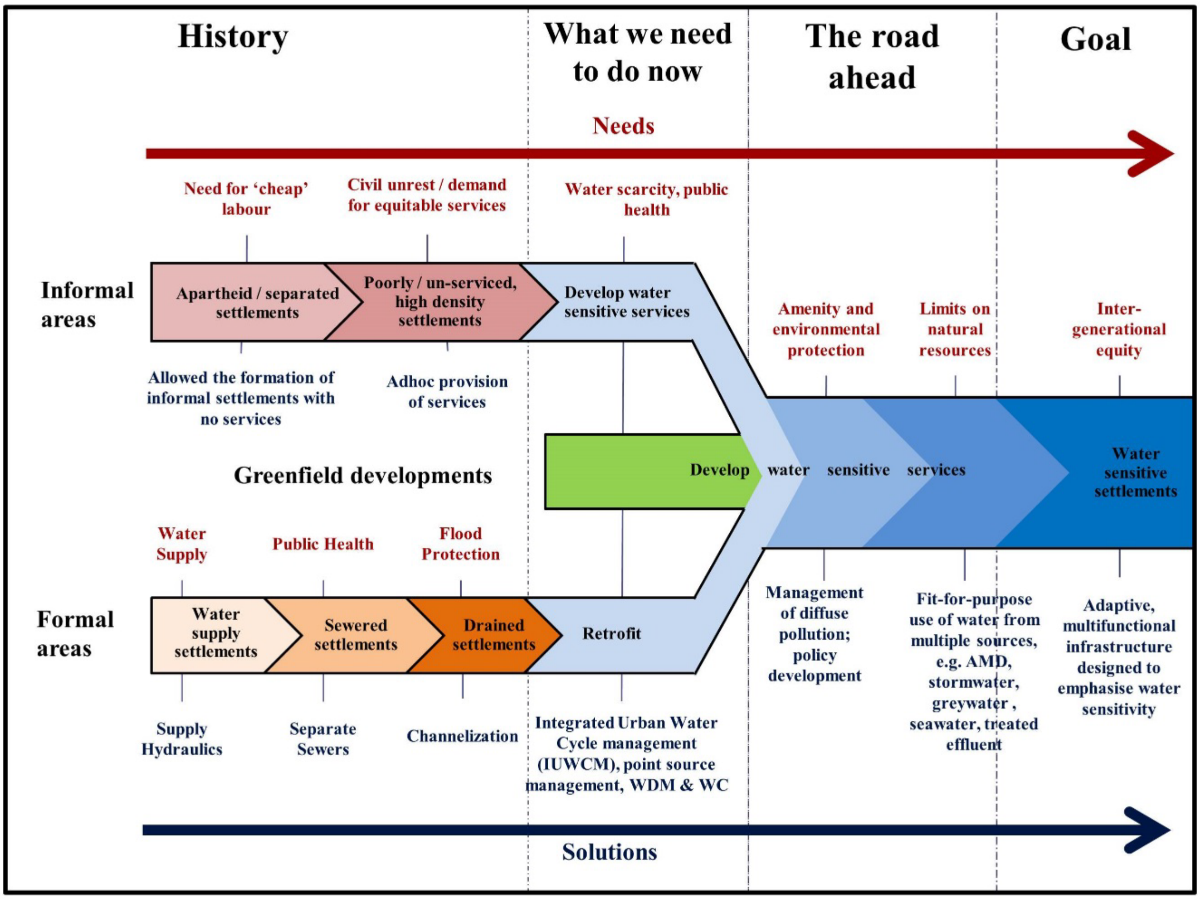

Figure 2.3: SA's transition to Water Sensitive Settlements: *'Two histories, one future'*
(Armitage *et al*., 2014; adapted from Brown *et al*., 2008)

As highlighted in the reference to 'Two histories, one future' in Figure 2.3, the incorporation of WSD is complex in the South African context as a result of dichotomous development and unequal provision of services. Whilst service delivery and social upliftment are high on the political agenda, the challenge is to promote economic and social equity whilst simultaneously ensuring environmental sustainability, particularly in urban areas. In this regard, the implementation of WSD itself creates market and/or business opportunities, as well as the potential for job creation (specifically 'green' jobs), as emphasised in the GreenCape 2017 Water Market Intelligence Report (GreenCape, 2017).

Attempts to transition to water sensitivity will need to consider both the formally-developed areas in South Africa (equivalent to settlements in Australia, North America and Europe), as well as the informal settlements where high densities and limited infrastructure are common:

- **Formal (brownfield) areas**: Currently developed mostly as ‘drained cities’, these areas should attempt to transition through retrofitting and redeveloping brownfield sites in a water sensitive manner.
- **Informal areas**: once formal areas have begun to be retrofitted and the technologies have been tested on willing participants there, informal areas (currently developed as ‘water supply cities’ with limited sanitation) should be redeveloped in as water sensitive a manner as possible. Development of informal settlements should attempt to ‘leapfrog’ the stages through which formal areas develop, thus negating the need at a later stage to retrofit these areas. Using water sensitive technologies should also result in a range of secondary benefits for these communities. Care should however be taken to make certain that programmes are put in place to ensure adequate maintenance of the system/s.
- **Greenfield developments**: Greenfield developments (in both formal and informal areas) should be undertaken in as water sensitive manner as possible from the outset, particularly in the case of private developments where the municipality can use development planning approval processes to ensure that the concept of water sensitivity is incorporated.

It is important that the (re)development of informal areas in a water sensitive manner takes place simultaneously with the residents of formal areas being educated and encouraged to retrofit their systems to be more water sensitive – interventions are thus likely to have a bias towards behavioural aspects on the one side and technical on the other. To transition either formal or informal areas alone would be not be possible in South Africa; the ‘burden, benefits and responsibility’ of and towards implementing WSD has to be borne by all residents. Ideally this would lead to a point where both formal and informal areas have transitioned to a ‘waterway city’ state. It would then be possible to move forward equitably and continue to transition towards water sensitivity. It should be noted however that current constraints (social, technical, physical, capacity, and financial) in South Africa, along with an urgent need to improve conditions in informal areas, mean that it is unreasonable to expect informal areas to leapfrog further than the ‘waterway city’ state.

2.3 WSD interventions

WSD is an effective tool for advancing the principles of sustainable development within the urban water management discipline – focusing on the interaction between the urban built form and water resources management (Wong, 2006). The overarching theme of WSD is ecologically sustainable development; by considering all aspects of the water cycle and their interaction with urban design, it aims to be the medium through which sustainable development can achieve sustainable urban water management. WSD brings together a range of activities under one umbrella, but there are two main components – urban water infrastructure and design & planning – as shown in Figure 2.4.

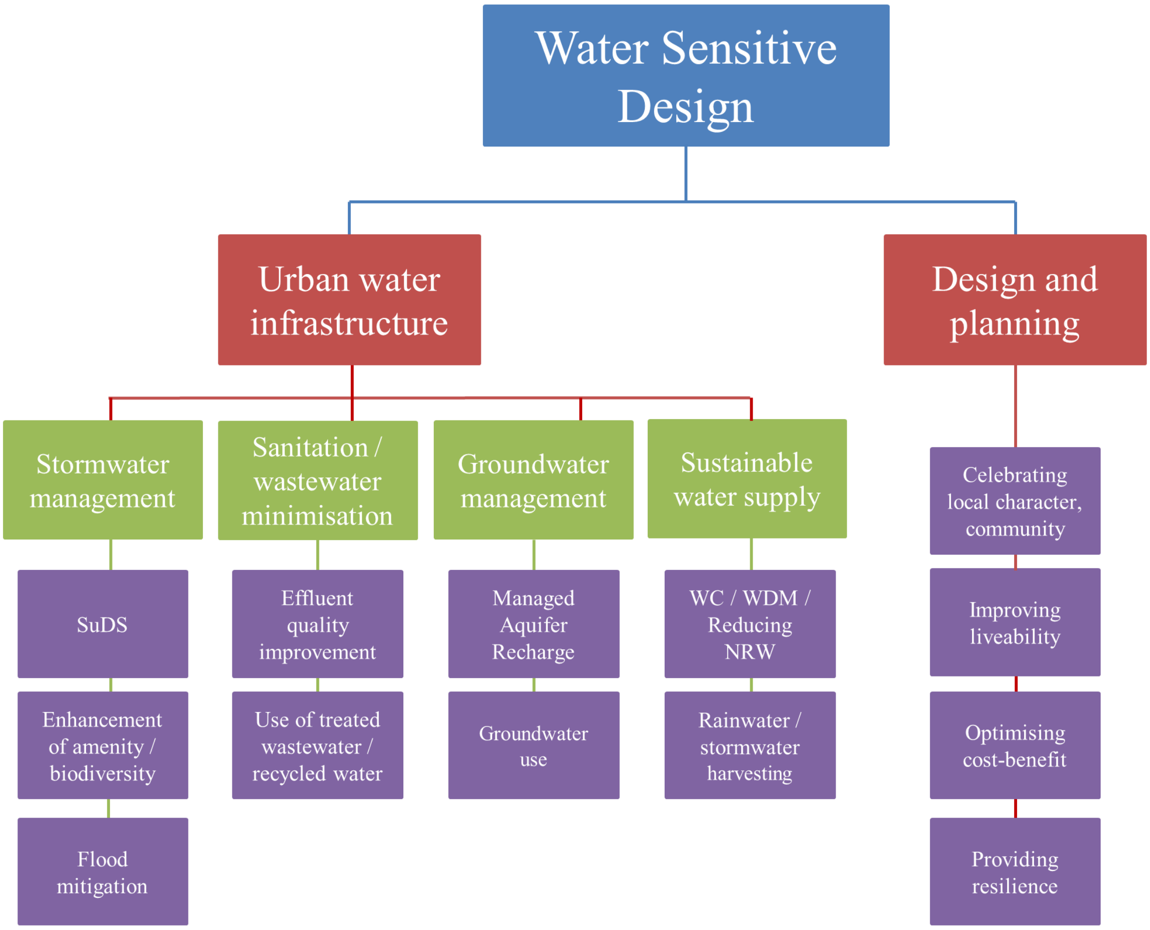

Figure 2.4: WSD activities

Further detail on the WSD activities associated with these two main components (as outlined in Armitage *et al*., 2014) is as follows:

1. **Urban water infrastructure** – all infrastructure elements of the water cycle considered concurrently so as to sustain the environment and meet human needs:
    - Stormwater management – taking a SuDS approach which incorporates elements such as the enhancement of amenity and biodiversity, and flood mitigation.
    - Sanitation / wastewater minimisation – including effluent quality improvement, and use of treated wastewater / recycled water.
    - Groundwater management – including artificial recharge, use of groundwater.
    - Sustainable water supply options – including water use efficiency, water conservation (WC) / water demand management (WDM), reduction of non-revenue water (NRW), alternative water sources, e.g. rainwater / stormwater harvesting.

2. **Design and planning** – consideration of the water cycle throughout the design and planning process:
    - Celebrating local character, environment and community.
    - Optimising cost-benefit of infrastructure and built form.
    - Improving liveability.
    - Providing resource security and resilience.

Whilst these areas / activities in which WSD can be expressed are often dealt with separately by different professionals, the holistic approach emphasised by WSD requires that they be considered simultaneously. As is evident, there are a wide range of urban water infrastructure strategies which can be used to effectively incorporate WSD into planning and design. It should be noted that the four streams (stormwater, wastewater, groundwater and water supply) of the urban water cycle are intricately linked; different technologies and strategies apply to each of the streams with several strategies applying to one or more of the streams. The ultimate goal is thus the holistic management of the urban water cycle to simultaneously achieve the desired economic, environmental, and social benefits.

One of the most critical components of WSD is the focus on sustainable water supply options, through consideration of the four streams of the urban water cycle. Any water sensitive 'design' process therefore has to firstly take into account the overall water demand of a development, precinct or city, followed by consideration of socio-economic aspects and climate aspects – thereby making it a truly multidisciplinary and holistic process. In this way, the necessary planning can be undertaken to determine an appropriate mix of water sources within that design.

2.4 Sustainable water supply options

Interventions to improve water use efficiency include: reducing 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), and include four basic approaches (Flack, 1981; Still *et al.*, 2008):

i) Structural methods – physical infrastructure interventions that improve the efficiency of distribution systems. Water savings devices, and the use of pressure-reducing valves to reduce pressures and thus leakage rates in the distribution system, are examples of structural methods.

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

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

iv) Socio-political methods – education and awareness campaigns as well as laws and regulations that act as 'push factors' to move users towards water efficiency.

There is a close relationship between the structural, operational, economic, and socio-political aspects of water management, and many water savings interventions encompass more than one of the above listed methods. As an example, the City of Cape Town uses three broad categories to summarise these sustainable water management objectives and the various interventions available to address them, as shown in Figure 2.5 (CoCT, 2007).

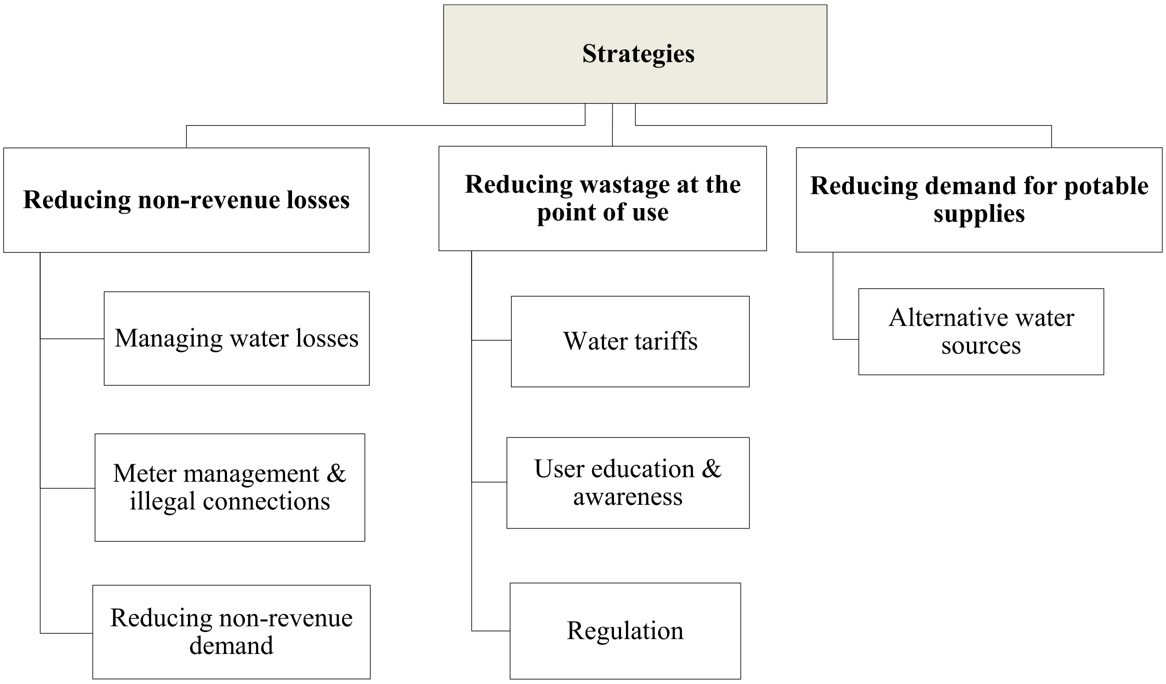

Figure 2.5: Interventions available to improve the efficiency of water use (CoCT, 2007)

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 & 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) – with appropriate health and environmental risk prevention measures in place. Table 2.1 illustrates some 'fit-for-purpose' uses of different alternative water sources which are evaluated in terms of their appropriateness for domestic use (Landcom, 2004b).

Table 2.1: 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.

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.*).

2.4.1 Stormwater as a resource

Whilst there is a significant body of international research focused on RWH at site scale, there has been limited consideration of the regional scale impacts (positive or negative) of urban RWH. In South Africa in particular, there has been relatively little notable research into the impacts of urban domestic RWH. Jacobs *et al*. (2011) showed that RWH for garden irrigation in the Western Cape would not be viable due to the climate (winter rainfall), but did not consider alternative uses such as toilet flushing. Similarly, whilst Mwenge Kahinda (2010) studied the regional impacts of RWH, the methods employed were not based on data representative of urban development or demand. Until recently, there were no studies in South Africa that considered the costs, stormwater management impacts, or water demand benefits of RWH. Additionally, both internationally and locally there is little research on the stormwater management benefits of RWH, as water conservation is often the primary goal of implementation (De Busk & Hunt, 2014).

SWH is increasingly being considered in water management planning internationally, but there has been little experience in South Africa apart from the isolated example of the Atlantis Water Resource Management Scheme (AWRMS), which started off as an interim solution in 1979 while a more conventional pipeline was being developed (DWAF, 2010). To date, there have been no studies, aside from those focused on the AWRMS, considering the viability and benefits of harvesting stormwater. It appears that one of the major barriers to the widespread implementation of SWH is the paucity of reliable and affordable treatment technologies (Hatt *et al.*, 2004; Philp *et al.*, 2008). Currently, practice is ahead of research, which poses a risk to the long-term success of SWH – particularly in the event that a system fails and SWH develops a poor reputation.

Very few studies have been undertaken internationally, that consider the impacts of RWH and SWH in combination. While RWH and SWH have broadly similar benefits, there are distinct differences as well, which may impact the harvesting 'scheme'. For example, if roof runoff (rainwater) is managed at site scale, it might result in a reduction of stormwater runoff, consequently compromising the viability of SWH.

2.5 Modelling RWH and SWH

A 'model' is *"a concept (or object) that is used to represent something else*" (James, 2005). Models, which simplify reality into a form that can be understood, have become essential tools in the management of water systems (Van Waveren *et al.*, 1999; James, 2005; Wainwright & Mulligan, 2013) and there is an abundance of literature in this regard to support the importance of modelling and which demonstrates its complexities. For example, Van Waveren *et al.* (1999) and Wainwright & Mulligan (2013) provide comprehensive reviews of: the types of model, the purpose of modelling, uncertainty when modelling, calibration, sensitivity analysis and overviews of responsible / best practice when modelling water systems. Similarly, Zoppou (2001), Elliott & Trowsdale (2007), Mitchell *et al.* (2007), Last (2010) and Bach *et al.* (2014) describe in detail the available tools for modelling urban water systems both independently and in an integrated manner. Lastly, Fletcher & Deletic (2008) detail the data requirements for integrated water management and consider how it affects modelling.

Access to data is critically important for studies of this nature. It is also clear that many of the most advanced studies are from 'developed' countries, such as Australia, where data is freely available. South Africa is a developing country where useful data is often not available, so this potentially poses a problem. Data availability allows for more complex models, which in principle should provide more accurate results. However, owing partly to limited data in South Africa, there have been few studies on the costs and benefits of alternative approaches to water management, such as RWH and SWH. International literature has shown that the costs of these alternative approaches can act as barriers to their wider acceptance and adoption (Hatt *et al.*, 2006; Leonard *et al.*, 2014) – both institutionally and socially. The need was identified therefore, for a study that considers the benefits and costs of RWH and SWH, which could be used to motivate for or against the adoption of RWH and/or SWH in South Africa. This study will be described in detail in Chapter 4.

2.6 Urban groundwater: the WSD approach

Groundwater is an increasingly important resource in urban areas (Hancock, 2000; Vázquez-Suñé *et al.*, 2005). Many of the world's largest cities, such as Mexico City, Shanghai, Jakarta, Cairo, London and Beijing all rely on groundwater for more than 25% of their water supply (Wolf *et al.*, 2006). South Africa on the other hand, depends largely on its surface water resources, with only 15% of the total water supply coming from groundwater (Sililo *et al.*, 2001). Turton (2008) suggests that approximately 98% of South Africa's available surface water resources have been allocated. Given the strain on the available surface water resources, groundwater may hold the potential to meet some of South Africa's growing water requirements (DWA, 2010; DWA, 2013). Therefore groundwater needs to be considered as a resource that has the potential to meet demand requirements, particularly in urban areas.

There is a strong interaction between groundwater and urban areas; however, groundwater is often overlooked in urban water management (Foster *et al.*, 2010b; Foster & Ait-Kadi, 2012). Sustainable groundwater management is critical for urban planning and management (Collin & Melloul, 2001; Morris *et al.*, 2001); however, if groundwater management is to be successfully achieved then strong management approaches are required that are focused on the complete water cycle, which includes the regulation of groundwater. In general, groundwater management in urban areas is concerned with improving or maintaining the appropriate quantity and quality of groundwater at the lowest cost, while preventing irreversible degradation (Todd & Mays, 2005). These objectives can be enforced using specific regulatory code or through planning and consultation (Foster *et al.*, 2010a; Foster *et al.,* 2010b).

Groundwater management in South Africa has been largely overlooked, and suffers from a lack of investment and attention (Tuinhof *et al.*, 2011). In many instances groundwater management is not politically attractive as it may only yield benefits in the long term (Foster *et al.*, 1998). Foster *et al.* (1998) describe groundwater as "*out of public sight, and therefore out of political mind*" and Hancock (2000) suggests that groundwater should be viewed as a valuable resource which, if not managed correctly, could be over-exploited or overlooked completely. This highlights a central problem for sustainable groundwater governance; i.e. that groundwater lacks public, professional and governmental awareness (FAO, 2003). It is therefore important to develop groundwater policy and legislation, particularly in an urban context. Public, professional and governmental groundwater perspectives need to be changed through improving the awareness of the economic, social and environmental value of groundwater. The development of groundwater monitoring and management strategies help to account for current and future groundwater use, allowing for sustainable use and risk assessment. Moreover, an integrative approach to groundwater management is required where health organisations, water utilities and government departments all contribute to raising issues and concerns, and assist in improved decision making (Foster *et al.*, 2010c).

Given the known impacts of urban areas on groundwater, it is imperative that urban groundwater resources are sustainably managed (Foster *et al.*, 1998; Hancock, 2000; Lerner, 2002; Morris *et al.*, 2003). WSD offers a holistic approach to urban water management that recognises the resource value in all forms of urban water, *viz.* stormwater, wastewater, potable water and groundwater (Whelans *et al.,* 1994; Wong, 2006; Water by Design, 2009; JSCWSC, 2009; QDIP, 2009). Mudd *et al.* (2004), in a review of groundwater in the Australian city of Melbourne, link groundwater to WSD through infrastructure, wetlands and aquifer storage and recovery (ASR). Although these groundwater links were specific to Melbourne, the general principles relating to groundwater and WSD helped to formulate an approach for including groundwater within the WSD framework, i.e. groundwater is impacted by water-related infrastructure; it has an important ecological role through interaction with surface water; and it is a potential means of water storage (Figure 2.6).

Figure 2.6 summarises how urban water (stormwater, wastewater and potable water supply) interacts with groundwater in WSD. Groundwater can be used as a means of supply (light blue) or it can be used for the storage of stormwater (dark blue arrows) or treated wastewater (light brown arrows) for later reuse. Stormwater or treated wastewater can be stored using infiltration devices, which allow the water to naturally infiltrate from the ground surface to groundwater, or the subsurface injection of water into an aquifer. Many ecosystems, such as wetlands, are dependent on groundwater contributions or may contribute to groundwater recharge (green arrows). Leakages from urban infrastructure are a concern, as this can result in uncontrolled increases in water level, as well as groundwater contamination. The areas that are at risk of contamination are marked with an 'X' in Figure 2.6. These include leakages from sewerage networks, the infiltration or subsurface injection of stormwater or wastewater, as well as the potential for polluted surface water that may contaminate groundwater, and *vice versa*. This conceptual schematic of the role of groundwater in WSD, while helpful in understanding the overall concept, is simplistic and generalised in its approach to urban water management. There is a need to enhance this simplistic conceptual understanding, and this can be achieved through a physically-based modelling approach where the conceptual processes outlined in Figure 2.6 can be tested based on actual catchment and aquifer properties. This is described in detail in Appendix B.

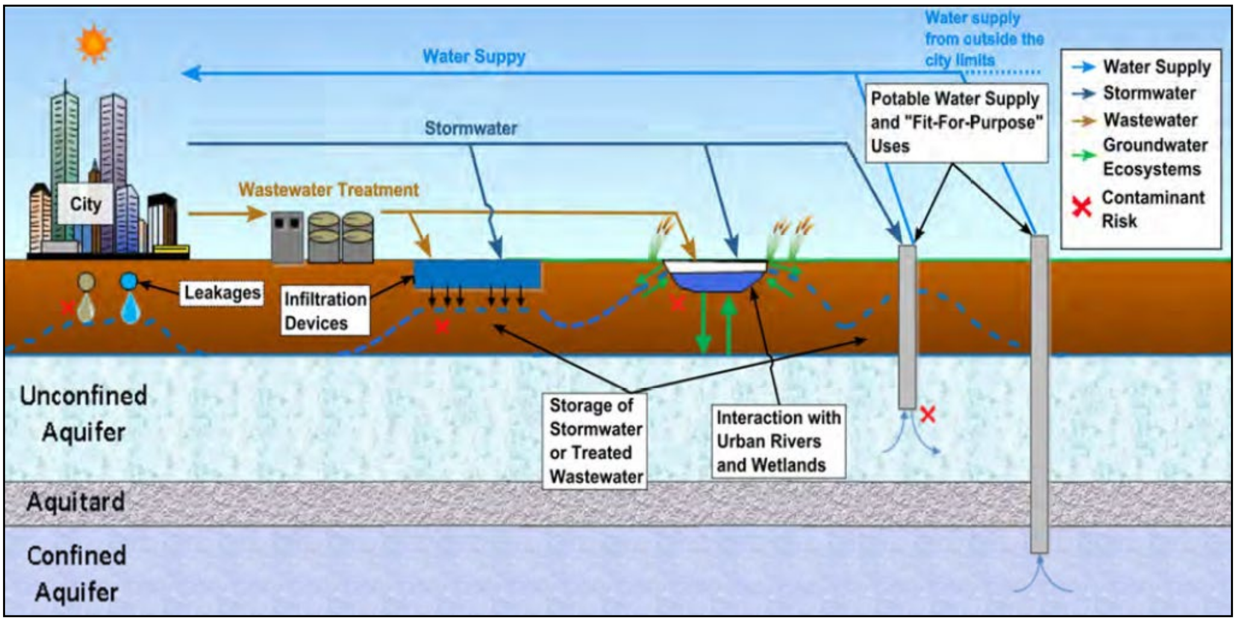

Figure 2.6: Inclusion of groundwater within the WSD framework
(Armitage *et al.*, 2014)

The most established role of groundwater within WSD is for treating infiltrated treated wastewater and stormwater and for storage (Water by Design, 2009; Wong *et al.*, 2012). This is valuable as infiltration can help prevent contamination of the local surface and groundwater resources and the storage capacity of groundwater can help to reduce peak discharges and slow the generation of storm flows. Many of the techniques used for stormwater management can be directly or indirectly linked to various forms of management of aquifer recharge or managed aquifer recharge (MAR), for example: aquifer storage and recovery (ASR), aquifer storage transfer and recovery (ASTR), infiltration ponds, as well as rainfall harvesting techniques (Dillon, 2005). MAR fulfils a number of WSD objectives, such as stormwater management, stormwater / wastewater reuse, and reducing demand for potable water by providing alternative sources of water that can be used for a number of 'fit-for-purpose' applications.

2.6.1 MAR objectives

The objectives of MAR are site specific and are dependent of the desired outcomes of the MAR application; i.e. water supply, flood prevention, etc. (Figure2.7). Aquifer characteristics such as the geology, aquifer storativity and hydraulic conductivity are the most significant limiting factors, determining how much water can be stored within the aquifer and how easily it can be recharged and abstracted (Murray *et al.*, 2007). Moreover, there may be risks associated with MAR under certain geological conditions, for example the formation of sink holes in areas of dolomitic aquifers or the risk of aquifer collapse after the aquifer has been dewatered following the recovery phase of MAR.

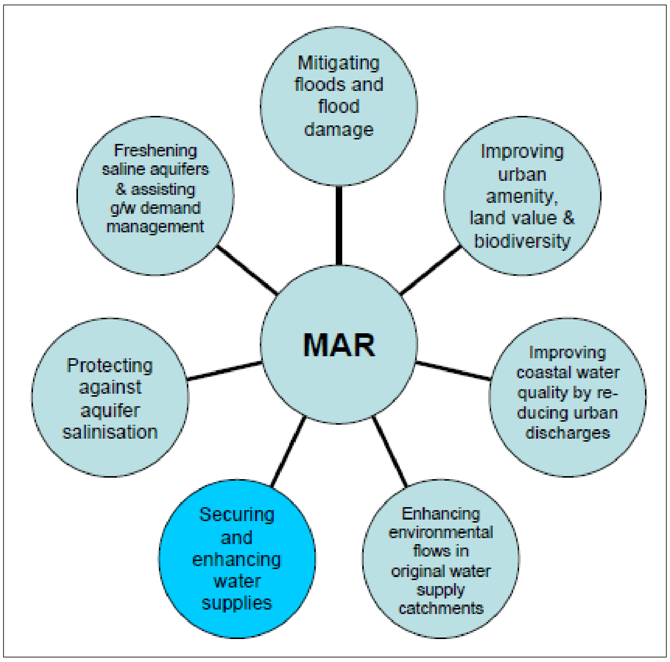

Figure 2.7: The main objectives of MAR (Dillon *et al.*, 2009)

One of the most frequent reasons for the implementation of MAR schemes around the world is the ability to sustain or enhance water supply from an aquifer for urban and agricultural purposes. By supplementing aquifer recharge with water from additional water sources such as surface water from dams and rivers, groundwater in adjacent aquifers or recycled water from urban stormwater or treated wastewater; it is possible to enhance the assurance of supply that can be obtained from an aquifer. The application of MAR to sustain or enhance water supply from groundwater has proven successful in a number of countries such as the United States of America, India, the Netherlands, Australia and Israel. In addition to this international experience there are a number of good examples of the application of MAR in Southern Africa. Most notable is the MAR scheme in the Atlantis aquifer in the Western Cape, which has been the primary water supply to the town of Atlantis for over 30 years (Murray *et al.*, 2007). Furthermore, in aquifers where the abstraction rate exceeds that of the natural recharge rate, MAR can assist in maintaining or restoring natural groundwater level fluctuations that are important for sustaining groundwater dependant ecosystems such as wetland and rivers. Recharge water can also be used to protect or improve water quality of the groundwater resource.

2.7 Modelling urban groundwater

Hydrological modelling in urban areas is complex as it is dependent on both surface and subsurface hydrological processes. Surface water, urban infrastructure, soil characteristics and pipe leakages all determine the amount and rate of groundwater recharge, flow and storage. Linking standalone models that represent the individual surface and subsurface components of the urban hydrological cycle has been the most common method of modelling urban groundwater. This method has been used to develop decision support systems (DSSs) as shown in studies by Wolf *et al.* (2006), Droubi *et al.* (2008) and Kalbacher *et al.* (2012). Urban stormwater models, such as SWMM, MOUSE, P8 or MUSIC are often used to model urban water resources as these models are capable of representing urban land use and urban infrastructure, however they are limited in their ability to represent groundwater processes (Elliot & Trowsdale, 2007). Thus, there is a need for more detailed groundwater models to address more detailed urban groundwater problems.

Three-dimensional, finite element groundwater flow models such as MODFLOW and FEFLOW are well equipped to address the most complex groundwater problems. For example, MODFLOW is one of the most well applied, tested and supported groundwater models available and is recognised as an industry standard for groundwater modelling (Yan & Smith, 1994; Camp Dresser and McKee Inc., 2001; Rowan, 2001; Kumar, 2002; Droubi *et al.*, 2008; Yergeau, 2010; Boskidis *et al.*, 2012). MODFLOW has also been applied in urban applications through the coupling of urban stormwater models (Rowan, 2001; Yergeau, 2010). The coupling of these two models is limited and therefore information is not easily transfer from one model to the other. There are also limitations with groundwater models such as MODFLOW. In most groundwater flow models the unsaturated zone is not considered in flow interactions between rivers and groundwater. There are often scale issues when using groundwater model for groundwater and surface water interactions due to mismatches between the river width and cell size. The differences in the discretisation of the surface water and groundwater may also cause errors in the simulated surface water or groundwater levels (Brunner *et al.*, 2009).

Given that current urban stormwater models (e.g. SWMM, MOUSE, P8 or MUSIC) have limited groundwater modelling capabilities as outlined in Elliot & Trowsdale (2007) and the limitations experienced through the application of the loosely coupled surface and groundwater models, there is a need to for a fully integrated surface water and groundwater modelling (Barron *et al.*, 2013). There are a number of surface water and groundwater models available, that are fully integrated and spatially distributed, that may be more suitable for modelling surface-groundwater interactions, such as InHM (VanderKwaak & Loague, 2001), MODHMS (HydroGeoLogic, 2006), HydroGeoSphere (HGS) (Therrien *et al.*, 2009), MIKE SHE (Freeze & Harlan, 1969), Wash123D (Cheng *et al.*, 2005) and ParFlow (Kollet & Maxwell, 2006). A recent application of MODHMS by Barron *et al.* (2013) was used to identify the impact of urbanisation on shallow groundwater in Western Australia, highlighting the potential for the further application and testing of fully integrated, spatially distributed hydrological models in urban areas. Another option that is available is MIKE SHE, which is part of the MIKE Zero suite of hydrological models developed by DHI Water & Environment. These models are able to represent the complete hydrological cycle from surface water processes such as evaporation, runoff and streamflow, as well as sub-surface processes such as infiltration, recharge and groundwater flow. Integrated hydrological models are also well equipped to model a range of land uses due to their detailed physical representation of land use.

2.8 Stakeholder engagement – a critical aspect

As has been described, conventional approaches to urban water management may not be sustainable in the long term and a change in approach is required. Chocat *et al.* (2007) stress that increasing awareness amongst all stakeholder groups will be key to influencing the radical shift in thinking required – and that this could even require that some experts in the water area "*de-learn*" so that they could embrace a broader vision. It has been suggested that one of the key challenges to urban water reform is the disconnection between the 'community' and its water systems; thus, to enable a transition to water sensitivity, citizens need to be treated as partners in the decision-making processes (CRCWSC, 2016). The theory of organisational change provides a useful way of highlighting the change management processes that are required to fully embed a new paradigm such as WSD into an institutional system. Figure 2.8 shows a classic change curve with the addition of thematic solutions-mapping at various stages along the curve.

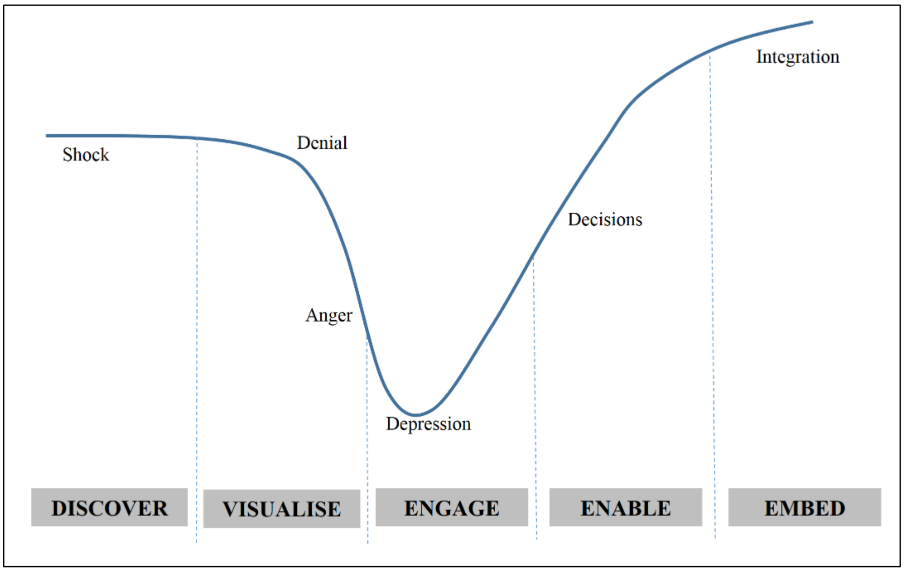

Figure 2.8: Change management processes required for WSD
(adapted from G2G3, 2013)

Additionally, Abbott *et al.* (2013) identify various 'agents of change' that are needed to help the promotion, delivery and adoption of WSD including:

- The presence of a coordinating body;
- Reliable science, research and training;
- The presence of WSD champions;
- A supportive planning / design process and legislation; and
- Strategic funding and incentives.

2.8.1 Communities of Practice

According to Wenger (1998), communities of practice are groups of people who share a concern or passion for something they do and who interact regularly in order to learn how to do it better. The concept has been taken up in various contexts – business, organisational design, government, education, professional organisations, development projects, and civil society – and includes: peer to peer collaborative networking; willing participation of members; focus on learning and building capacity; and engagement in sharing knowledge, developing expertise and solving problems (ADB, 2008). The Cooperative Research Centre for Water Sensitive Cities (CRCWSC) based at Monash University in Melbourne is a useful example of a well-functioning CoP in this field. The CRCWSC was established in 2012 with the objective of changing the way cities are built – through building awareness of the valuable contribution that water makes to economic growth and development (CRCWSC, 2014). The CRCWSC is involved in a large number of research projects across multiple disciplines, including a range of stakeholders from government, water utilities, industry, urban developers and academia. It aims to "*support the transition towards a water sensitive city.....by developing inter-disciplinary knowledge and providing ...the processes and pathways to assist organisations achieve their own sustainable, resilient, productive, liveable urban places*" (CRCWSC, 2014).

2.8.2 Learning Alliances

One of the ways of raising the profile of WSD amongst the South African engineering fraternity, as well as with national and local government officials, planners, and developers is to establish Learning Alliances (LAs) in different towns / cities in order to link the various actors in these urban water systems and promote shared learning and innovation around sustainable water management practices. LAs, or "*platforms that bring together stakeholders from a range of institutions: Municipalities, service providers, universities, and in some cases NGOs and user groups – to think, act and learn together, using action research to test ideas*" (Butterworth *et al.,* 2011), are one way of raising awareness about WSD; they allow researchers, local stakeholders and users to work together to create shared visions, analyse options and develop new strategies for the management of diverse forms of infrastructure, including urban water systems. In other words, they are a way of achieving the required trans-disciplinarity for WSD. The purpose of a LA is to do things differently in order to have more impact on policy and practice – this is achieved through the skilled facilitation of a locally-derived and managed action approach (Verhagen *et al*., 2008).

Linked to the Learning Alliance approach is the concept of 'shared' or 'social' learning, which draws on concepts of resilience thinking and 'social-ecological systems' (SES) to promote learning / co-production of knowledge; build networks across scales and sectors; build stakeholder capacity; and spark innovative responses to problems (Reed *et al*., 2013). 'Shared' learning is geared towards addressing complex problems under conditions of uncertainty, and seeks to engage stakeholders in a structured process of exchanges. The potential role of social learning as a mechanism for managing water resources has been frequently highlighted over the past decade (Bouwen & Taillieu, 2004; Collins & Ison, 2009; Blackmore, 2010) and is characterised by shared interest, joint activities, discussions and sharing of information to enable a community of practice to learn from each other. A compelling argument for this approach is offered by Pahl-Wostl *et al.* (2008) and Blackmore (2010) who suggest that the transition towards sustainable strategies in water resources management is best achieved by moving from the need to deploy more information through scientific research that feeds into informing policy cycles, to an adaptive management approach that is embedded in social learning processes. The challenge in South African water management is to create an enabling environment first and foremost. This challenge is exceptionally difficult, however, as improved water provision and services have to be provided in an environment of poverty set within a weak / fragile institutional domain where there are limitations in centralised and hierarchical stakeholder participation, inadequate human resources and capacity, and where water pollution and water supply problems are increasing (Mwendera *et al*., 2003; Berkes, 2006).

2.8.3 Integrating societal and ecological processes

Cities are functional ecosystems governed by interacting social and ecological patterns and processes (Grimm *et al*., 2000); yet urban design and infrastructure have a strong tendency to disconnect residents from natural processes and obscures the inherent relationships between societal and ecological conditions (Wong & Eadie, 2000; Selman *et al*., 2010). This is particularly true for stormwater systems – conventional stormwater management is designed to address flooding and public safety risks by removing runoff as quickly and efficiently as possible (Butler & Davies, 2011). These critical management objectives often overshadow environmental concerns and the complexity of social-ecological systems, resulting in poor water quality and degraded urban rivers (Walsh *et al*., 2005; Butler & Davies, 2011).

A transition to WSD requires that people are not only connected to technology, but also with policy, planning, current available knowledge and the decision-making processes (Brown, 2005; Brown *et al.,* 2009; Rauch *et al*., 2005; Pahl-Wostl *et al*., 2007; Wagner, 2008). For example, Haskins (2012) points out that the drivers of sustainable municipal stormwater strategies should be manifested in the form of goods and services, and management decisions must incorporate technical information (e.g. nature of discharges, water quality, ecological conditions) that is balanced with considerations of socio-economic factors, and local needs and values. Understanding the local water culture and resulting behavioural patterns can then be used to develop a sequence of educational campaigns that seek to improve environmental awareness and shift behavioural patterns (Brown *et al.,* 2009; Ramkissoon *et al*., 2015).

The condition of urban waterways is the result of dynamic interactions between people, technology, and ecological systems (Paul & Meyer, 2001; Konrad & Booth, 2005; Walsh *et al.*, 2005). This is highlighted in the Urban Ecology model, which views societal and ecological patterns and processes as inherently linked (Grimm *et al*., 2000; Collins *et al*., 2011). It accounts for the dynamic interactions, feedbacks, and linkages between biophysical variables (e.g. climate, geologic context, and natural cycles) and the individual decisions of various human actors (e.g. government, planners, businesses, and households) (Collins *et al*., 2011). The model illustrates how environmental contexts (e.g. climate and watershed dynamics) and social processes (e.g. policy or management) inform and constrain land use and land use change – see processes 'A' and 'B' in Figure 2.9 (Grimm *et al*., 2000). It suggests that environmental patterns and processes are enhanced or impaired due to feedbacks from land use or management decisions (processes 'C', 'F', and 'I'). The current state of an ecological system, land use, or changes therein, can influence the perceptions of individuals towards that ecosystem and its management (through processes 'D', 'E', and 'G'), with the potential to feed back to and influence societal patterns and processes ('H'). In turn, society can respond directly to undesirable changes in ecological conditions ('J') or can respond to the mechanisms causing those changes ('K').

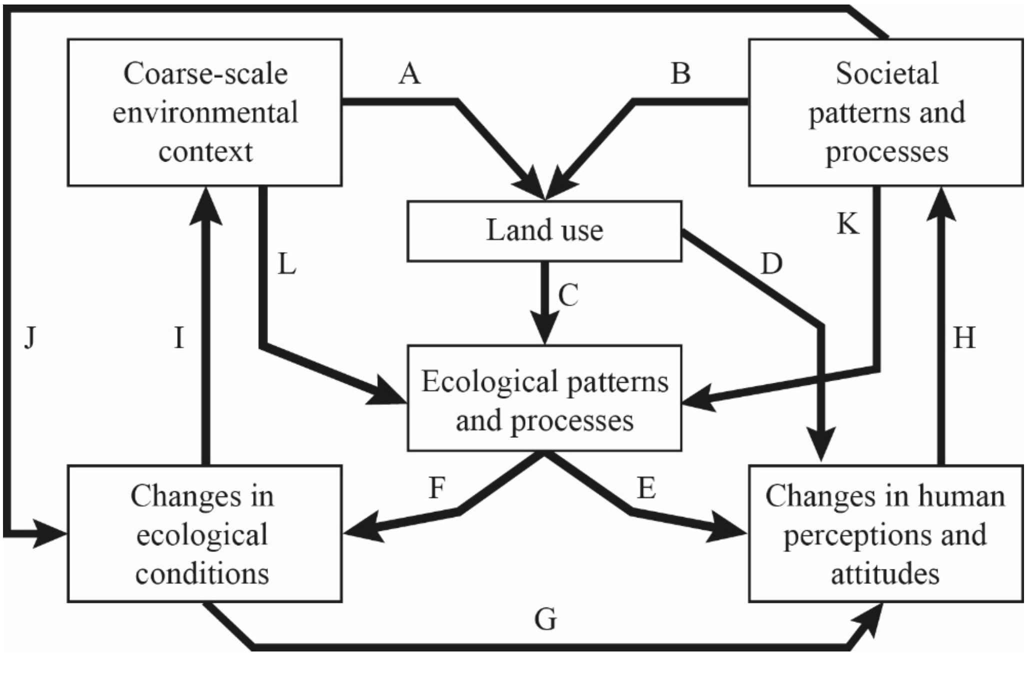

Figure 2.9: Urban Ecology model, illustrating the integration of societal and ecological processes that influence conditions in the urban landscape (Grimm *et al*., 2000)

Interactions within this model illustrate a sequence of phases, where 'Land Use' and 'Ecological Patterns and Processes' are a snapshot within a single point in time. When a change occurs in these conditions or environmental problems arise, a sequence of interactions and feedbacks follow, which could include solutions or adjustments in management decisions and operations. In a transition toward more sustainable urban water management, the linkage represented by ‘H’ is a potentially valuable tool, whereby changes in perceptions or attitudes towards a land use, ecological patterns, or altered ecological conditions can influence societal patterns and processes towards re-evaluating ecological systems and regenerating environmental services offered within urban waterways.

2.9 Drivers and barriers to the uptake of WSD

There is limited literature available that provides South African context-specific findings on the drivers and barriers to the uptake of WSD, although recent research by Ellis *et al.* (2016) has suggested that there are six different drivers for WSD system implementation and uptake, at varying levels of importance, as follows (further details are provided in Section 5.4):

- Approval / legislation mechanisms;
- Institutional champions;
- Economic incentives;
- Green Building Rating Tools (GBRT);
- Physical constraints; and
- Sensitive environments.

Fisher-Jeffes *et al.* (2012) identified several socio-institutional challenges to the uptake of WSD, including: fragmented water management institutions; underfunded organisations; resistance to innovative approaches; lack of political will; and technical capacity problems. These resemble some of the twelve well-defined socio-institutional WSD barrier themes consistently included in Australian literature; particularly by Brown & Farrelly (2009), which comprises a meta-analysis of existing peer-reviewed, empirical and analytical literature; and Tjandraatmadja *et al.* (2014), a more recent but smaller survey-based study in South Australia. Additional Australian barriers include: uncoordinated institutional frameworks; limited community participation; inadequate regulatory frameworks; lack of information, knowledge and understanding of WSD; poor communication; no long term vision or strategy; technocratic path dependencies; and little or no monitoring and evaluation (Brown & Farrelly, 2009; Tjandraatmadja *et al.* (2014). Many of these have resonance in the South African context; however, it is important to note that different drivers and barriers are experienced at different states of transition along the path to complete WSD inclusivity (Brown *et al.*, 2008). This has particular relevance to South Africa, as any given town or city can have several distinct water management approaches, notably between formal, semi-formal and informal urban areas (Fisher-Jeffes *et al.*, 2012; Armitage *et al.*, 2014).

Other literature that provides indirect examples of drivers and barriers to WSD in South Africa refers to the sectoral analyses of the green building industry (GBI) in the country and the emergence of Socially Responsible Investment (SRI)[5] and disclosure mechanisms, both locally and abroad. Literature in both cases points to the growing importance of sustainable development initiatives in South Africa – including WSD – with the concepts of ‘doing the right thing’ or ‘environmental, social and governance (ESG) stewardship’ being acknowledged as prominent drivers (Viviers *et al*., 2008; McGraw Hill Construction, 2013; Nurick & Cattell, 2013). Further drivers and barriers specific to the South African GBI are provided by Nurick & Cattell (2013) with most correlating strongly to the widely accepted GBI findings demonstrated in many studies (Green Building Council of Australia, 2006; Ellison *et al*., 2007; Myers *et al*., 2007; Bowman & Wills, 2008; Nelson *et al*., 2010). With regard to SRI in South Africa, Giamporcaro *et al*. (2010) note that this is largely focused on the social and governance aspects of the ESG criteria, with the environment receiving comparatively less attention; citing the availability and variability of environmental disclosures by South African companies as the primary impediment to this.

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[5] SRI is broadly defined as the application of capital for an acceptable return on investment that supports environmental, social and governance (ESG) issues so as to influence the manner in which investors or consumers make decisions (Nurick & Cattell, 2013)

3. Research approach

The research was aimed at determining the potential for implementing WSD principles to strengthen planning for a transition towards water sensitive settlements in South Africa. To this end, it centred on an intensive study of an urban catchment in Cape Town – the Liesbeek River catchment – in an attempt to gather sufficient data to provide a business case for the implementation of WSD principles, including aspects such as:

- Developing a total water balance for the catchment(s).
- Investigating water (re)use, including stormwater, rainwater, greywater, wastewater and groundwater – including quality aspects.
- Assessing property values and evaluating redevelopment opportunities.
- Exploring architectural knowledge / influences in WSD.
- Determining the social, environmental and economic externalities / benefits of WSD.
- Investigating whether 'blue-green infrastructure' – including urban river and wetland 'rehabilitation' – has measurable benefits for all.

In addition to this catchment study, a range of other sites in and around Cape Town which demonstrate various aspects of WSD and which offer – or are of particular interest to – a means of developing a practice for WSD, were explored (see Section 3.2). Various disciplinary perspectives were adopted in this regard, including: engineering, environmental goods and services, social / institutional, property studies, etc. The main focus areas of the research were the identification of opportunities and constraints of WSD implementation, i.e. what kinds of WSD interventions are appropriate at an urban catchment scale and how can these forms of interventions make a difference to both the quality of the adjacent waterways and flows (quantity) of surface and groundwater. Attention was also paid to trying to determine the economic costs and benefits of WSD.

3.1 Methodological framework for the research

A trans-disciplinary research framework was adopted for this study, in order to allow for better engagement with the empirical data that was collected and with the various issues that relate to this data.

The suggested methodological framework as shown in Figure 3.1, highlights the potential for trans-disciplinary knowledge generation within the context of WSD – through combining the hard sciences of engineering, economics and environmental science with sociology, politics and philosophy; and founding it all on the norms and values provided in the South African Constitution. It also provides a way of mapping the current state of knowledge and action in WSD in South Africa; i.e. determining who the various stakeholders are; what the gaps in knowledge, actions and intentions are, etc.

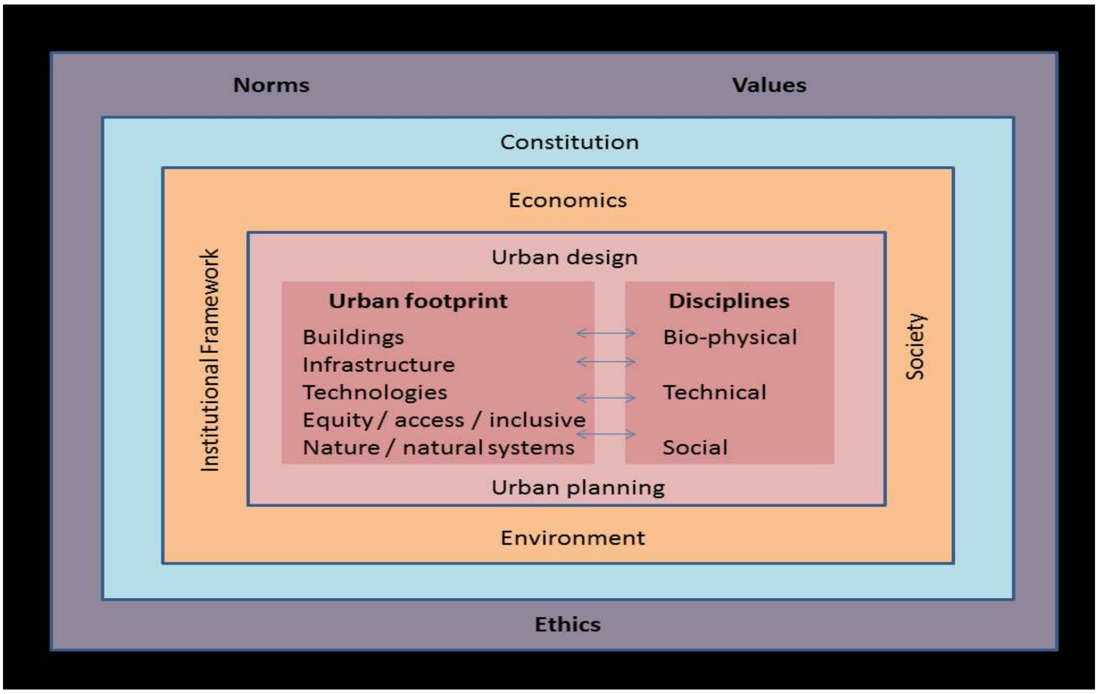


Figure 3.1: Trans-disciplinary research framework

3.2 Baseline catchment studies

Various postgraduate research projects contributed to the baseline catchment studies and these are briefly described in the following sections (also summarised in the table shown in the Acknowledgments). The detailed accounts of the methods employed to carry out these studies and the results that were obtained are provided where relevant in the appropriate descriptive sections of this report.

3.2.1 PhD theses

- *The viability of rainwater and stormwater harvesting in the residential areas of the Liesbeek River catchment, Cape Town* (Fisher-Jeffes, 2015 – see http://open.uct.ac.za/handle/11427/16523). This study set out to determine whether rainwater harvesting (RWH) and stormwater harvesting (SWH) could present a viable means of improving water security in urban residential areas. It concluded that SWH could be a viable alternative water resource for urban residential areas in South Africa – depending on the scale at which it is implemented, the end use for which it is utilised, and the population density that drives the water demand. Municipalities should, therefore, consider SWH as a potential water source in future infrastructure planning. RHW, on the other hand, has limited potential – depending on climatic conditions; it may, for example, be viable in areas with year-round rainfall.
- *Managed Aquifer Recharge (MAR) for the management of stormwater on the Cape Flats* (Mauck, under examination). The aim of this research is to investigate the feasibility of implementing Managed Aquifer Recharge (MAR) as a WSD strategy on the Cape Flats

Aquifer (CFA), so as to (i) improve water security for the City of Cape Town and (ii) manage stormwater on the Cape Flats to prevent groundwater related flooding. The study involved the development and calibration of a MIKE SHE model to identify the hydrological processes that drive groundwater recharge, storage and surface water interactions in the CFA and the groundwater resource potential at a regional scale.

3.2.2 Masters dissertations

- *Quantifying the potential for potable water savings in the Liesbeek River catchment* (Coulson, 2014 – see http://open.uct.ac.za/handle/11427/13197). This research set out to quantify the potential potable water savings that could be achieved through the implementation of selected sustainable water management interventions (i.e. using water efficient devices, reducing on-site leakage, rainwater harvesting, and greywater harvesting) in the Liesbeek River catchment, Cape Town. The study highlighted the significant impact that water saving interventions could have in the catchment and provided a methodology for assessing other catchments with a similar, largely residential development profile.
- *Analysing peak flow attenuation in an urban wetland* (Giermek, 2015 – see http://open.uct.ac.za/handle/11427/19960). The attenuation capacity of a small-scale wetland adjacent to the Liesbeek River was measured in an attempt to improve the methodology for ongoing studies, and provide motivation for expanding SuDS within the catchment. The study used a 2D PCSWMM hydrodynamic model, which ran historic flow data to determine the attenuation capacity and to measure peak flow reduction.
- *Public knowledge and stormwater quality in Cape Town, South Africa: a case study of the Liesbeek River* (Ward, 2014 – see http://open.uct.ac.za/handle/11427/9101. In order to understand some of the societal linkages between biophysical (specifically stormwater) and social systems, a study was undertaken in the Liesbeek River catchment. The findings suggested that targeted stormwater management techniques and improving public education and integration in institutional processes could improve the overall societal response to poor stormwater quality and degraded urban waterways.
- *Analysing stormwater temperature at site specific discharge points along the Liesbeek River, South Africa* (Crisp, 2016 – see http://open.uct.ac.za/bitstream/handle/11427/22883/). During a rainfall event, runoff temperature is elevated as it makes contact with, and passes over surfaces which have a large heat storage capacity, such as pavements, roofs and roads. The extent of impervious surfaces and resulting thermal pollution produced by them is poorly understood, although it is thought to be a major contributor to stream degradation. The aim of this study therefore, was to determine the extent and risk of thermal pollution at site specific discharge points, along the Liesbeek River.
- *Local groundwater flow simulation using site specific conceptual and numerical model, Cape Flats Aquifer, Cape Town, South Africa* (Gxokwe, in progress) – the aim of this study was to test the applicability of WSD techniques and technologies at a local-scale on the Cape Flats, specifically addressing the application of MAR for the management

of stormwater in this area. This included assessing groundwater-surface water interactions within the CFA region using Principal Aquifer Setting, hydrochemistry and environmental isotopes in order to establish the spatial-temporal aspects of the interactions and the influences on the quantity and quality of the interacting waters. Aquifer parameters (transmissivity and storativity) were estimated in order to determine storage volumes, and groundwater flows were simulated at site specific scale.

- *Amenity function and social perceptions of stormwater ponds* (De Chavonnes Vrugt, in progress) – this study focused on recreational amenity functions of stormwater ponds in an urban greenbelt locality in Cape Town. It aimed to document the relationship between the greenbelt as a whole and the stormwater ponds within it in terms of their recreational facility value. In doing that it also considered the appropriateness of other potential uses of the greenbelt and of the importance and value of WSD amongst city residents.
- *The viability of using the stormwater ponds on the Diep River in the Constantia Valley for stormwater harvesting (*Rohrer, 2017) – this study focused on the economic viability of harvesting stormwater from existing stormwater ponds, using the Diep River catchment as a case study. The study concluded that harvesting stormwater from existing stormwater ponds is potentially viable. It also demonstrated an effective method to maximise a catchment's storage capacity using distributed storage. For stormwater harvesting to be viable however, stormwater should be used to supplement a large percentage of non-potable end-uses and requires significant uptake amongst catchment residents.
- *An investigation into how value is created through WSUD, using the V&A Waterfront and Century City as Case Studies* (Mallett, under examination) – the aim of this research is to evaluate the impact of WSD and waterscape strategies on the property sector and to investigate the role that WSD can play in leveraging societal and financial value and the achievement of sustainable urban precincts.
- *Exploring architectural knowledge in Water Sensitive Design* (Bhikha, in progress) – using a case study approach, this study aims to consider the design of water sensitive buildings and/or precincts, and to determine and assess the influencing factors for a WSD approach. The research questions include: "What is the value that an architect can bring in making water sensitive design a feasible option?"; "How could WSD elements from other research fields be incorporated into a site to form a fully functional building that is feasible and both aesthetically and functionally valuable?" and "What knowledge can be contributed by architectural research to the WSD urban realm?".

3.2.3 Honours projects

- *Cape Town's Ponds* (Rohrer, 2014) – this study was aimed at locating and classifying each of Cape Town's stormwater ponds and thus compile a register to enable further insight into the distribution, use and management of the city's ponds as they relate to WSD. The study identified 737 stormwater ponds within 16 of the 21 major river catchments in Cape Town and an evaluation of each pond's performance was also made.

- *Feasibility study of implementing Water Sensitive Urban Design in Sir Lowry's Pass Village* (A'bear, 2014) – a feasibility study in the Sir Lowry's Pass Village was carried out to determine the potential for the implementation of WSD principles, in an attempt to reduce the flood impact on properties within the settlement, maintain the ecological environment, improve the stormwater runoff quality and increase water efficiency of the settlement.
- *Investigation into the viability of implementing an integrated water management system within a Water Sensitive Urban Design framework for the proposed Two Rivers Urban Park (TRUP) development in Cape Town* (Wale, 2014) – this study aimed to provide a conceptual design of a sustainable water management system for a specific site forming part of the TRUP development in Cape Town. The design for the site incorporated WSD principles, with the objective of minimising the demand for potable water supplied by the municipality, and improving the quality of the water retuning to the river and aquifer.
- *Evaluating the potential of selected WSUD measures in a generic middle income urban catchment in South Africa* (Gobin, 2014) – this study examined the effects of implementing a range of WSD measures (and specifically in terms of the use of alternative water sources such as rainwater and greywater) to meet water demand in middle income suburbs found in the City of Cape Town. It then compared the results of implementing the same measures in the eight other Metropolitan municipalities that form the South African Cities Network.
- *Development of a decision support system to provide direction with Sustainable Drainage Systems selection* (Brooks, 2015) – a Decision Support System (DSS) was developed to guide decision-makers through a selection process towards implementing suitable SuDS technologies for a development. A series of diagnostic questions form the framework of the DSS and selected responses form decision-flow paths.
- *Opportunities for using Water Sensitive Urban Design to reduce the negative impacts of the developing industries in Saldanha Bay Municipality* (Fry, 2015) – the objective of this research was to identify opportunities to utilise alternative water management strategies, specifically WSD, in order to reduce the negative impacts of developing industries in Saldanha Bay Municipality (SBM). The research showed that there is some application of WSD principles, but that more benefit could be gained from striving to develop in a more water sensitive manner.

3.3 WSD options

The following Honours-level projects were some of those undertaken in an attempt to determine which sustainable urban water management options could feasibly be included in an overall WSD approach.

- *Evaluation of the filter drain at the MyCiti bus depot* (Van der Byl, 2015) – the study aimed to evaluate the water quality efficacy of a filter drain that was installed as a prototype design at the MyCiti bus depot in Cape Town in an attempt to determine if it met the CoCT's Stormwater Policy water quality criteria, and its appropriateness as a SuDS measure.

- *Review of Cape Town's recreational water ('spray') parks* (Mbengwa, 2015) – water spray parks have been implemented in Cape Town as urban amenities to offer safe water play for children. The purpose of this research was to evaluate Cape Town's experience with these spray parks in terms of their benefit to community members, as well as how they fit into the bigger context of WSD and environmental sustainability.
- *Benefit cost analysis of the implication of permeable pavements used to harvest rainwater in Cape Town, South Africa* (Ralfe, 2015) – the purpose of this study was to investigate using permeable pavements to harvest and store rainwater as a supplementary source of water, for fit-for-purpose uses such as toilet flushing and irrigation. A benefit cost analysis was carried out on two existing permeable pavements located in the Cape Town area, by linking the permeable pavement system(s) to nearby development.

A more complete study of the treatment efficacy of permeable pavements, and an assessment of their suitability for inclusion in a WSD approach, was reported on as part of a separate WRC Project no. K5/2409 – 'An investigation of the treatment efficacy of permeable pavements with a view to harvesting stormwater for use in South Africa'. The study made various recommendations in respect of the implementation and management of permeable pavements in South Africa, including: investigating the use of washed aggregate during the construction process; and the need for construction and maintenance guidelines, as well as standard procedures for dealing with aggregate. Further research was recommended in terms of continuing with the laboratory and field experiments so as to investigate, *inter alia*, alternative pavement designs, PPS treatment efficacy with washed stone; the performance of different types of geotextiles in the pavement design; testing for a wider range of pollutants; and nutrient / other pollutant leaching capabilities of different aggregate types.

3.4 Development of a WSD Community of Practice

As described by Armitage *et al.* (2014), WSD is seen as the enabler which could move South African institutions and local authorities closer to meeting developmental goals. If South Africa is to advance this vision of WSD, however, there will need to be a societal openness to embracing a water sensitive design vision as part of its broader developmental vision. This is likely to involve, *inter alia*, re-organizing planning departments and processes, adopting new technologies and adapting old technologies, reviewing and applying new policy and legislation, building capacity (skills, competencies and judgment), initiating demonstrators for technology transfer with partners, actors and stakeholders and ensuring that the principles of WSD are increasingly rapidly understood and accepted by on-the-ground water users.

The WSD CoP is the proposed vehicle for providing the sorts of opportunities for engagement, shared learning and capacity building that are required with respect to meeting the objectives of the WRC Water Sensitive Design Lighthouse, including:

- Demonstrating the positive influence of coordinating bodies (such as Learning Alliances and other stakeholder groupings) and 'champions' in terms of raising awareness about WSD and facilitating change.
- Generating strategic evidence of how WSD implementation projects might create new efficiencies, as well as a new understanding about innovative practices and reflexive learning within WSD.
- Developing knowledge connected to policy development and change to influence planning and design towards water sensitive cities.
- Developing an understanding of the potential for transforming socially-divided settlements through the implementation of WSD.

As a first step towards advancing the WSD vision for South Africa, the WRC established a Water Sensitive Design (WSD) Community of Practice programme in 2014 (WRC Project K5/2413), with the aim of highlighting the critical linkages between the various aspects of this new paradigm through engagement with a wide range of stakeholders. The overall aim of the programme is to identify and disseminate the necessary information to 'tell a clear story' about WSD in South Africa. In particular, the CoP attempts to address the notion of managing the complexity inherent in an approach such as WSD, in order to develop an intellectual contribution in this regard, and to ensure that it can influence planning and the alignment of governance aspects at a high level. The main focus areas have been the establishment of a project register to aid in the broad consolidation of WSD practices throughout the country, the development of an information transfer system, awareness-raising and training activities (using the framework and guidelines for WSD, and including the development and monitoring of appropriate Learning Alliances and other information-exchange platforms), and scoping studies to identify the main drivers and barriers associated with implementing WSD into the planning and implementing environment at local and national government level. In order to achieve this, the programme has comprised a managed process of multiple social learning case studies with interested players engaging in WSD throughout South Africa. Several different local-level CoPs are therefore being monitored and assessed, and various WSD feasibility projects – particularly in respect of the use of alternative water resources (such as greywater) in the context of increasing water scarcity – have been used as dialogue platforms to assess where and how WSD can be implemented, and the associated institutional / policy impacts. Whilst empirical research only forms a small part of the overall methodological approach in terms of developing the CoP, the results from any associated WSD research are taken into account when developing the relevant platforms to share information and drive WSD uptake.

4. Catchment-based studies

4.1 Opportunities for WSD in the Liesbeek River catchment

In order to be able to more fully consider the benefits of WSD in an urban area it was decided to model an entire catchment by taking into account a range of WSD technologies and strategies. A number of catchments in the City of Cape Town (CoCT) were considered including, amongst others, the Salt River (the catchment was considered to be too large), Disa River (the catchment was considered to be too small with insufficient development diversity and poor data availability), Sand River (too many informal settlements and poor data availability), etc. The Liesbeek River catchment was selected for this study as it incorporates a diversity of land uses, represents a range of wealth levels, has significant historical importance for the CoCT and for South Africa, and had the necessary data available for the effective development of the detailed models required for simulating catchment-wide WSD. While the catchment represents a range of wealth levels, it does not contain any informal settlements typical of many urbanised catchments in the country. This is fortunate for the following reasons:

i) The data required for the proposed analysis were not available for informal settlements.

ii) Due to high population densities, poor provision of services and high levels of pollution, the complexities and challenges with regard to the management of risks associated with the use of alternative water sources in a fit for purpose manner within informal settlements are magnified in comparison to formal settlements.

iii) Informal settlements in South Africa are typically associated with extremely poor runoff water quality which would negatively impact on the viability of certain WSD technologies (e.g. stormwater harvesting).

One of the biggest challenges in the research was dealing with the complexity of an urbanised catchment that has a significant amount of irrelevant ‘data’, but very limited relevant data to explain the significant variations in social, economic and climatic variations seen in the catchment. Further details on the available data, as well as the baseline assessment of the catchment are provided in Appendix A.

The study of the Liesbeek River catchment focused on the following WSD opportunities: Rainwater harvesting (RWH), Stormwater harvesting (SWH), Greywater harvesting (GWH), and Water efficient devices (WED).

4.1.1 Rainwater Harvesting

Fisher-Jeffes (2015) found that RWH is generally not a financially viable option for the majority of households due to the cost of installing and maintaining RWH systems compared with the benefit of the likely reduced water bills. Nevertheless, if property owners harvest runoff from the majority of their roof areas and use water for a diversity of end uses, RWH is potentially a financially viable option for between 8% and 9.5% of households in the Liesbeek River catchment. This would equate to approximately 7% of total residential water demand. If the municipality wishes to incentivise the widespread adoption of RWH by making it more financially attractive, it would need to increase water tariffs by between two to four times what they currently are. Increasing the tariffs by more than four times will yield relatively limited additional benefits. Climate change is typically a concern for water resource planners. The analysis of 31 different climate change scenarios demonstrated that, above all, the future is uncertain. While some climate change scenarios indicated significant decreases in runoff, others showed limited change. Overall, it seems reasonable to expect a slight decrease in volumetric reliability in the lower reaches (Observatory) of the catchment and a slight increase in volumetric reliability in the upper reaches (Kirstenbosch). The change in cost per kilolitre is inversely linked to volumetric reliability; as such, it is likely to decrease wherever volumetric reliability increases and vice versa.

RWH is often considered an on-site stormwater management tool and is highlighted as such in some stormwater management guidelines. This study, however, suggests that it would not be particularly effective in doing so in the Liesbeek River catchment. While it does reduce the volume of runoff and may attenuate peak flows, it fails to consistently attenuate the peak flows of storms with a return interval of greater than one week. With this in mind, it is unreasonable to consider RWH as having any significant stormwater management benefits. It is true that RWH improves water quality by intercepting pollutants prior to any spillage; however, dissolved pollutants will not be removed, and alternative means of removing pollutants may be more cost effective for the individual.

All things considered, RWH primarily offers a means of reducing municipal water demand, with negligible stormwater management benefits. Currently it is only financially viable for the minority of property owners, most commonly the more affluent households. RWH is generally only financially viable under the following conditions:

- Harvested rainwater is used for as many end uses as possible.
- The largest possible catchment area (as much of the roof area as possible) is connected to the RWH storage tank.

4.1.2 Stormwater Harvesting

SWH has the potential to reduce the total current potable water demand of the Liesbeek River catchment by up to 20%; a significant reduction for the CoCT (Fisher-Jeffes, 2015). In order for such a reduction in water demand to be realised however, would require that all residents and businesses make use of harvested stormwater for at least flushing toilets and outdoor irrigation. This would likely require changes in the regulations related to the supply of water in the CoCT. Therefore, while technically and economically SWH might be an option for reducing potable water demand, the social, institutional and political implications would still need to be investigated – as well as the financial implications of retrofitting dual reticulation systems if relevant.

SWH, unlike RWH, has the potential to offer additional benefits (including water quality treatment, amenity value, etc.), which can partially offset the costs of operating the SWH system so as to make it equivalent in cost or potentially cheaper than the potable water currently supplied by the CoCT. This is especially true in the higher density catchments, where there is a relatively high demand (e.g. where there are blocks of flats / small properties). Additionally, through active management of the SWH storage units, there is the potential to significantly attenuate peak flows during both small and extreme events. While a similar benefit might, in principle, be realised through the active management of RWH systems, SWH has the advantage of being a quasi-centralised approach. At the scale for it to be economically viable, it would require the management of roughly 20 storage units (ponds) instead of over 6,000 RWH storage units (tanks). Thus, practically, SWH is a better option.

It was also evident that lower-than-expected demand, as a result of lower adoption, poor-quality data, or the installation of water-efficient devices, could negatively affect the economic viability of SWH. This highlights the need for access to credible end-use water demand data for estimating water demand for such schemes, as well as in-depth social studies that assess the communities' willingness to adopt alternative water supplies.

Evaporation is expected to increase with climate change impacts in the Cape Town area, while precipitation is expected to decrease (Fisher-Jeffes, 2015). The analysis using the adjusted runoff – based on the expected changes in evaporation and precipitation from the 31 different climate change scenarios – indicated that it is very likely that SWH systems will have a decreased volumetric reliability and the cost of harvested stormwater is likely to increase.

SWH offers a means of reducing municipal water demand, decreasing total runoff volumes, offering amenity benefits and, if actively managed, a means of attenuating peak flows. In certain areas, it offers a means of financially and economically providing water that is less expensive than the currently supplied potable water. Currently, therefore, SWH is a viable option that should be investigated under the following conditions:

- Harvested stormwater is used for as many end uses as possible – primarily toilet flushing and irrigation.
- SWH is more viable at higher population densities, which equate to a higher and more constant water demand (toilet flushing throughout the year).
- Additional benefits may be realised through actively managing the volume in storage, in order to attenuate peak flows, through detaining stormwater runoff.

4.1.3 Greywater harvesting

The preliminary results of the greywater reuse study (Coulson, 2014), indicated that greywater could be used to significantly reduce the demand for potable water in the Liesbeek River catchment. 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 per Jacobs & 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 would require high levels of treatment before being considered for harvesting. Figure 4.1 illustrates the yields that could be achieved with increasing rates of adoption (number of households reusing greywater) of GWH.

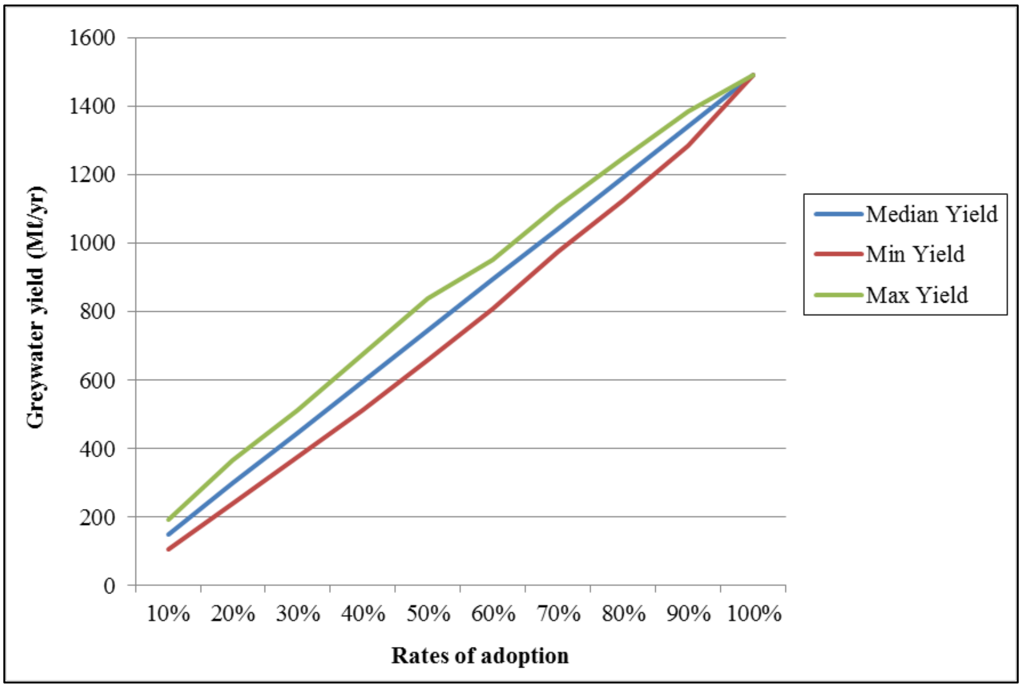


Figure 4.1: Potential water savings with increased adoption of greywater harvesting

As with rainwater harvesting, the increase in greywater yield at the catchment scale is linked to the rate of its overall adoption in the catchment. The maximum and minimum yield lines represent 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, yielding a maximum volume of 1500 Mℓ/yr of harvested greywater, equivalent to approximately 25% of the catchment's total water demand. Although significant water savings could be achieved through the adoption of greywater reuse, the complexity of installing and managing greywater systems presents a significant challenge within an urban catchment. Greywater reuse is a decentralised approach, and the responsibilty of managing these systems falls as such on individual property owners. Improper treatment, storage and use present a number of potentially serious health risks, and the active participation of users in the management of such systems is essential. The local authority would therefore need to carefully (re)consider its regulatory frameworks if greywater reuse were to be encouraged, and provide guidelines to users (see also Carden *et al*., 2017).

The one main advantage of greywater reuse over RWH / SWH is that the supply of greywater is constant throughout the year, meaning that the seasonal variation of outdoor water demand can be catered for. This also has an impact on the selection of tank size, meaning that properties need smaller storage units, which in turn has financial and economic benefits. With this in mind, even though greywater reuse appears to offer a significant opportunity in terms of reducing demand for potable water, it was felt that the associated health risks were too high to encourage its wide scale adoption. The focus of the research on greywater reuse was therefore shifted to commercial and institutional properties only, where it is more likely that the system could be better monitored by dedicated maintenance / cleaning staff. The proportion of greywater within the non-domestic sector was calculated by assuming that all indoor water use that was not designated as toilet water was to be considered as greywater; i.e. Commercial – 63%; Education – 55%; Community – 55%.

Figure 4.2 highlights the fact that the potential greywater yields that could be achieved through the implementation of greywater reuse for commercial and institutional purposes amount to 750 Mℓ/yr – nearly 12% of the Liesbeek River catchment's total water demand. This is significantly lower (half) than the estimated 1500 Mℓ/yr that could be harvested from all of the residential properties in the catchment; however, given the limitations of greywater harvesting at the individual property level, it is likely to be a more realistic result.

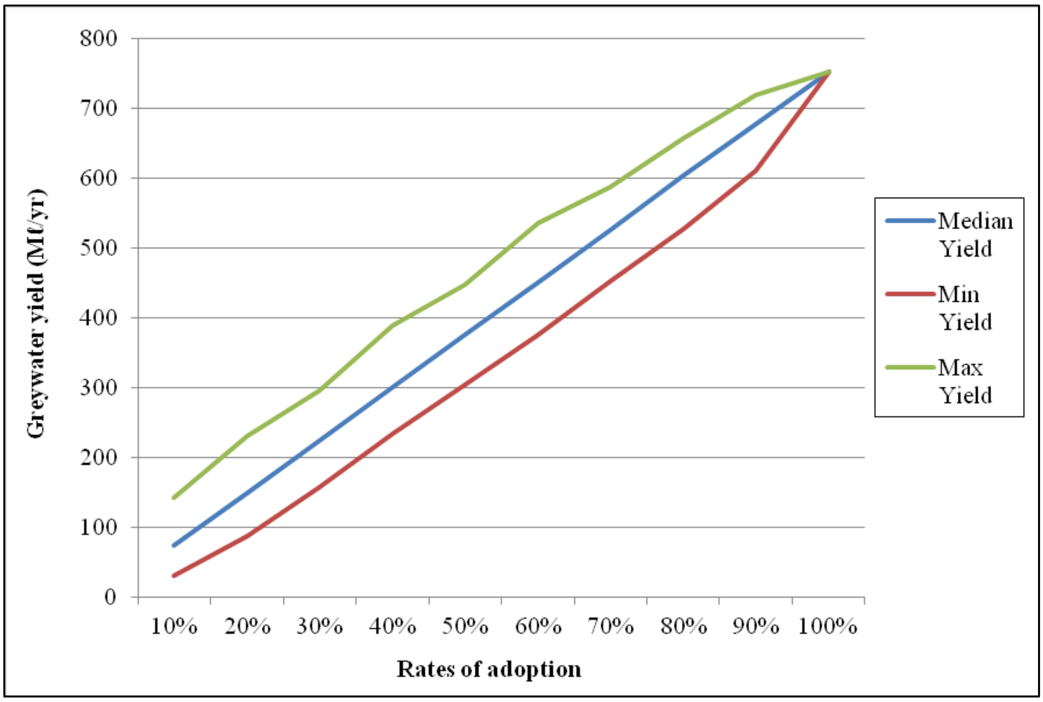


Figure 4.2: Greywater yields after exclusion of general residential properties

4.1.4 Water efficient devices

Coulson (2014) indicated that the implementation of water efficient devices could have a significant impact on reducing water use in the Liesbeek catchment. Figure 4.3 illustrates the likely reduction of indoor water demand with increasing rates of adoption (number of properties using water efficient devices) 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.

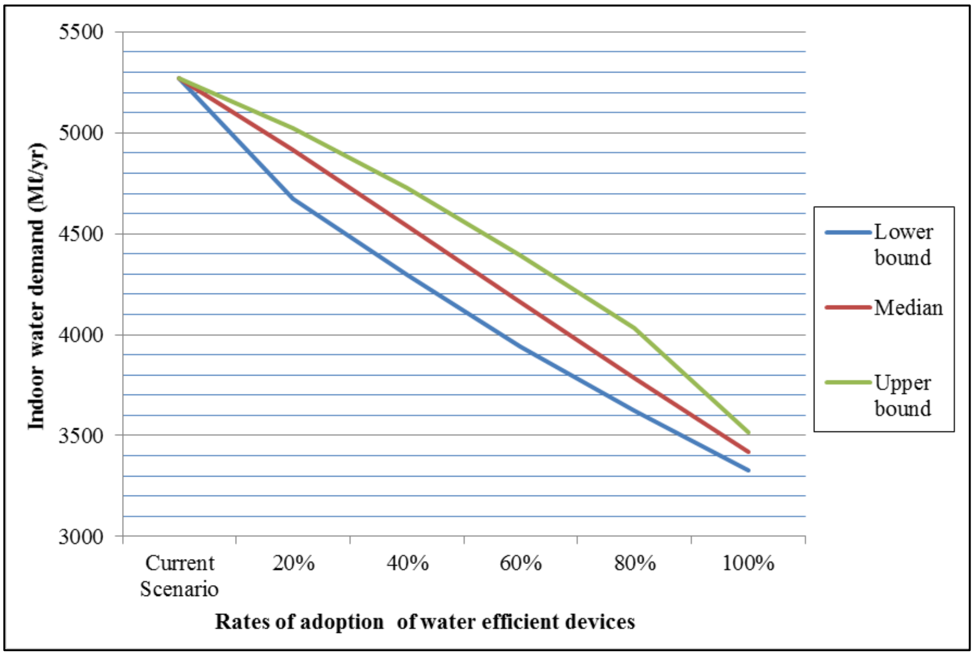


Figure 4.3: Reduction in indoor demand with increasing use of water efficient devices

At a 40% adoption rate, water efficient devices could save between 540 Mℓ/yr and 974 Mℓ/yr; this represents a 10-18% savings in indoor water use. At 100% adoption – i.e. all properties within the Liesbeek catchment adopting the use of water efficient devices – water savings of up to 37% could be achieved, representing a total of 1941 Mℓ/yr.

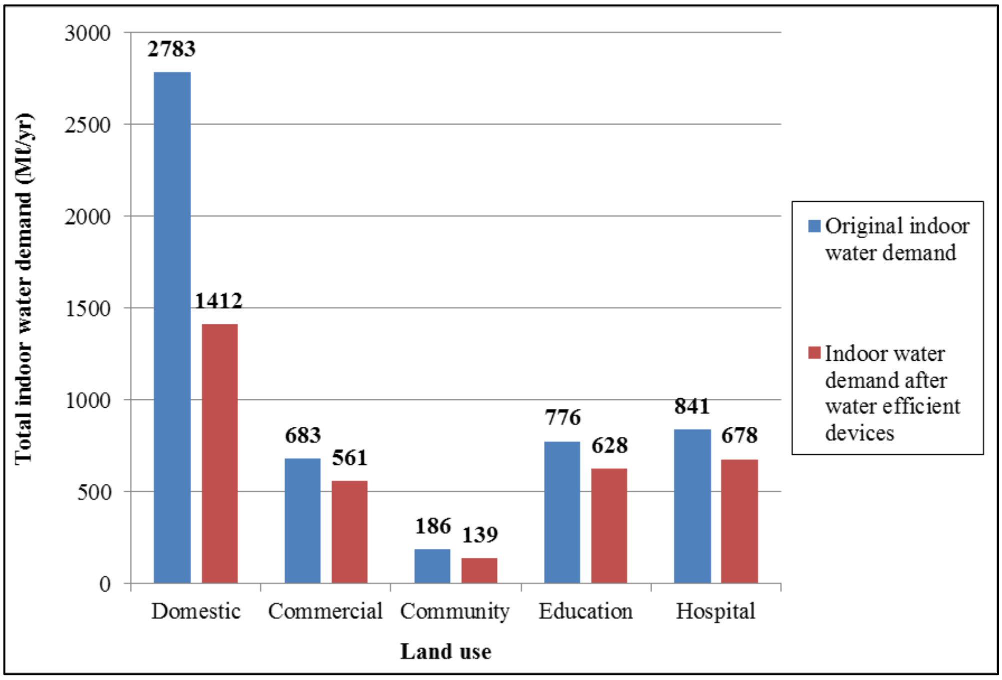


Figure 4.4: Total indoor demand before and after water efficient devices

The relative impact of water efficient devices varies between the different land uses; Figure 4.4 illustrates the total indoor water demand for the different land use categories both before and after the implementation of water efficient devices. The results showed that the implementation of water efficient devices had the greatest impact on the domestic sector. Installing water efficient devices in domestic properties could potentially reduce indoor water use by nearly 50%, thus saving 1371 Mℓ/yr. The savings achieved by installing water efficient devices were significantly lower for the non-domestic sector. Water savings ranged from 18% for the commercial sector, 25% for community facilities, and 19% for educational institutions and hospitals. Although not as effective as in the domestic sector, water efficient devices could however still save a total of 481 Mℓ/yr in the non-domestic sector, which constitutes approximately 9% of the catchment's total indoor water demand.

4.1.5 Economic viability of WSD approaches

A key goal of this study was to develop an understanding of when, where and under what circumstances WSD is economically viable, and to develop a 'business case' for the development of water sensitive settlements across South Africa.

4.1.5.1 Rainwater Harvesting

In order to assess the implications of economic variability on the viability of RWH, a sensitivity analysis was conducted on these scenarios using discount rates of 3.1% to 4.5%. The results presented in Figure 4.5 show the change in average cost per kilolitre throughout the catchment and indicate that an increase in the discount rate will increase the cost per kilolitre. The difference is approximately a 4.5% increase in the cost per kilolitre (between a discount rate of 3.1% and 4.5%). 3.1% was considered the most reasonable estimate of the discount rate based on an analysis of inflation and the government bond yields between 1997 and 2012.

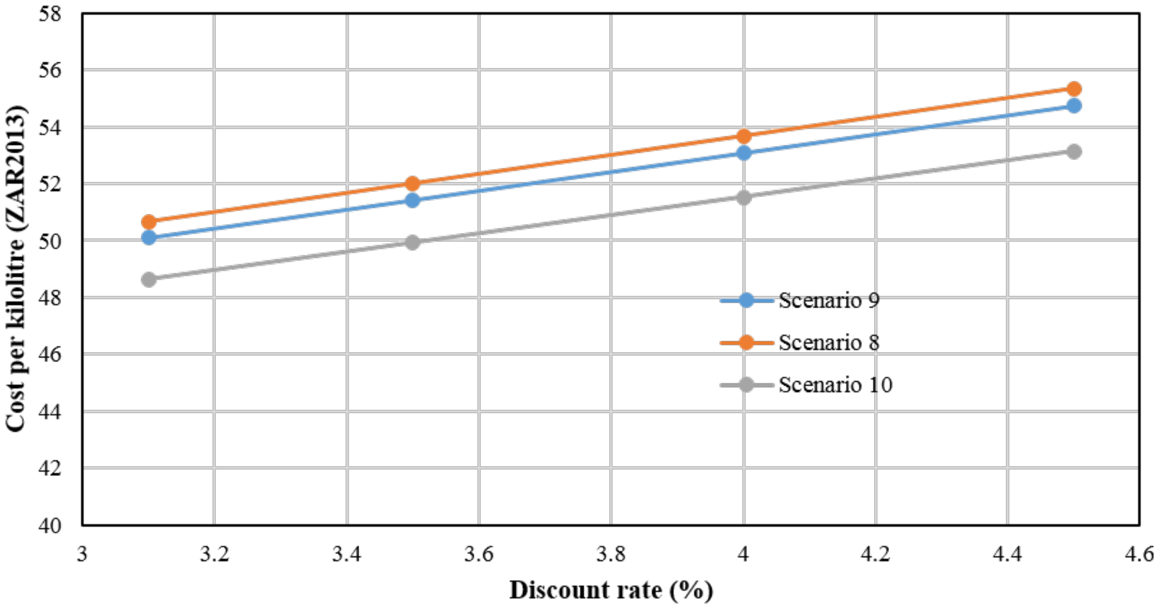


Figure 4.5: Sensitivity to changes in the discount rate

Fisher-Jeffes (2015) showed that RWH may offer negligible peak flow attenuation and that it will improve runoff water quality by intercepting pollutants prior to any spillage – captured in the coarse filter and/or first-flush filter. Dissolved pollutants will, however, not be removed, although this level of water quality improvement could be achieved in a cost effective manner, e.g. through the installation of coarse filters and/or first flush filters on the gutter downspouts. Additional benefits besides a reduction in water demand have, thus, not been considered.

4.1.5.2 Stormwater Harvesting

In order to assess the implications of economic variability on the viability of SWH, a sensitivity analysis was conducted using discount rates of 3.1% to 4.5%. The results presented in Figure 4.6 shows the change in average cost per kilolitre throughout the catchment.

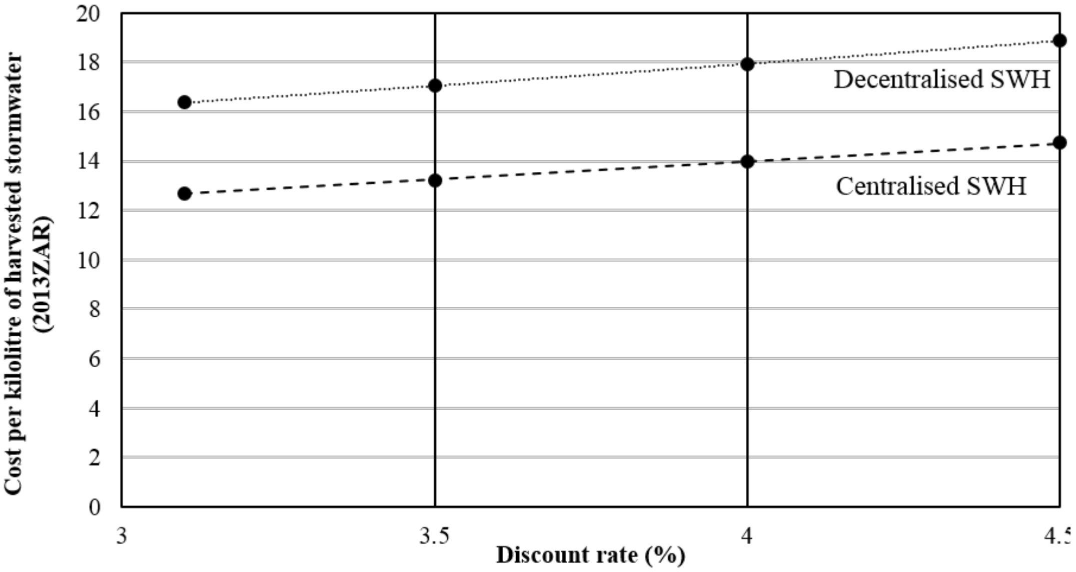


Figure 4.6: Sensitivity to changes in the discount rate – SWH

The analyses show that an increase in discount rate will increase the cost per kilolitre. The difference equates to an approximately 16% increase in the cost per kilolitre (between a discount rate of 3.1% and 4.5%). Considering the uncertainty as to future prices of water, future prices of electricity, future availability of water, etc. the use of a discount rate of 3.1% provides a reasonable indication of the potential of SWH in the Liesbeek River catchment. The increase in cost per kilolitre (between a discount rate of 3.1% and 4.5%) is approximately triple (as a percentage) the increase in cost per kilolitre expected for RWH systems, but the overall cost is roughly equivalent in Rand terms (± ZAR 2).

4.1.5.3 Valuation of additional benefits

In line with one of the objectives of this research, the value of the additional benefits has been considered. De Wit *et al.* (2009) undertook an investigation of the value of natural assets in the City of Cape Town. Through their own investigation and review of literature, they monetised the value of different 'natural assets' and ecosystem goods and services from wetlands and parks. These values were adjusted to 2013ZAR and are presented in Table 4.1. While parks, wetlands and open spaces, such as those that might be created for an SWH system, have been considered here to provide a positive amenity value, De Wit *et al.* (2009) note that some can provide a negative amenity value.

Table 4.1: Value in 2013ZAR/m^2 of different 'natural assets' per year

	Minimum	**Average**	**Maximum**	**Method of estimation**
Parks	0.46	0.74	1.03	Contingent valuation
Wetlands	0.37	0.63	0.89	Contingent valuation
Parks and wetlands*	8.14	10.91	15.13	Hedonic pricing – increased property value
Wetlands	3.8	4.02	4.24	Replacement cost – water treatment and flow attenuation

*The analysis of values reported using the Hedonic method assessed property prices in relation to their proximity to a park or wetland.

From Table 4.1, it is clear that the maximum benefits (recreational use, added property value, water treatment, storm flow attenuation) could be considered at around 2013ZAR 20.40/yr.m^2. Thus considering the size of the systems (cumulatively at catchment scale), there could be significant value, estimated at 2013ZAR 2-7.2 million/yr. within the Liesbeek River catchment. Internationally, open space typically accounts for between 10% to 17% of a development (CSIR, 2005). In the urbanised portion of Liesbeek River catchment, 14% of land is currently undeveloped – well within international norms. SWH in the Liesbeek would, if designed to minimise cost (excluding land costs), require between 0.7% and 3.33% of the catchment (Table 4.2).

Table 4.2: Surface area of SWH storage as a percentage of total catchment area

Scenario	**End use consider**	**% of Liesbeek River catchment used for SWH**
Scenario 21	Gardens (at subcatchment scale)	3.17
Scenario 22	Gardens (catchment scale)	2.5
Scenario 23	Gardens and pools (at subcatchment scale)	3.33
Scenario 24	Gardens and pools (catchment scale)	2.50
Scenario 25	Gardens, pools and toilets (at subcatchment scale)	1.98
Scenario 26	Gardens, pools and toilets (catchment scale)	0.75

If land is set aside along or near the river, and facilities are designed in a multipurpose manner before a catchment is developed, the inclusion of SWH ponds should not be an insurmountable problem. There is a problem with the current configuration of the Liesbeek River catchment, however, in that 4.27% of this land is at the mouth of the Liesbeek River, which is adequate for a centralised system (2013ZAR 2 million), but would not provide the same level of environmental benefits as a decentralised system (2013ZAR 7.2 million). Additionally, the majority of the remaining open space is either not situated in areas where it could be used for SWH – i.e. the edge of the catchment – or is used for other purposes such as school sports fields. If the benefits of SWH were to be included in an analysis, it would also be fair to consider the value of the land on which such facilities are built. An analysis of the average value of undeveloped land was undertaken using the 2012 General Valuations role. This resulted in an estimated value of 2012ZAR 3600/m^2, which was adjusted to 2013ZAR 3880/m^2 according to property inflation in the City of Cape Town. If this is annualised (using a discount rate of 3.1%) over 100 years, it equates to a value of 2013ZAR 126/m^2. This would equate to an annual cost of between 2013ZAR12-42 million/yr. It is evident that this cost significantly exceeds the benefits of SWH.

Table 4.3 provides the total cost of flood damage over 100 years, which has been annualised (De Wit *et al.,* 2009). Therefore, were SWH able to reduce all flooding – highly unlikely – it would equate to the reported annual benefits. While the values (costs and benefits) are cumulatively significant, in order to consider the viability of SWH, including benefits, they need to be reduced to a per-kilolitre value.

Table 4.3: Value of additional costs and benefits per kilolitre

No.	Description	Scenario 26 – centralised (2013ZAR/kℓ)	Scenario 23 – decentralised (2013ZAR/kℓ)
1	Benefits	2.27	5.16
2	Land costs	14.01	31.85
3	Net benefits (1-2)	-11.74	-26.69
4	Reduced flood costs	0.00	3.74
5	Cost of SWH, excluding benefits and land costs	12.85	16.38
6	Cost, including benefits and land costs (5-1+2)	24.59	43.07
7	Cost, including only benefits	10.58	11.22
8	Cost, including benefits and land costs (5-1+2+4)	10.58	7.48

It is evident that the cost per-kilolitre of harvested stormwater will roughly double [Table 4.3, (5) *vs*. (6)] if the cost of land is included. However, the outcomes of the analysis would be significantly different if the urban area had been planned with SWH in mind. If public open space was utilised so it could perform the functions laid out in Table 4.1 and therefore not require additional urban space, these facilities could offer significant value to the community. The per-kilolitre cost would significantly decrease, and would be approximately equivalent to what the CoCT currently charges residents who use 6-10.5 kℓ/month. This would make SWH viable for the vast majority of households in the catchment. Furthermore, SWH was found to have the potential to significantly reduce flooding. If this were realised, for example in Scenario 25, the net cost [Table 4.3, (8)] would be further reduced.

4.1.6 Implementing multiple WSD technologies concurrently

WSD focuses on a range of goals including, *inter alia:* developing resilience; recognising the intrinsic value of water; mitigating the effects of climate change; developing amenity; and protecting biodiversity. Implementing different technologies together has the potential to positively and/or negatively affect the achievement of the goals of WSD. The implementation of RWH and SWH in conjunction was found to be a potentially unwise strategy. As would be expected, RWH and SWH are both most economical under maximum demand. Reducing the demand for harvested rainwater due to the use of 'cheaper' harvested stormwater will only make RWH less viable and vice versa.

An important consideration would be the practicality of having a three-pipe supply system (potable, rainwater and stormwater) as this would no doubt increase the risk of cross connections, thus posing potential public health risks. A situation can be envisaged where SWH provides water for irrigation, while RWH and potable supplies provide water indoors. Alternatively SWH could act as the primary back-up supply for RWH – assuming the harvested stormwater is of an acceptable quality. However, the decrease in constant demand for harvested stormwater will affect the benefits in terms of stormwater peak flow attenuation – unless the ponds are actively managed. The analysis of the stormwater management benefits showed no discernible difference, and as such, the implementation of RWH alongside SWH provides no additional stormwater management benefit – as was the case with RWH in isolation.

While encouraging RWH in conjunction with SWH would increase the total volume of demand met, it will come at an economic cost where either the cost per kilolitre of harvested rainwater or stormwater increases. It would also increase the financial and economic risks for the implementing agent – the CoCT, in this case. Therefore a long-term plan incorporating both RWH and SWH is not a viable option for the Liesbeek River catchment and needs to be carefully considered elsewhere.

4.1.7 Impact of modelling methods

The methods and spatial scale used in modelling RWH and SWH can have an impact on the results of the analysis – this is described in more detail in Appendix A (section A2).

For RWH, it is apparent that, at the property scale and using the same storage size, there can be significant differences in performance when using hourly time steps in comparison to daily time steps. At the catchment scale, the differences are small (demand met, 1%; volumetric reliability, 1.4%; percentage collected, 3%) and considered acceptable. The most significant difference is found in smaller systems, as expected (Fewkes, 1999), where the system could potentially fill and empty multiple times in a single day. The time step can, however, have a significant impact on the optimisation and selection of the storage size of an individual system. In South Africa, RWH systems are typically sized based on daily demand simulations;

therefore, it would seem rational to size systems based on the results of modelling using a daily time step. Importantly, it is evident that the use of linear extrapolation to infer the catchment-scale impacts of RWH is likely to lead to errors. Based on the analysis conducted in the Liesbeek River catchment, the error in estimating volumetric reliability typically ranges between 8% and 9%. The error in estimating spillage typically ranges between 7% and 18%. While extrapolating to the suburb level improves the accuracy of the results, there remains an inherent error. Additionally, the above linear extrapolations have the advantage of being based on the mean (arithmetic or geometric) data from every household; where only a sample of data is used, the errors could potentially increase.

In terms of SWH, the spatial scale of analysis (whether systems are modelled independently or lumped) can have an impact on the results. For this study, where the storage volume significantly exceeds the 16 kℓ/ha suggested by Mitchell *et al.* (2008), it is of little significance whether the ‘yield after storage’ (YAS) or yield before Storage (YBS) algorithm is used for modelling the SWH systems' storage (see Appendix A, Section A2.2). In this research, the use of either a daily or hourly time step is acceptable for sizing the SWH systems' storage volume and the only performance parameter that will show any variation is the percentage of dry periods.

4.1.8 Public knowledge and stormwater quality

An additional focus area of the study of the Liesbeek River catchment was the examination of the simultaneous interconnections of stormwater drainage systems, runoff quality, and resident knowledge and experience. Conventional drainage infrastructure fails to connect citizens with their downstream impacts on ecological systems and environmental services. Ward (2014) analysed surface water flowing into roadside catchpits and societal attitudes and behaviours in generating runoff, and used social surveys, interviews and observations to explore how local residents perceive their impacts on the quality of an urban river. The findings suggest that the predominant focus on technological solutions and flood prevention do not persuade citizens to account for actions which result in the deterioration of downstream environmental conditions. It also highlighted how changes in land use could influence ecological patterns and processes resulting in changes in ecological conditions. Similarly, these changes have potential to change human behaviour for better (e.g. positive attitudes) or to the detriment of the environment (e.g. negative behaviours that are detached and even threaten ecological processes). It was thus concluded that WSD (in this case, in the form of Sustainable Urban Drainage Systems, SuDS) could be a visible ‘switch’ enabling improved quality of runoff and a more measured flow rate from the land to the river. In addition, WSD brings attention to the use of green infrastructure that has many positive benefits, including its contribution to public education.

4.2 Use of groundwater as a resource through Managed Aquifer Recharge on the Cape Flats Aquifer

As outlined previously, the most established role of groundwater resources within the WSD framework is for the treatment and storage of urban stormwater or treated wastewater (Water by Design, 2009; Wong *et al.*, 2012). This process of intentionally enhancing the recharge of an aquifer is known as Managed Aquifer Recharge (MAR) (Dillon *et al.*, 2009). MAR has a number of objectives that range from enhancing aquifer yield, managing groundwater levels and improving water quality. The objectives of MAR coincide with a number of WSD objectives in terms of maximising the benefits of available water resources whilst ensuring sustainable use and protection of ecosystems and human health.

Given the alignment of MAR objectives with those of WSD, and the success of MAR around the world it is important to incorporate, where possible, MAR into a city's WSD strategy. In the City of Cape Town (CoCT) it is assumed that the Cape Flats Aquifer (CFA) may provide a valuable means of temporary storage. The CFA underlies a surface area of approximately 630km^2 representing a region of coastal sands between Table Mountain in the West and the hills of Tygerberg and Kuilsriver (Figure 4.7).

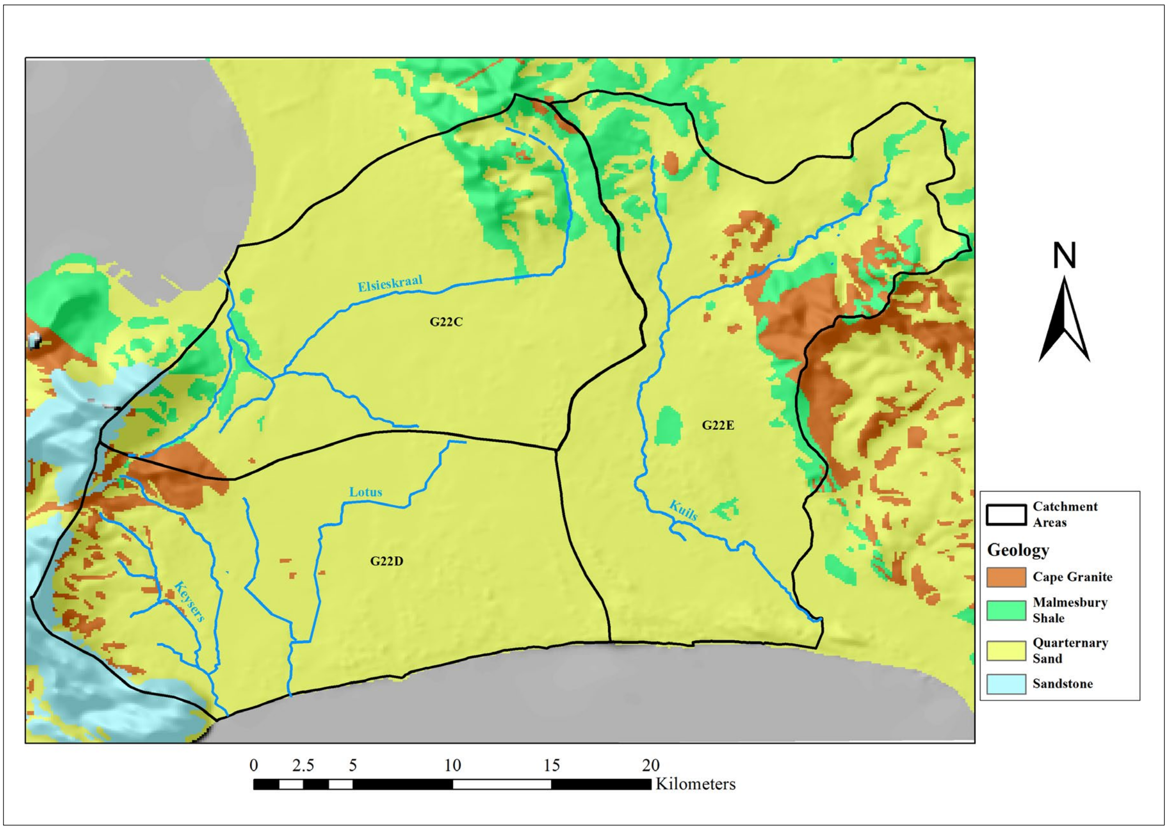


Figure 4.7: The geology and hydrology of the Cape Flats

The Cape Flats form part of the large undulating sandy area that connects to the hard rock of the Cape Peninsula (Maclear, 1995). The area is generally lowland with varied terrain ranging from low-lying plains with an average elevation of 30 m (Adelana *et al.*, 2010). There are various land use activities taking place in the area, including formal and informal settlements, industry, agriculture, open areas and sand mines. These have a significant impact on both surface and groundwater in terms of quality and quantity.

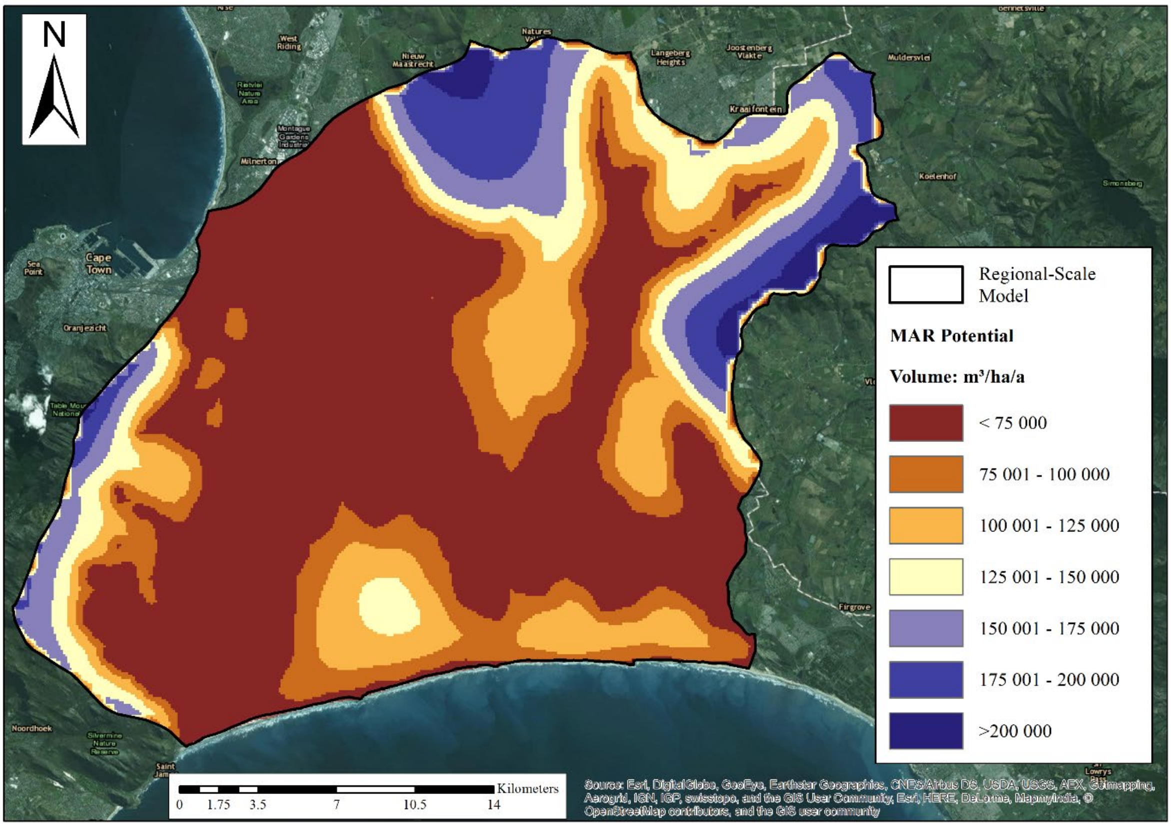
The CFA itself is an unconfined, sandy aquifer situated in the quaternary sands of the Cape Flats, and has been under consideration as a potential resource for water supply since the early 1980s when it was also considered for wastewater reuse. Because the CFA has relatively high hydraulic conductivity and storativity values, this makes it ideal for MAR. One limiting factor of the CFA is that the area is prone to high water tables, and this reduces the storage available for additional water. This is particularly true during the wet winter season in Cape Town, and as result flooding can be particularly problematic on the Cape Flats. Thus, there is a need to create storage capacity within the aquifer during summer so that there is capacity for winter stormwater. Thus, the following research question was posed: *"Is there potential to infiltrate winter stormwater into the Cape Flats Aquifer? And can the storage capacity of the Cape Flats Aquifer be enhanced through controlled summer abstractions for fit-for-purpose uses?"* In order to answer these questions the investigation had two main objectives:

- To develop and calibrate a MIKE SHE model to identify the hydrological processes that drive the groundwater recharge, storage and surface water interactions in the CFA at a regional scale – through the use of available data, information and conceptual hydrogeological models for the CFA. This modelling approach is important for testing and comparing the established conceptual hydrogeological models and to identify the dominant hydrological and hydrogeological processes and the groundwater resource potential of the CFA.
- To test the applicability of WSD techniques and technologies at a local-scale on the Cape Flats, specifically addressing the application of MAR for the management of stormwater in this area.

The first of these objectives has been completed (see Mauck, n.d.). A MIKE SHE model was set up and calibrated to describe the hydrological and hydrogeological processes at a regional scale. The testing of MAR at a local-scale on the CFA is currently being finalized (Gxokwe, in progress). The selection of an appropriate site for local-scale modelling based on regional hydrogeological modelling output is described in more detail in Appendix B. In short, MAR requires a site that has storage potential for water, but that is also in proximity of locations that are prone to seasonal flooding. The aquifer is also required to have the appropriate storativity and hydraulic conductivity properties that allow for ease of the recharge and abstraction of water from the aquifer.

4.2.1 Summary of groundwater design aspects

The results of the regional scale MIKE SHE model for the CFA were crucial in providing insight into the hydrogeological processes of the CFA and provided valuable information such as mean groundwater level, groundwater head elevation and recharge. These model results together with information from literature and past hydrogeological exploration aided the site selection process. The Philippi and Mitchells Plain area in the Southern region of the CFA were evaluated to be the most appropriate for MAR (Figure 4.8). This finding correlated with that of Seyler *et al*. (2016) in their study on ‘Regional Water Sensitive Design scenario planning for Cape Town’ (WRC Project K5/2441) in which they delineated areas on the Cape Flats where infiltration should be encouraged / discouraged based on (potential) depth to groundwater at future development zones.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 4.8: MAR potential for the Cape Flats Aquifer

A more detailed local-scale MIKE SHE model was used to perform a scenario analysis of the MAR options available that attempt to reduce winter flooding while supplementing the demand for water during summer. The following were the main findings from the groundwater study:

- The use of integrated hydrological modelling, able to represent both surface and groundwater processes, was demonstrated as a valuable means of understanding the complete urban hydrological cycle for aiding urban water management, such as WSD.
- The integrated modelling approach allowed for a physically-based determination of groundwater recharge for the CFA. Previous attempts for evaluating recharge for the CFA have relied largely on empirical methods.
- The MAR potential was mapped for the CFA which is valuable for future MAR planning and design. With improved information on aquifer characteristics, water quality, land use, soil and geology, this mapping methodology could be an essential tool for groundwater management and planning on the CFA.

- The use of MAR, through controlled groundwater abstractions, to artificially lower the water table was demonstrated as a feasible means of reducing groundwater related flooding on the CFA.
- MAR was shown to be a viable water supply option for the city of Cape Town by facilitating the reuse or recycling of stormwater or treated wastewater, potentially contributing approximately 18 Mm^3 per annum (approximately 5% of the average potable water demand) per year towards the city's water supply. The injection or infiltration of water from urban stormwater or treated wastewater into the CFA could result in a doubling of the yield to nearly 40 Mm^3 per annum – equating to 11% of the average demand. Abstracted groundwater could be used to augment potable water supply, or for 'fit-for-purposes' uses to off-set potable demand, depending on the level of treatment adopted.
- The research suggests that it is possible to manage the recharge of the aquifer not only to improve groundwater storage capacity, but to reduce the flooding in low lying areas that occur every winter during the rainfall season.
- The evaluation of the simulation of contaminant (TDS) transport demonstrated the primary contaminant flow paths from the Flood and MAR sites. This showed downstream sites that are at risk of contamination should MAR be conducted or not.
- The integrated hydrological modelling approach was used to quantify the likely impacts of future climate change on the entire water balance. This is particularly essential from a groundwater perspective as these impacts have not been evaluated for the CFA as yet and can easily go undetected due to the 'hidden nature' of the resource.
- Based on the results of the integrated hydrological modelling, the resource value of the CFA was reiterated. As a result, it was acknowledged that a pilot study is an essential step towards ensuring this resource is utilised in the near future.
- It was shown that MAR is a tool for application of WSUD in Cape Town, offering value for water supply and stormwater management. Additionally, WSUD and its application in MAR offer valuable benefits including pre-treatment, enhanced public amenity and improved biodiversity.

5. Implementing water sensitive design – results of feasibility studies

Water Sensitive Design (WSD) is based on the premise that any development or redevelopment must address the sustainability of water (Engineers Australia, 2006). It is evident in this definition that WSD is not only focused on the design of the individual elements or technology/ies – although these are also important – but rather on how the system is managed as a whole. In other words, the innovation in WSD arises from the systems approach that it demands. This is further evidenced by the realisation that whilst a technology such as rainwater harvesting may have been used by communities across the world for millennia, it nonetheless continues to constitute an important technology option which now needs to be better understood in the context of WSD.

A key finding of WSD-related research in South Africa is that while much can be gained from international experience, there is a need to test technologies within the local context. To this end, it is worth noting that substantial local research has been conducted into the site scale implementation of some WSD technologies – including rainwater harvesting (Fisher-Jeffes, 2015; Mwenge Kahinda *et al.,* 2008); stormwater harvesting (Fisher-Jeffes, 2015); water efficient devices (Still *et al.,* 2008; Coulson, 2014); greywater harvesting (Carden *et al*., 2007; Rodda *et al.,* 2010; Ilemobade *et al.,* 2012; Coulson, 2014). This research will ultimately contribute to the development of technology-specific tools and guidelines for WSD in South Africa – parts of which are already in the process of being (or have been) developed – for example, the WRC-funded Water Harvesting tool which can be used to design household-level rooftop rainwater harvesting systems (http://cip.csag.uct.ac.za/webclient2/waterharvest/); and the recently-completed WRC project K5/2592 'Guidelines for greywater use and management in South Africa' (Carden *et al*., 2017). Much of the focus to date on WSD technology options has, however, been on alternative water sources. There has been very little research focusing on issues such as: stormwater, treated effluent and groundwater / Managed Aquifer Recharge (MAR) management activities associated with WSD; and the development of appropriate systems that promote amenity and biodiversity as part of WSD implementation projects in South Africa. Therefore, this section will focus on the following:

- Exploring the different factors that need to be considered when conceptualising WSD for a development, catchment, or city;
- Highlighting on-going work assessing groundwater as a resource and Managed Aquifer Recharge as part of a WSD system, and the links with stormwater and treated effluent;
- Highlighting the lessons learnt from local studies into the functioning of WSD stormwater and SuDS technologies (yet to be published); and
- Highlighting projects which have, or could have contributed to the amenity and biodiversity aspects of WSD.
- Presenting some of the preliminary findings in respect of identifying barriers and drivers to the implementation of WSD.

5.1 Conceptualising water sensitive design

Conceptualising the implementation of WSD requires an interdisciplinary perspective of a range of factors (technical; environmental / climatic; social; economic), many of which will be site specific. This project has investigated the feasibility of implementing a range of different WSD technologies – the findings of these studies are briefly summarised in Table 5.1, specifically in respect of the potential benefits each of the technologies can potentially provide.

Table 5.1: Technology-specific findings from WSD feasibility studies

WSD technology	Potential benefits of WSD technology implementation
Rainwater harvesting	Rainwater harvesting primarily offers a means of reducing municipal water demand, but with negligible stormwater management benefits. Currently it is only financially viable for a minority of the (more affluent) property owners (8% and 9.5%) in the Liesbeek catchment, and only if runoff is harvested from the majority of their roof areas and used for a diversity of end uses – equating to approximately 7% of total residential water demand.
Stormwater harvesting	Stormwater harvesting offers a means of reducing municipal potable water demand (potentially up to 20% in the Liesbeek River catchment), decreasing total runoff volumes, offering amenity benefits and, if actively managed, also a means of attenuating peak flows. In certain areas, it offers a means of financially and economically providing water that is less expensive than the currently supplied potable water.
Water efficient devices	Water efficient devices could have a significant impact on reducing water demand. The results from the Liesbeek catchment study showed that the implementation of water efficient devices had the greatest impact on the domestic sector. Installing water efficient devices in domestic properties could potentially reduce indoor water use by nearly 50%.
Greywater harvesting	Greywater could be used to significantly reduce the demand for potable water – by meeting outdoor water requirements – in the Liesbeek River catchment (whilst acknowledging potential health risks). The one main advantage of greywater reuse over RWH / SWH is that the supply of greywater is constant throughout the year, meaning that the seasonal variation of outdoor water demand can be catered for. Managed greywater reuse is considered most feasible for commercial and institutional purposes – and could contribute nearly 12% of the total water demand in the Liesbeek catchment.
Sustainable Drainage Systems (SuDS) – e.g. Permeable Pavement Systems (PPS)	SuDS such as PPS offer a means of not only improving the quality of polluted stormwater run-off in urban areas, but also offer potential for storing water for a range of fit-for-purpose uses. Proper design, installation, maintenance and operation of these systems is however crucial.
Managed Aquifer Recharge (MAR) – linked to stormwater harvesting	MAR could provide a viable water supply option for the city of Cape Town by facilitating the reuse or recycling of stormwater or treated wastewater, potentially contributing between 18 Mm^3 to 40 Mm^3 per year (5 to 11% of the average potable demand) towards the city's water supply. MAR is a tool for application of WSD in Cape Town, offering value for water supply and stormwater management. Additionally, WSD and its application in MAR offers valuable benefits including pre-treatment, enhanced public amenity and improved biodiversity.

Note that the research thus far has clearly indicated that while different WSD technologies may provide certain benefits in isolation, these benefits can either be substantially increased (e.g. where a treatment train is used for stormwater quality management) or decreased (e.g. where multiple alternative water sources are being used to supply water for only one end use). The linear-based, silo approach to designing water services which has historically been undertaken in the provision of water services can thus not be used when adopting WSD. Rather an iterative, systems-based approach is required. It is therefore not possible to lay out ‘guidelines’ or a set of ‘step-by-step’ instructions on how to implement WSD.

Some of the different considerations and design thinking processes associated with WSD are highlighted in this section – as illustrated in Figure 5.1, which provides a simple example of the development of a Decision Support System (DSS) framework which could be used in the conceptualisation of WSD at various scales.

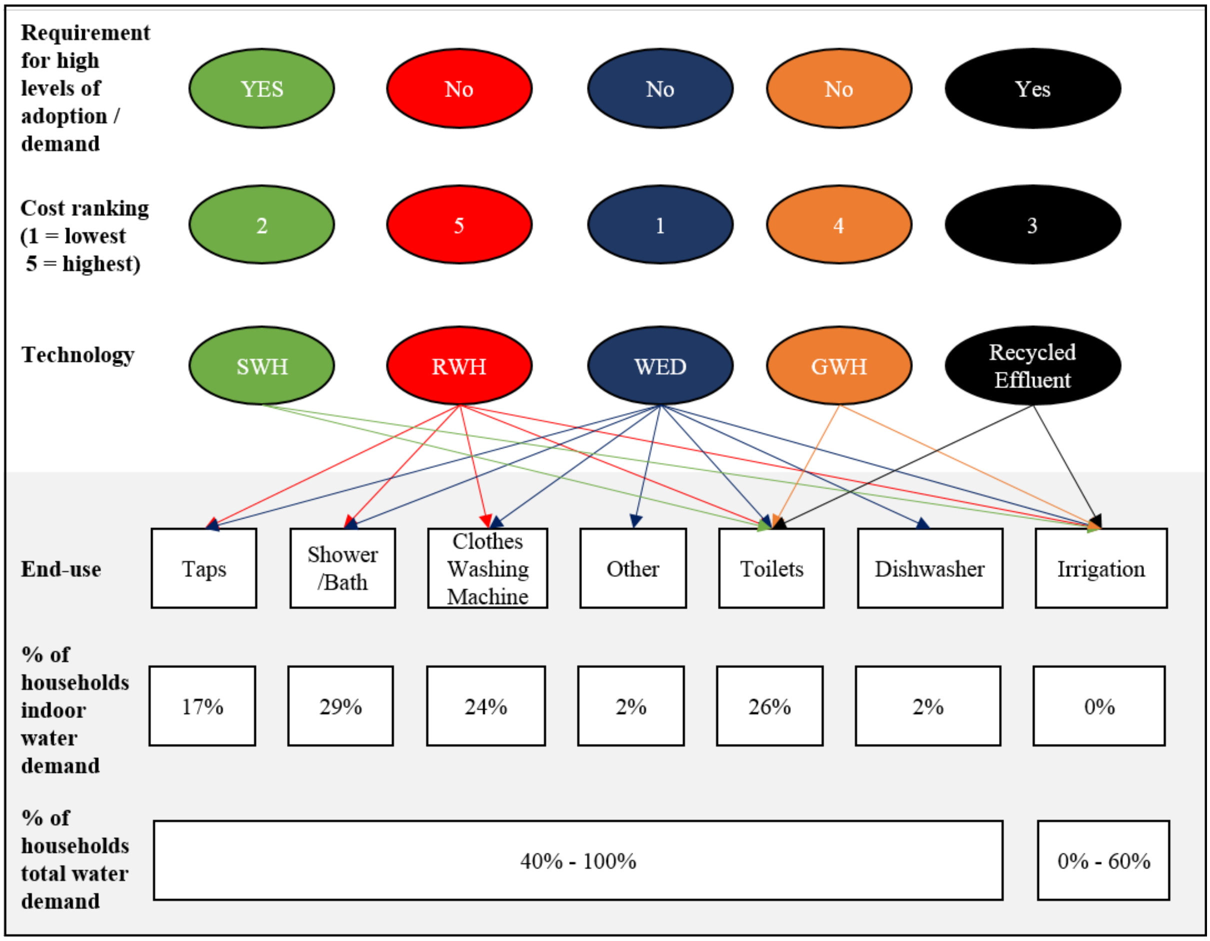


Figure 5.1: Interactions between different WSD technologies associated with alternative water sources

The DSS example in Figure 5.1 highlights the relevant information which needs to be considered when considering the use of alternative water sources, including:

- The different end-uses for which each alternative water source is appropriate;

- The contribution of each end-use to a typical household's indoor and outdoor water demand;
- The relative cost of each of the alternative water sources; and
- Whether the alternative water resources could be used by individual property owners or whether they require higher (larger-scale) levels of adoption.

Such a DSS highlights the fact that often more than one WSD technology could provide water for a specific end-use – or in the case of water efficient devices, could significantly reduce demand. As a result, the selection of which WSD technologies are most appropriate to a specific site is critical, as implementing multiple WSD technologies that all provide water for the same end-use would likely lead to a system that is not viable to operate. The possible reasons for this are discussed in the following Sections 5.1.1 to 5.1.3.

5.1.1 Water demand

The in-depth study of the Liesbeek River catchment (Fisher-Jeffes, 2015) highlighted the significant intra-suburb (potentially intra-catchment) variations in water demand (Table 5.2).

Table 5.2: Per-capita water demand by suburb

Suburb	**Estimated indoor AADD (ℓ/c.d)**	**Suburb**	**Estimated indoor AADD (ℓ/c.d)**
Bishopscourt	260	Observatory	180
Claremont	280	Rondebosch	210
Mowbray	220	Rosebank	240
Newlands	260		

Whilst not unexpected, the magnitude of the variation is significant and has been shown to affect the viability of WSD approaches. In some areas, such as Observatory for example, the per capita water demand may already be relatively near lower water demand targets set for WSD (e.g. 150 ℓ/c.d). In other areas, such as Claremont, the per capita water demand is significantly higher. As discussed previously, the success of a WSD design approach – including which WSD technologies form part of this design – depends on consideration of the viability of the different technologies within a specific context. For example:

- Rainwater harvesting might be viable for a number of households in Claremont due to their high water demand. However, if these households were to also adopt water efficient devices and make use of greywater harvesting (both more cost effective), rainwater harvesting might no longer be viable.
- Due to a number of factors, including small roof areas (catchments for rainwater harvesting), the benefits of greywater harvesting, stormwater harvesting or rainwater harvesting might be limited. For example, the most appropriate approach to better

managing demand in suburbs like Observatory would most likely be to support a switch to water efficient devices.

Another interesting study which formed part of this research – and also highlights the issue of water demand variations – looked at the impact of swimming pools on residential water demand. The study found that the presence of a swimming pool indicated significantly higher per capita water demand, but that the demand was not predominantly as a result of the pool itself. There also appeared to be a strong correlation with other drivers of increased water demand, for example, larger household sizes (families rather than individuals) and higher living standards that would normally be associated with having a swimming pool at one's home (Fisher-Jeffes *et al.*, 2015).

5.1.2 Economic and social factors

The viability of many WSD technologies is often not a case of technical viability but rather economic and social viability. Studies such as Wilson & Pfaff (2008) have looked at many of the social perceptions and acceptability of alternative water resources. The overall impression from the literature could be summed up as '*it's a good idea, but someone else should do it*'. Social perceptions and attitudes are particularly problematic when a city attempts to implement water restrictions. Social perceptions and what is acceptable may change over a period of time – for example, droughts could be a driver of such change – further research in this area is thus still required.

5.1.2.1 Economic viability

The focus of this research has generally been on the economic viability of alternative water resources. The findings largely match those of international studies, indicating that water efficient devices are the cheapest means of reducing water demand, and that rainwater harvesting is typically the most expensive. What this research has also highlighted is that the concurrent implementation of technologies aimed at reducing water demand – or substituting for it – is not always advisable. For example, Fisher-Jeffes (2015) showed that whilst it is technically possible to implement rainwater and stormwater harvesting in a single catchment, it would not be advisable since RWH and SWH are both, as would be expected, most economical under conditions of maximum demand. Reducing demand for harvested rainwater by using 'cheaper' harvested stormwater will only make RWH less viable – and *vice versa*.

Another key economic factor is the 'level of adoption' – i.e. the percentage of possible users making use of the technology. As might be expected, this has been found to be a critical driver of cost. At high adoption levels the cost rankings presented in the example shown in Figure 5.1 are valid, but as the levels of adoption decrease, the costs of 'semi-centralised' (e.g. stormwater harvesting) and centralised (e.g. recycled effluent) technologies rapidly increase. Ultimately, the level of adoption will be driven predominantly by social perceptions – especially those around what are 'acceptable' water resources. These perceptions may change over time, especially when an area or country experiences a drought, however – as has been the case in Australia, and more recently in South Africa (e.g. example of Beaufort West direct reuse of treated sewage effluent).

The DSS example shown in Figure 5.1 is most appropriate for greenfield development sites, as it does not highlight the constraints imposed when needing to retrofit in a more water sensitive manner. For example, stormwater harvesting has been shown to be a viable option for the Liesbeek River catchment, whereas rainwater harvesting is only viable for a small minority of property owners in the catchment. In retrofit cases, as would be the case of the Liesbeek River catchment, there may be no land available for an 'ideal' stormwater harvesting scenario – i.e. one that could be undertaken incrementally. Instead, a centralised system would need to be implemented at the catchment scale. This would require significant investment by the local authority involved (in this instance the City of Cape Town, CoCT), both financially and institutionally, and may take many years to develop. Since RWH systems have a life cycle of roughly 15 to 25 years, it would not be unreasonable to encourage their adoption where they are currently viable (technically, financially and economically) with a view to switching over to SWH at the end of the system's life cycle. This would require long-term planning on behalf of both individuals and the CoCT, however, including the development of institutional and regulatory frameworks. The risk with this approach is that property-owners who initially invest in a rainwater harvesting system may find it more desirable to continue using these private systems, and do not switch over to using harvested stormwater when the system gets implemented. This would then lower the level of adoption of stormwater harvesting and undermine the financial viability of the system.

5.1.2.2 Societal perceptions

In an attempt to try and better understand some of the societal linkages between biophysical (specifically stormwater) and social systems, a study was undertaken as part of the Liesbeek River catchment baseline assessment (Ward, 2014). It is widely recognised that poor stormwater quality is one of the main contributing factors to the deterioration of urban rivers. The result is that blue-green corridors through urban open spaces are compromised by the cumulative impacts of pollution that alter productive ecosystem services and are no longer able to support biodiversity. The resultant condition of urban waterways cannot however be understood simply as a cause and effect relationship, but rather as a result of interactions between people, (engineered) drainage systems and the natural environment. The study assessed the quality of stormwater flowing into roadside catchpits, and also used social surveys, interviews and observations to explore how local residents understand their impact on the quality of an urban river. The results showed that the quality of stormwater runoff is highly variable and that residents have a poor understanding of the linkages between what they do on the land and the runoff into waterways. The findings suggest that the predominant focus by local authorities on technological solutions and flood prevention do not persuade citizens to account for their actions that result in the deterioration of downstream environmental conditions. Furthermore, targeted stormwater management techniques and improving public education and integration in institutional processes could improve the overall societal response to poor stormwater quality and degraded urban waterways.

5.1.2.3 Amenity function of WSD

In an attempt to assess the social implications and amenity value of implementing WSD, a case study of the Constantia Alphen green belt and walking trail in the Diep River catchment, Cape Town was undertaken (de Chavonnes Vrugt, n.d.). The green belt in this area runs alongside the Diep River and has several examples of multi-functional SuDS (see Figure 5.2) – including detention / retention ponds, swales, etc. Constantia is classified as a high-income residential suburb and is mostly home to the 'wealthy'; however, a small informal settlement (the 'Rock area') has established itself in one of the open spaces along the greenbelt. The residents of this settlement do not have access to any form of water-based services, and therefore make use of the Diep River for both water supply and sanitation purposes. This fact led to a redefinition of the concept of amenity[6] for the purposes of this research – so as to expand it from the notion of 'pleasantness' (i.e. beauty, recreational value, naturalness, spatiality, desirability, etc.) into something more inclusive, to take into account issues of survival and basic human needs; i.e. clean drinking water, safety, work opportunities, place to live, etc.

Figure 5.2: Detention ponds along Constantia Alphen green belt
(Source: De Chavonnes Vrugt, 2016)

The study involved ethnographic observations and experiences from eight weeks of fieldwork, focusing not only on the Alphen hiking trail that is part of the so called 'amenity value' of the greenbelt and the ponds within it as aesthetically pleasing and easily accessible, but also looking at the Rock Area community that engage with a completely different set of resources also defined as 'amenities'. Weaved into this problematic understanding of 'amenity' are issues of 'homelessness', 'citizenship', 'access', 'privilege', 'wealth', 'safety', and 'urbanisation' – as well as matters of water scarcity and other environmental concerns. By bringing these issues to the surface, a voice is given to those individuals for whom 'amenity value' was not necessarily originally imagined, by showing that the 'value' or 'use' that they experience from

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[6] "*A desirable or useful feature or facility of a building or place*" or "*The pleasantness or attractiveness of a place*" (http://www.oxforddictionaries.com/definition/english/amenity)

having access to the resources produced both directly and indirectly by the social and physical assemblage of this space indeed present an important ‘amenity value’ to their existence.

The research has shown that amenity value changes based on users’ recognition of different spaces; and in this case, the trail is not recognised as a stormwater system, but rather as a green space. This highlights the fact that stormwater conveyance systems (and the SuDS approaches adopted to deal with flooding in urban areas) need to be developed holistically and managed as such to maintain their value. Further research is required to determine appropriate WSD amenity value for the needs of different social classes, taking into account the shared risks and benefits across multiple constituencies.

5.1.3 Climate considerations

As highlighted in Figure 5.1, the research associated with this project indicates that outdoor water demand (e.g. irrigation of gardens, topping up of swimming pools, etc.) could and should be targeted as part of any WSD implementation scheme. Outdoor demand is largely driven by climate and choice of vegetation. In order to assess the possible impact of variations in climate on WSD, a small study was conducted to model the use of alternative water sources (rainwater and greywater) to meet water demand in the suburbs of Gatesville and Surrey Estate in Cape Town (Gobin, 2014) – this was assumed to represent the Cape Town case. The model was then adjusted to reflect the differences in climate (specifically annual rainfall) for eight other major cities around South Africa, and was run for each of these cities in order to give a comparative assessment of the potable water savings that could be achieved through implementing the use of these two alternative water sources. The average annual rainfall figures for these cities are shown in Table 5.3.

Table 5.3: Annual rainfall in nine major cities in South Africa (Weather SA, 2014)

City	Annual rainfall (mm)
Cape Town (CT)	498
Bloemfontein (BFN)	552
East London (EL)	816
Port Elizabeth (PE)	615
Pretoria (PTA)	661
Springs	544
Pietermaritzburg (PMB)	763
Durban (DBN)	980
Johannesburg (JHB)	763

The results of the study are presented in Figure 5.3. While there is some level of variation in the percentage of water demand met through the two WSD technologies, the results for all the cities are roughly similar. This does not mean that WSD technologies all operate roughly the same anywhere in South Africa, but rather highlights the risks of using a ‘typical’ catchment (such as was done for the Cape Town case), with average climate data for these sorts of calculations.

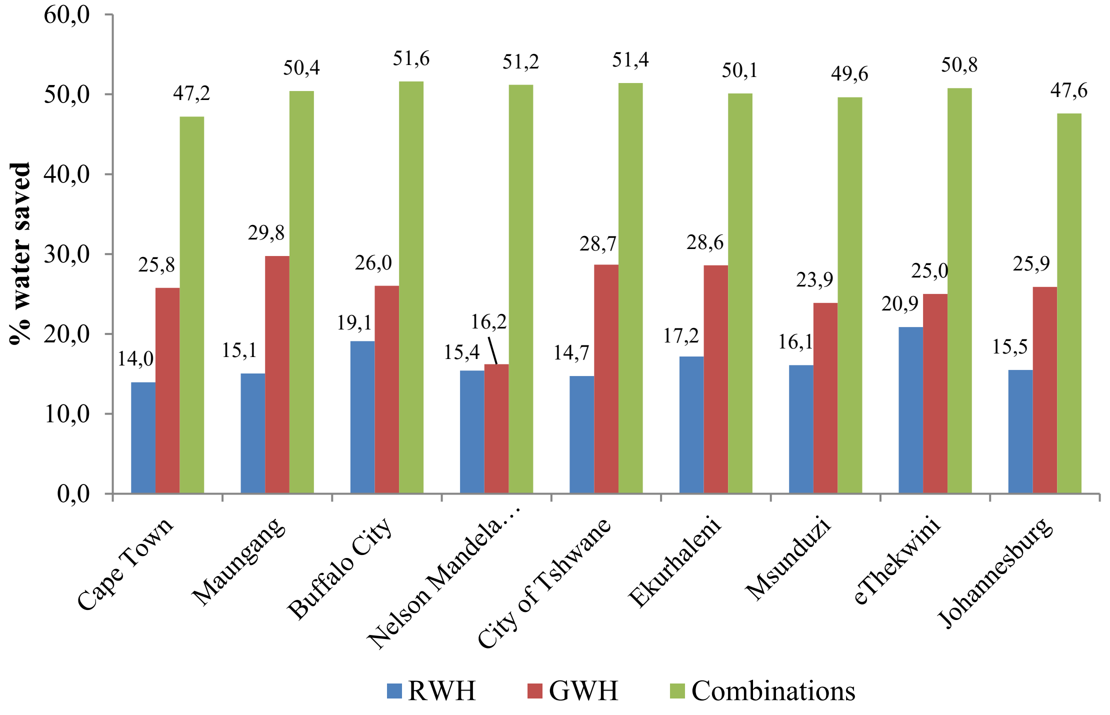

Figure 5.3: Impact of WSD adoption (alternative water sources) in nine cities in SA

The in-depth study of the Liesbeek River catchment (where rainfall varies from 600 mm to more than 1500 mm per year across the catchment) showed that the more rainfall an area received the more viable certain WSD technologies (e.g. rainwater harvesting) would become. However, the study also showed that the viability of certain technologies was dependant on how much they were used / how great the demand for water was. As has been highlighted in previous documents, water demand is largely driven by social affluence and therefore it is not surprising that the selection of two middle- to lower-income suburbs for the first phase of this analysis led to similar results. This methodology should therefore be applied and the study repeated for a greater range of suburbs and climatic conditions, in order to provide more definitive answers.

5.1.4 Selecting an appropriate 'mix'

This section has highlighted that the implementation of WSD does not necessarily incorporate all available technologies, but rather those that are most appropriate or 'fit for purpose'. The significant overlaps that exist between technologies must be taken into account when considering WSD – especially with regard to water supply options – and these overlaps may impact on the viability of certain combinations of WSD technologies.

5.1.5 The value of an architectural approach

In the academic sphere, much research has been conducted into the development of the design of water sensitive elements. However, the way in which these elements are brought together as an integrated unit is often not investigated further – this formed the basis of a study which aimed to show the value that an architect may bring in linking these disparate elements as an integrated entity with multiple values, taking into account the human experience of space and place-making (Bhikha, n.d.). The study was based on a previous architectural design (coded D1, the unit of analysis) that focused on restoring the quality of water in the Liesbeek River in Cape Town through passive water filtration methods (SuDS) – including constructed wetland systems – but also included support facilities and public amenities, all situated within a greater wetland recreational park (Bhikha, 2013). The process and final work of this original design was engaged with, interrogated and analysed, and the resultant revised building concept incorporated the practical, site-specific and aesthetic qualities of WSD to create a people-centred building in which the human experience and relationship to nature is improved. In this way, new insights into the design process and planning of water sensitive buildings were highlighted, thereby displaying the value that an architect may bring in creating a feasible WSD solution that incorporates ideas from multiple disciplines.

WSD must include interventions at multiple levels of overlapping scales which take into account the landscape, stormwater drainage, structural composition and configuration, urban morphology and aspects of ecosystem services (Bacchin *et al.,* 2013). D1 included proposals at the scales of urban, neighbourhood and site. At the macro scale, D1 was informed by the 2012 Cape Town Spatial Development Framework (CTSDF) (CoCT, 2012b) and focused on the aims dealing with natural assets and the environment. It therefore encompassed a network of interventions along the Liesbeek River which allowed for the reinstatement of wetland vegetation along the river banks, thereby restoring riparian ecosystems (Figure 5.4).

Figure 5.4: Passive water filtration design, D1

Multiple design iterations (D1, D2, D3 and D4) were subjected to a series of analyses in order to create a best-fit WSD solution for the site – informed by participant analysis with selected participants from different disciplinary backgrounds (ecology, water engineering, chemical engineering, architecture and teaching). The outcomes of this process dealt with both the design and presentation thereof, and revealed that energy and water efficiency needs to be considered in a more holistic manner in the design, that water and drainage processes needs to be more visible on site, that ecological systems must be emphasised and that the visitor's experience in the landscape must be better integrated. The resultant 'best-fit solution design (Figure 5.5) incorporates multiple water systems at overlapping scales. Water is treated to different levels according to its use and is displayed at most stages of the building. A rehabilitated site edge accommodates for seasonal variations in river water levels and provides natural habitats. Bio-filtration cells provide semi-filtered water for use in a wetland nursery, urban agriculture and further filtration for consumption. Simple and complex greywater systems are displayed within the buildings. Architectural boundaries are blurred through the creation of ambiguous indoor-outdoor spaces, thereby enhancing the connection to water on site. Through multi-scalar design, the building becomes part of the greater blue green network of the city.

Figure 5.5: View over redesigned site, D4

The results of the different evaluations provided insights into the design process that assists in understanding the architectural approach when collaborating across disciplines. Further, the process revealed general guidelines for implementing WSD, including that the effects of the building on the water cycle must be taken into consideration, and that the landscape, community and character of the place should be enhanced. Finally, community involvement is important, as WSD is an opportunity to educate people on the value of water in the urban environment. The value of an architect in the process is revealed in their ability to draw from different disciplines in order to create successful design solutions. As the design process includes continuous reflection and evaluation, an architect is constantly able to sense-check the design objectives for WSD, as well as evaluate the feasibility of the design.

5.1.6 Value capture and WSD

The linkages between WSD, Sustainable Urban Development and value capture were highlighted in a study that highlighted the importance of water and the role it plays in creating value at an urban level (Mallett, n.d.). A Strategic Facilities Management framework was applied to two case studies in Cape Town (V&A Waterfront and Century City) to determine whether investment in WSD (by the State or private investors) has the ability to create additional value. It was assumed that the use of urban Facilities Management (FM) principles can leverage this value at an urban precinct level in order to achieve Sustainable Urban Development.

Through a series of interviews, it was possible to attribute value to WSD, using the five dimensions of Sustainable Urban Development, namely: economic, social, ecological, physical and political. Each dimension has relevance, not only to the definition of WSD, but to the effective implementation of sustainable urban development within the respective case studies – thereby increasing value. For example, roof gardens are utilised at the V&A Waterfront, in unison with solar technology. In doing so, buildings are able to capture water for irrigation purposes, as well as generate energy, which is directed back into the building. The aim is to get not just the new-builds in this precinct onto solar energy but to retrofit older buildings, too. This highlights the use of environmentally friendly or sustainable solutions leading to improved financial viability and hence economic sustainability. Moreover, there are numerous social aspects that can be assigned to this example, particularly with regard to improved public / local authority relationships.

One of the key findings from the study was that neither the V&A Waterfront nor Century City currently identify or make use of value capture mechanisms. This is largely due to the nature of ownership; however it shows that there is room for these types of mechanisms within other development projects. Both case studies have facilities managers that are cognisant of the seriousness of South Africa's drought conditions and are implementing sustainable solutions across the respective precincts. SuDS are utilised at both a micro, building level scale, as well as a macro, precinct-level scale; attempts to become more water-sensitive in both cases have resulted in additional benefits of improved sustainability. For example, the V&A Waterfront make use of seawater cooling, which not only reduces their potable water usage but also decreases electricity demand. Century City has been developed in an area with a high water table, so the canal system is of vital importance; in spite of its value, however, it is an expensive asset to manage and maintain. Another key attribute at Century City is Intaka Island, the natural wetland. Century City has gained socially sustainable attributes as a result of the upgraded and better-kept island. For example, it is used for education purposes and provides public amenity. This implies that WSD creates value for urban precincts in terms of achieving more sustainable cities. The implementation of value capture mechanisms for future projects should thus be tested and further research is required to assess its applicability in a South African context.

5.2 SuDS options

The following sections are aimed at providing specific feedback related to some design elements associated with the SuDS options associated with WSD.

5.2.1 Permeable pavements

Permeable Pavement Systems (PPS) are constructed in such a manner that they allow water to infiltrate through a load-bearing surface material (usually permeable concrete block pavers, brick pavers, stone chip, porous concrete or porous asphalt) and into the aggregate beneath – thereby reducing drainage volumes; attenuating peak stormwater flows; and potentially improving water quality of storm runoff into the soil or drain outlets. Additional benefits of PPS include the retention of stormwater for potential reuse, increased groundwater recharge and an overall reduction in the urban heat island effect. PPS are SuDS source control technologies that have found relatively widespread acceptance in practice in South Africa, mostly as parking lots in new developments.

In order to develop a broader understanding of performance, treatment efficacy, water storage and harvesting potential of PPS in a South African context, a study was undertaken, which included: monitoring stormwater quality at selected existing PPS sites in Cape Town; establishing a new PPS test site for long-term monitoring of the permeable pavement parking area for the New Engineering Building (NEB) at the University of Cape Town (UCT); and setting up a laboratory simulation experiment (for both short- and long-term monitoring) in the Department of Civil Engineering laboratory at UCT (Carden *et al.*, 2016). The main findings of the study related to PPS construction practices in South Africa, when it became clear that the use of unwashed stone as bedding material appears to contribute to significant pollution (in particular, TSS, ortho-phosphate and ammonia) of the water exiting the system. This was highlighted in both the laboratory experiment, as well as the field tests, although the effects of this pollution and the length of time it took to flush the system of pollutants after construction were more obvious in the laboratory experiment. Having said that, the quality of water exiting the PPS in the field tests was generally found to be compatible for use in industrial processes and irrigation, and produced mostly acceptable water quality for downstream aquatic ecosystems – highlighting the fact that, once all of the dust / sediment attached to the stone has been flushed out, PPS have the potential to improve stormwater quality, and to provide fit-for-purpose water as an alternative to potable water in certain applications. To meet Orthophosphate criteria, however, another SuDS technology with better phosphate removal capacity would have to be included in a SuDS treatment train. The results indicated the need for the development of a comprehensive set of construction and maintenance guidelines for the implementation and ongoing management of PPS.

5.2.2 Filter drains

In an attempt to meet the quality and quantity criteria associated with the City of Cape Town's 'Management of Urban Stormwater Impacts Policy' (CoCT, 2009), a number of Sustainable Drainage Systems (SuDS) were included as part of the design of the water management system at the MyCiti inner city bus depot (ICBD) in Cape Town. One of the SuDS implemented was a filter drain, which was of particular interest as it was a prototype design and hence its efficacy was unknown.

This study (Van der Byl, 2015) aimed to evaluate the water quality efficacy of the filter drain in order to determine if it met the CoCT's Stormwater Policy water quality criteria; namely: an 80% reduction in total suspended solids (TSS); and a 40% reduction in total phosphorus (TP). An initial site inspection revealed that, owing to the fact that a pre-treatment bay had not been included in the design for the filter drain, and little or no maintenance had been performed, corrective maintenance was first required to unblock the drain before it was possible to evaluate its water quality efficacy. After the filter drain was rehabilitated it was tested by discharging synthetic stormwater (municipal water dosed with TSS and phosphorus) into the system. Influent and effluent samples were analysed for TSS and orthophosphate, and compared in order to determine the water quality efficacy of the filter drain. This method was repeated for three varying (low, medium and high) pollutant levels. Figure 5.6 shows the extent of the blockage of the filter drain as a result of inadequate maintenance.

Figure 5.6: Sediment in inlet manhole (left) and debris blocking roadside inlet (right)

The study concluded that adequate pre-treatment of stormwater runoff and routine maintenance is essential for the successful implementation and ongoing effective operation of SuDS. It was found that the water exiting the filter drain meets the CoCT's Stormwater Policy water quality criteria in terms of percentage reduction; however it was noted that the concentration of Ortho-P in the effluent was significantly higher than that prescribed as part of the South African Water Quality Guideline for coastal marine water. This indicates that the percentage reduction performance metric is not always the most appropriate performance indicator to use when evaluating the water quality efficacy of SuDS.

5.3 Environmental system design and planning aspects

A number of studies were conducted on the system design and planning aspects of WSD, thereby taking into account some of the associated non-infrastructural considerations. Brief details of two of the most pertinent studies in terms of design aspects are included here, as examples of this approach.

5.3.1 2D modelling for wetland design

Attenuation of peak stormwater flow using natural wetlands is one of many SuDS approaches used to reduce flooding. In an attempt to measure the attenuation capacity of a small-scale wetland (Valkenburg wetland) adjacent to an urban river, a study was carried out on a site located within the Liesbeek River catchment, which is prone to localised flooding during annual winter rainfall events (Giermek, 2015). The study used a 2D PCSWMM hydrodynamic model, which ran historic flow data to determine the attenuation capacity and to measure peak flow reduction. Peak flow of the Liesbeek River was reduced in scenarios with the Valkenburg wetland accepting a portion of this flow. Attenuation was most effective for rainfall events with sudden spikes in peak flow, where a 42% reduction in peak flow was observed. For a scenario with lower flow rates but prolonged peak flow rates, the wetland was less effective, with a 20% reduction observed. The wetland was found to have the potential to provide valuable ecosystem services to the area by attenuating peak flow and thus reducing the occurrence of property damaging flooding downstream. While the peak flow reduction provided by the wetland are not sufficient to totally reduce damaging floods, the findings provide new knowledge and understanding of the attenuation capacity of this wetland, the methodology for ongoing studies, and motivation for expanding SuDS within the catchment.

5.3.2 Designing for amenity – the example of water spray parks

Water spray parks have been constructed in cities around the world as urban amenities to offer safe water play for children. The City of Cape Town launched a pilot project in 2013 to install six spray parks in selected low-income areas (Valhalla Park, Scottsville, Ocean View, Nyanga, Khayelitsha and Du Noon) as community amenities (Figure 5.7). The purpose of this project was to evaluate Cape Town's experience with water spray parks in terms of the perceived benefits to community members, issues with their design and operation, and how they conform to WSD principles (Mmbengwa, 2015).

Figure 5.7: Nyanga spray park

The research method involved meeting with CoCT's recreational amenities planners and landscape architects, as well as visiting the various spray parks in the city. A ranking system was developed to evaluate the parks in terms of their benefit to communities, conformation to design guidelines, effectiveness of designs, operation and maintenance issues, environmental sustainability, and integration of WSD strategies. Based on this process, it was concluded that there is a considerable need for water-based amenities such as spray parks. The use of these facilities could be improved with the inclusion of better safety features, provision of shade structures, showers and change rooms, and the addition of security measures against vandalism. The training of spray park operators in operation and maintenance procedures is critical, particularly in respect of water recycling systems. The inclusion of WSD strategies – specifically SuDS to collect, treat and store stormwater that can then be harvested for further use in the spray parks – is recommended.

5.4 Drivers / barriers to design, implementation and operation of site specific WSD interventions

A study is being undertaken to identify the drivers that encourage South African developers (both public and private) to incorporate WSD approaches, and where possible, the barriers that impede them (Ellis *et al.*, 2016). The investigation has adopted a comprehensive case study approach where 21 selected developments were reviewed against a range of different criteria. The developments were situated in five of the metropolitan areas and four small to medium sized towns and included over 25 distinct types of WSD system interventions – falling mainly into the categories of SuDS and alternative water resources. Information was collected through interviews held with relevant professionals who were familiar with one or more of the project phases including: planning, design, and operation and maintenance.

Six drivers were identified that are common in all of the reviewed case studies, including: Approval / legislative mechanisms; Institutional champions; Economic incentives (particularly in respect of perceived benefit provided to return on investments); Green Building rating; Physical constraints (such as infrastructure capacity limitations, stringent water quality standards, pre-existing and protected buildings, zoning restrictions and/or difficult site); and Sensitive environments (e.g. wetlands, dry coastal forests, estuaries):

i) *Approval / legislation mechanisms*: This refers to the development approval process presided over by municipal officials and the enabling legislation that promotes the inclusion of WSD. In South Africa, there has been a gradual increase in the presence of local legislation available to guide and enforce the implementation of WSD (specifically stormwater policy), as seen in Table 5.4 which highlights relevant policy in selected metropolitan municipalities in South Africa (note that this policy is generally limited elsewhere). Furthermore, these frameworks are almost exclusively concerned with the management of stormwater quantity; with only Cape Town and Johannesburg including stormwater quality objectives also.

Table 5.4: Stormwater GI policies and by-laws in selected metropolitan municipalities

Municipality	Stormwater quantity	Stormwater quality
Buffalo City	✗	✗
Cape Town	✓ (Policy) 2009	✓(Policy) 2009
eThekwini	✓ (Policy) 2008	✗
Ekurhuleni	✓ (Draft By-law) 2013	✗
Johannesburg	✓ (By-law) 2009	✓ (By-law) 2009
Tshwane	✗	✗

ii) *Institutional champions*: Individuals within responsible institutions that are instrumental in the uptake of WSD. Institutional champions include: corporate directors / project leaders, community leaders, engaged consultants, and proactive municipal officials. The latter example differs from the approval / legislation driver as it represents an individual in a specific catchment who has taken it upon him/herself to engage with the various project professionals to achieve a solution that goes beyond the basic approval / legislation requirements.

iii) *Economic incentives*: This refers to the uptake of WSD due to the perceived benefit provided to return on investments (RoI). Examples of this include: adding value to the asset though the incorporation of green infrastructure with high amenity and/or recreational value; and 'doing the right thing' from the perspective of environmental stewardship and the associated benefits achieved through Socially Responsible Investment (SRI).

iv) *Green Building Rating Tools (GBRT)*: This refers to implementation of WSD resulting from an intent to achieve sufficient points to secure the desired green building rating through fulfilment of stipulated water credit requirements. It is important to note that certified green buildings may provide economic incentives but in this investigation the link to GBRT was considered separately due to the specific inclusion of WSD (and specifically stormwater) credit requirements. Such requirements are often very similar in both prescription and format to those stipulated in legislation but are generally less sophisticated due to the need to assign discreet points to each parameter. These tools include: the Green Building Council of South Africa's (GBCSA) Green Star; and the United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) tools.

v) *Physical constraints*: Any site specific physical constraints that lead to the adoption or promotion of WSD. Such constraints include: downstream infrastructure capacity limitations that prompt the need to better manage stormwater and/or wastewater onsite; space restrictions that limit the use of centralised management facilities and promote the inclusion of source controls and/or treatment trains; stringent water quality standards that encourage at source infiltration controls; pre-existing and protected buildings; and difficult site locations that encourage greater onsite management due to the potential danger that the development may pose to neighbouring properties.

vi) *Sensitive environments*: Downstream environments that are dependent on the continued supply of surface and groundwater of appropriate quantity and/or quality coming from a particular site or precinct. Sensitive environments include: wetlands, dry coastal forests, and conservation areas, although many other examples could also be included.

The identified drivers and barriers were compared within differing geographic, legislative and land-use categories in an attempt to better understand the main influences. Preliminary findings point to the importance of proactive municipal officials (Institutional champions), with supporting legislation only being effective when such personnel are involved. In cases where proactive officials are present without legislation, other site specific drivers such as Physical constraints or Sensitive environments can be used as effective enforcement measures. Additionally, approval conditions for developments in environmentally sensitive areas can lead to the inclusion of WSD options. Green Building rating is often used as a driver in cases where approval / legislation drivers or economic incentives are not present, but there are current shortfalls in the format of the tools (i.e. too little focus on water management) which could potentially result in the low adoption rate of WSD interventions like SuDS and the inclusion of alternative water sources that may be overvalued in terms of their perceived economic benefit.

Appendix C includes an example of an ongoing WSD design process in the Liesbeek River catchment, Cape Town, and is included here as a working example of the type of planning / design process and associated stakeholder engagement that is required to develop WSD objectives in a particular precinct in a city.

6. Conclusions and recommendations

The various elements contributing to the current water ‘crisis’ in South Africa – including climatic factors (e.g. droughts and flooding), urbanisation and population growth, increasing water demand, over-reliance on stressed surface water resources, and deteriorating water quality – are prompting a change in the way water is managed in urban environments. In particular, alternative approaches to conventional water management which aim to facilitate a change from ‘water-wasteful’ to ‘water-sensitive’ environments are being sought.

6.1 Findings from intensive catchment studies – Liesbeek River and CFA

Several model-based feasibility studies – mostly in the Liesbeek River catchment in Cape Town – have been undertaken as part of this research effort in an attempt to determine whether the implementation of a Water Sensitive Design approach will start to address issues of water security in South Africa. These studies have provided useful lessons and evidence for the potential for water sensitive management within South African cities – for example, in terms of the opportunities for using stormwater and groundwater storage infrastructure to deal with water scarcity / drought, as follows:

- Rainwater harvesting (RWH) could meet a significant portion of total water demand but is, in general, not viable in South Africa except where a property has a relatively high demand for water.
- Stormwater harvesting (SWH) may be a viable alternative water resource, dependent on the scale at which it is implemented, the end use for which it is used and the population density that drives the water demand. This does not mean that development needs to always include stormwater harvesting, but a long-term view needs to be adopted, one that recognises that in the future there may be a need to harvest stormwater. Development should thus carefully consider the following:
    - Whether SWH is a viable option for meeting non-potable water demand – this includes recognising the potential benefits that SWH might offer.
    - The location of public open space within future developments, to ensure that an adequate area is located in the lower reaches of the watershed(s) being developed – and not at the top of the watershed, as is the case in the Liesbeek River catchment. This will allow for the future development of WSD systems – SuDS or SWH.
    - Properties should be developed in such a manner that the plumbing systems are designed to accommodate dual reticulation if necessary.
    - Water services authorities and/or local authorities should develop the necessary regulations and guidelines to regulate the use of harvested grey- / rain- / stormwater.
- Water Efficient Devices (WEDs) have a significant impact on reducing total water demand. The economic viability of WEDs is still under consideration, however

international experience suggests they are among the most economic (financial perspective only) WSD technologies.

- Greywater harvesting (GWH) could significantly reduce water demand – specifically outdoor demand. It is however worth noting that the ability of GWH to meet outdoor demand could be reduced if WEDs are implemented. This also highlights the need to promote indigenous and/or waterwise gardening. The economic viability of GWH is still under consideration.
- The use of groundwater stored within aquifer systems such as the Cape Flats Aquifer (CFA) is another water resource option that shows significant potential in certain areas of the country. However, if an aquifer becomes actively managed through recharge and flood control, and is used as a 'fit for purpose' water resource, then the ecological risks will need to be understood, as well as the implications for supporting and improving ecological services within the relevant urban areas.

If these options are considered sufficiently early on in any design process – in association with the planning for potable water and sewage treatment systems – WSD could potentially provide urban areas in South Africa with supplementary sources of non-potable ('fit-for-purpose') water and/or alternative sources of potable water, thereby reducing the demand for potable water. This in turn, may assist in ensuring that all South Africans have access to sufficient water, in line with the Constitution (RSA, 1996), and could contribute to improved health outcomes for the country as a whole as a result of increasing the provision of water at determined service levels. Conversely, due consideration must be taken of the potential health risks associated with alternative water resource use; although this can be countered with the proposed / desired 'fit-for-purpose' uses of the water, and the fact that further treatment processes can be put in place if necessary.

Proper design (including pre-treatment where necessary), maintenance and operation of WSD systems (and specifically SuDS) is crucial – and in particular, there needs to be far better control over the installation of these systems. Failure to properly consider the options may result in WSD becoming an uneconomical (e.g. through the cost of land acquisition) or impractical (not possible to move development) option. This would result in the need to consider other options that are less desirable.

The catchment studies have also raised the issue of utilising WSD to ultimately take urban areas 'off the water grid' and for towns and cities to start operating within the limits of their existing water resources; i.e. to begin to manage and use these urban areas as catchments. In Cape Town, for example, the average annual amount of rain that falls on the city equates to almost three times that of its potable water demand; however, innovative ways of storing this rainwater will need to be found if it is to be used as resource. Also, the management of water has to encompass all aspects of the urban water cycle, including water supply, sewerage and stormwater management, so that water of different levels of quality can be made available for a range of 'fit-for-purpose' uses and the demand for potable water is thus reduced. In this regard, the new element of sanitation as a resource ('waste to wealth') also needs to be considered as a lever for WSD. This is not only in terms of reducing water use through dry sanitation or low-flush options for waterborne sanitation , but also in terms of other resource capture options such as nutrients, energy, etc.

It appears that the potential value capture from WSD is not yet being emphasised in spatial planning decisions, nor are planners sufficiently aware of the positive role of sustainably-managed stormwater and river systems – although there are examples of property owners funding the SuDS maintenance required because they want high levels of service in their area and recognise the value of these assets.

Finally, the use of catchment-based modelling studies – including the calculation of water balances – is critical in terms of supporting a transition to water sensitive towns and cities. This again emphasises the importance of monitoring information and data availability.

6.2 Overall conclusions

Research activity on sustainable urban water management practices, urban river restoration, integrated urban water management and new theories on governance has been growing in South Africa in recent years, and it is now widely acknowledged that urban water issues are complex and can no longer solely rely on the input of particular technologies. The implementation of WSD at local, site or city-scale, requires much more than just the careful design, operation and management (including monitoring) of separate WSD infrastructure elements. It also requires the involvement of and consultation with relevant stakeholders and officials (e.g. through the development of Communities of Practice and the setting up of Learning Alliances), so as to explore new ways of thinking based on the knowledge and experiences of a wide range of participants, and to deal with any potential conflicts of interest that may arise specifically from a lack of understanding and ability to interpret WSD systems as a whole.

In order for WSD to become entrenched in water services planning in the country, the institutional and technical linkages that have been highlighted by way of the research will need to be translated into policy and organisational structures. This is especially important when considering the trade-offs between managing water as a resource (the central tenet of WSD), and protecting biodiversity and human health; for example, including more SuDS features will necessarily change the form and maintenance requirements of stormwater ponds and other drainage infrastructure, thus necessitating changes with respect to the way these features are operated and maintained. Institutional acceptance is thus critical, as the more landscaping that is involved, the less it appears as an 'engineered solution' (even though there is often very precise engineering involved), and the less effort is put into maintaining it by the municipality. SuDS features must form part of the municipal engineering maintenance schedule, and be budgeted for accordingly. There is also the issue of different perception of green space and open bodies of water, particularly amongst low-income groups who may find these areas undesirable (from a safety / health risk point of view). Trade-offs may thus also be required when determining the best use of resources either for addressing development and equity issues, or for developing multi-functional urban areas that are resilient and adaptable to change. It is important to note that by including ecological infrastructure in the design of urban spaces, natural ecosystems can assist in recreating catchment (i.e. water capture and storage) conditions and improving water quality, as well as enhancing and improving the liveability of towns and cities (e.g. through reducing urban heat island effects and mitigating storm intensities).

The challenges with WSD implementation in the context of municipal planning are mainly as a result of: institutional and planning fragmentation and power dynamics within local authorities; a mindset of lack of resources and time constraints; the traditional planning and engineering paradigm not being suited to current complex water issues (for example, the fact that stormwater is viewed as a threat to roads infrastructure); and an overall resistance to change. This study has shown that Water Sensitive Design has the potential – through relatively modest interventions – to change the way in which water is managed in South Africa so as to increase sustainability and develop resilience within water systems. It is acknowledged, however, that embedding a new paradigm such as this will take time, and will be dependent on local-level knowledge and the appropriate 'champions' with some level of recognition and political acceptance to take it forward.

6.3 Recommendations for implementing WSD

As has been made clear throughout this report, the WSD feasibility assessment that was undertaken as part of this study was dominated by the mostly-technical catchment studies, and the policy, legislative and organisational / behavioural change aspects which are essential to implementing WSD were largely omitted. Drawing on the South Australian Government's position on WSUD 'targets' for new developments in their document entitled, 'Creating more liveable and water sensitive cities in South Australia' (DEWNR, 2013), the following key actions are suggested as central to speeding up implementation and ensuring the feasibility of WSD in South Africa:

- Establishing clear and consistent objectives and targets for WSD with regard to new urban developments and infrastructure;
- Ensuring stronger linkages between the urban development and planning system and urban water management;
- Ensuring a consistent approach to WSD across all relevant government policy areas;
- Establishing processes for national and local government leadership in adopting WSD principles in its own developments;
- Providing local government and private sector support by building capacity and skills through an ongoing capacity building initiative;
- Supporting ongoing research into WSD approaches and impediments;
- Establishing arrangements for ongoing monitoring and assessment to demonstrate the benefits of WSD are achieved and sustained over the long term.

It is suggested that a similar publication to this one, that is easily transferable and useful for officials, be developed for the implementation of WSD in South Africa.

Based on these recommended actions, and specifically in respect of the South African context, the following is recommended as a way forward for implementing Water Sensitive Design more broadly in this country:

- WSD should be incorporated into the overall regulatory structures of local authorities, including future Integrated Development Plans (IDPs), Spatial Development Plans (SDPs), Water Services Development Plans (WSDPs), bylaws and policies – and taking into account oversight and accountability mechanisms.
- An integrated 'Water Sensitive' strategy and/or Plan and associated targets – with resilience as the main focus – should be developed for all towns and cities, and should link to the WSD framework and guidelines (Armitage *et al.*, 2014). This plan should include all aspects of WSD, with a specific focus on Water Conservation and Water Demand Management strategies.
- The concepts of WSD / SuDS (and their focus on resilience) should be included in the Guidelines for Human Settlement Planning and Design, the 'Red Book' (CSIR, 2001) currently under review.
- The integration of departments dealing with water and spatial planning – at both site and regional scale within local areas – is critical to ensure that planning support for WSD options is secured, particularly in respect of greenfield development.
- WSD / SuDS and other green infrastructure elements within urban areas should be included in local authority asset registers, and provision made for suitable design, installation, operation and maintenance of these elements (in terms of budget allowance as well as available capacity).
- The implementation of all new WSD / SuDS systems should make provision for the monitoring (and benchmarking where appropriate) of these systems, – so that a better understanding is created of the way in which they perform.
- One of the key challenges to urban water reform is the disconnect between water systems and the people served by them – engaging residents / communities is therefore crucial in order to effect the behaviour change needed to implement WSD.
- Use the existing WSD Community of Practice (CoP) programme to generate increased understanding about innovative practices and reflexive learning within WSD in South Africa, and to develop knowledge connected to policy development and change to influence planning and design towards water sensitive cities.

6.4 Recommendations for future research

The study has highlighted several gaps in the knowledge and potential areas of follow-on research in this field, as follows:

- A detailed review of the institutional challenges associated with implementing WSD into the planning and implementing environment. This should be used to develop knowledge connected to the national, local and inter-governmental policy environment required to influence planning and design for WSD in South Africa. The research should also include consideration of existing or potential supporting strategies, such as Water Use licence conditions (Department of Water & Sanitation), and the environmental approvals required by the Department of Environment Affairs.

- Consideration of the impact on each of the various highlighted WSD options on the efficacy and viability of other options when adopted alongside other WSD practices. This could be significant, as the evidence from the RWH and SWH study showed that the cost per kilolitre increased if both SWH and RWH were implemented together. This is owing to the fact that there is reduced demand but only a limited reduction in total cost. There is a need to consider not only the cost per kilolitre, but also the total cost per household as well as the economic implications for the local water authority.
- Investigate how the principles of WSD could inform spatial planning decisions – this could potentially form the basis for a series of development dialogues / workshops dealing with issues such as: holistic city planning; dealing with complexity; cross-sectoral development; and tensions between site and local-level planning.
- Consider how much investment in WSD practices there is in terms of Corporate Social Investment projects, particularly those linked to BEE scorecards – for example, are companies able to score points which could add value to their business; and could this be a driver for implementing WSD? Can Green Accounting be used to promote the notion of WSD? The creation and distribution of the value from WSD needs to be taken into account – WSD should be implemented in areas where there is potential for high value capture.
- Investigate the interplay between surface and groundwater in many areas. Using aquifers as temporary storage (e.g. for stormwater or treated wastewater) may work in some places – such as Atlantis, Western Cape – but not in others, and the implementation of such schemes therefore need to be carefully considered. Similarly, the science of managing the process and risks to the integrity of natural wetland and surface systems is not well understood. There is potential to manage the recharge and to extract water in a managed aquifer approach, but the impact on surface water systems and ecological services requires further research and analysis. Assessing these interactions can also help to identify points of interaction for monitoring nutrients (specifically movement through the aquifer) which may influence WSD – an in depth study on quantifying / determining interactions in relation to WSD is required.
- Evaluate the treatment capability of various WSD / SuDS infrastructure options and strategies in different environments; including, *inter alia*: biofiltration cells, sand filters, and real time control (RTC) of stormwater ponds / wetland systems.
- Investigate different participatory approaches to the design and development of water sensitive building and precincts – including people's interests, values and perceptions.
- Investigate the social externalities (intrinsic value) linked to the ecosystems services that are provided through the implementation of WSD.

- Develop design guidelines for WSD / SuDS implementation, operation and maintenance.
- Evaluate the contribution of hydrogeological information in terms of implementing WSD.
- Evaluate the opportunities for determining thresholds for water sensitive planning within urban areas; create a benchmark of settlement size that requires a different approach in terms of water sensitive planning. Current stormwater master plans are linked to the local authority's governance and institutional structure (e.g. within Roads departments); consider alternative structures as part of a Water Sensitive approach.
- Assess the impact of the heat-island effect on the incidence of short-intensity storms within cities – and the potentially positive influence of green infrastructure.
- In order to assess the possible impact of variations in climate on WSD, conduct a comparative assessment of the potable water savings that could be achieved through implementing the use of various alternative water sources – across a range of suburb types and climatic conditions.

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Appendix A

Catchment study – Liesbeek River, Cape Town

A1 Baseline assessment

A1.1 History of the Liesbeek River catchment

The Liesbeek River catchment is situated on the eastern slopes of Table Mountain in the City of Cape Town (CoCT) (Figure 4.1) (Evans, 2007; Robinson, 2011). The Liesbeek River was 'discovered' by European settlers on the 28 April 1652. Jan Van Riebeeck – commander of the Dutch settlement – described it as '*the loveliest of fresh rivers*' (Murray, 2003). Initially, it was named '*Varsche*' and subsequently the '*Soete'* and then the *'Amstel*'. Finally, by 1657, Van Riebeeck had settled on the name '*Liesbeek*'. The Liesbeek River catchment is approximately 2,600 hectares in extent and is the oldest urbanised river valley in South Africa (Evans, 2007). The river itself is approximately 9 km long and is fed by numerous streams running down the eastern slopes of Table Mountain (Evans, 2007; Brown & Magoba, 2009; Robinson, 2011).

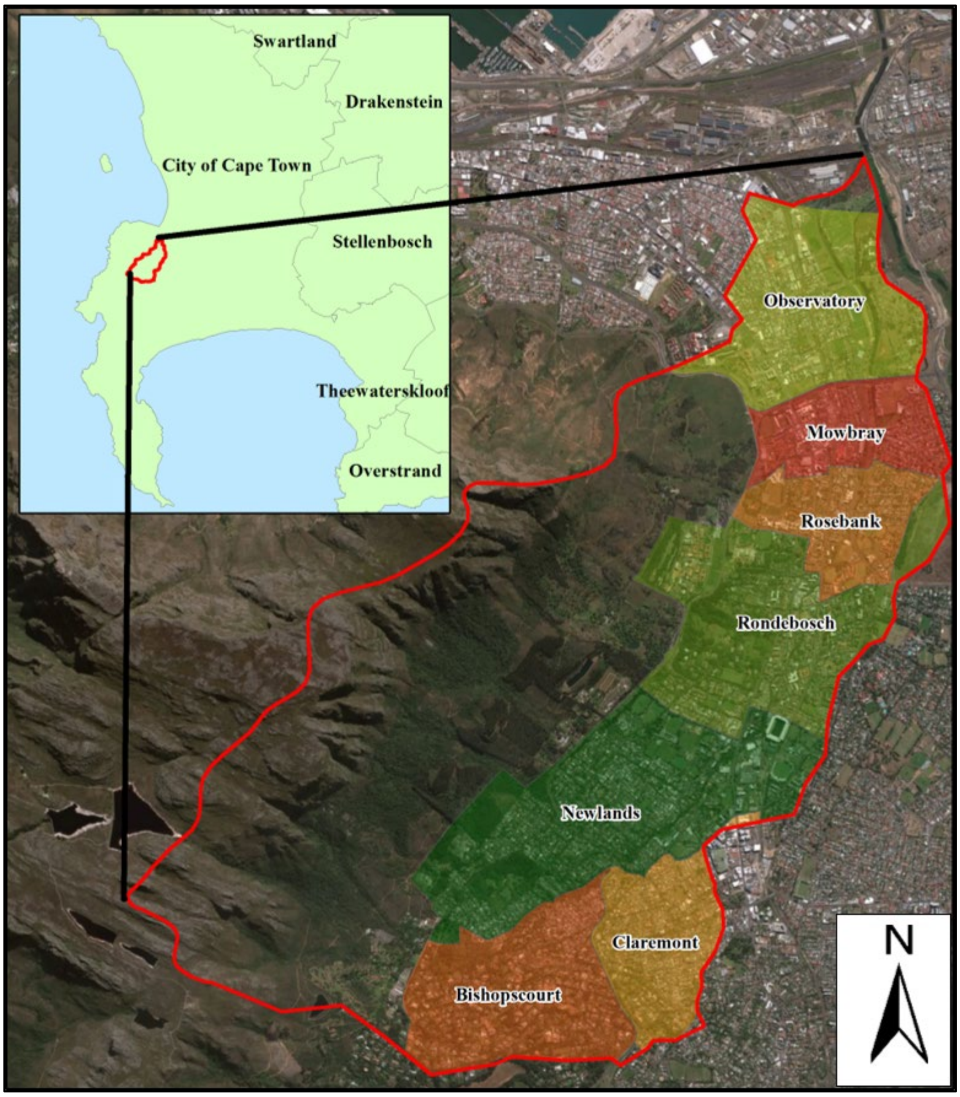

Figure 4.1: Liesbeek River catchment

When Van Riebeeck began setting up the first European settlement in the Cape, there was no intention to develop a colony. Instead, he was tasked with setting up a defensible fort, acquiring fresh water, planting fresh produce and bartering with the local inhabitants – Khoi-Khoi – for sheep and cattle. However, as a result of tensions with the Khoi-Khoi and the growing population of settlers, it became difficult to meet demand. A decision was made to expand the settlement (Robinson, 2011). In February 1657, the first real colony was established along the Liesbeek River at Rondebosch by nine of the Company's servants who were discharged from Company service and were allotted parcels of land, approximately 8.6 hectares each (Brown & Magoba, 2009; Robinson, 2011). In this manner, the colonisation of South Africa was begun (Badlam, 2011).

As the settlement grew into a colony and the colony expanded, infrastructure such as railways was put in place. This ultimately led to the draining of the marshland, which disturbed the '*natural conditions of the watercourses and created an artificial canal on a new route*' (Murray, 2003). In the first half of the twentieth century, flooding started to become a serious problem in the Liesbeek River catchment as a result of increasing urbanisation. Consequently, between 1942 and 1962, large portions of the Liesbeek River were canalised.

Currently, the river is highly impacted by urbanisation. In total, approximately 50% of the catchment is urbanised – with the balance taken up by the Kirstenbosch Botanical Gardens, forestry plantations and the Table Mountain National Park. Six of the CoCT's suburbs are either partially or entirely located within the Liesbeek River catchment (Figure 4.1). The lower reaches of the river have the highest levels of urbanisation within the catchment. Since 1990, there have been many initiatives to re-establish aquatic life and improve the aesthetics of the river (Evans, 2007; Brown & Magoba, 2009). These attempts have largely been localised around the banks of the river and have not targeted the catchment as a whole. While there is evidence of gradual densification in the catchment, in the form of new blocks of flats being constructed in place of former free-standing houses, the catchment as a whole has shown no signs of significant change in the last 14 years.

A1.2 Land use, property value and income in the catchment

The diversity of land uses found in the Liesbeek River catchment is illustrated in Figure A.2 (whole catchment) and Figure A.3 (urbanised part of the catchment) and is expressed as a percentage of area occupied by each. Only 50% of the catchment is effectively urbanised; the other 50% is made up of 'conservation and nature areas' (43%) and 'urban open space' (7%). Within the urbanised part of the catchment, the southern end (Bishopscourt) consists almost entirely of general residential suburban households. Throughout the rest of the urbanised part of the catchment, general residential properties are interspersed with blocks of flats, educational institutions and community facilities. Commercial activities are largely focused around Main Road which runs the length of the catchment – see Figure 4.4.

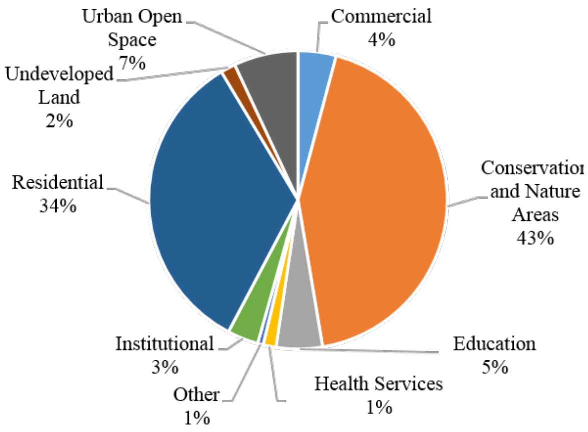

Figure A.2: Breakdown of land use in the Liesbeek River catchment overall

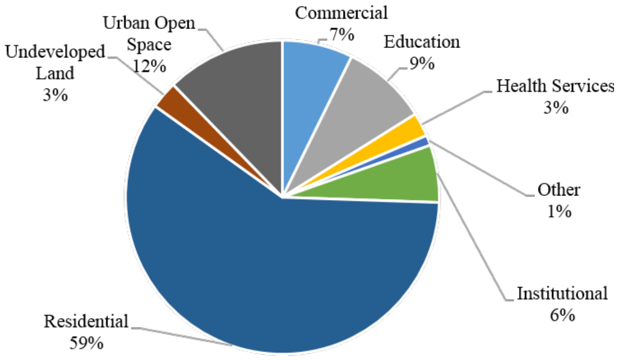

Figure A.3: Breakdown of land use in the urbanised area of the Liesbeek River catchment

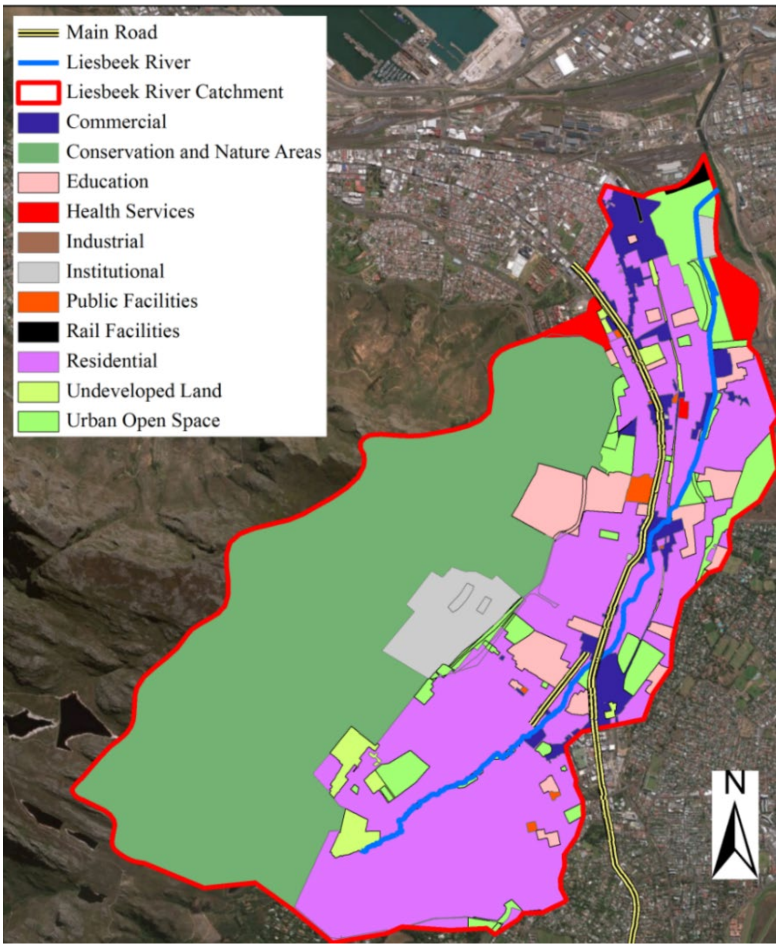

Figure 4.4: Land use in the Liesbeek catchment

According to StatsSA (2013), the Liesbeek River catchment had a population of approximately 31,000 people in 2011. The population was, and continues to be, unevenly distributed across the catchment. Bishopscourt, the most affluent suburb, has a density of around four people per hectare, whereas most of Rosebank, Mowbray and Observatory have a density of between 40 and 60 people per hectare. In areas where there are university residents and/or blocks of flats, the density reaches a maximum of 300 people per hectare. Table A.1 presents typical property value and household income from the property valuation data available from the CoCT (CoCT, 2012a) and household data from Census 2011 (StatsSA, 2013), respectively.

Table A.1: Overview of land use data within the Liesbeek River catchment

Suburb	**Average erf size (m^2)**	**Median Household income (2011ZAR/yr.)**	**Median property value (2012ZAR)**	**Median property value (2012ZAR/m^2)**
Bishopscourt	3,200	697,000	8,000,000	3,800
Claremont	870	493,000	3,730,000	5,700
Mowbray	470	243,000	1,490,000	3,600
Newlands	920	535,000	3,600,000	5,300
Observatory	280	188,000	1,190,000	5,100
Rondebosch	590	268,000	2,510,000	4,400
Rosebank	650	179,000	2,510,000	4,400

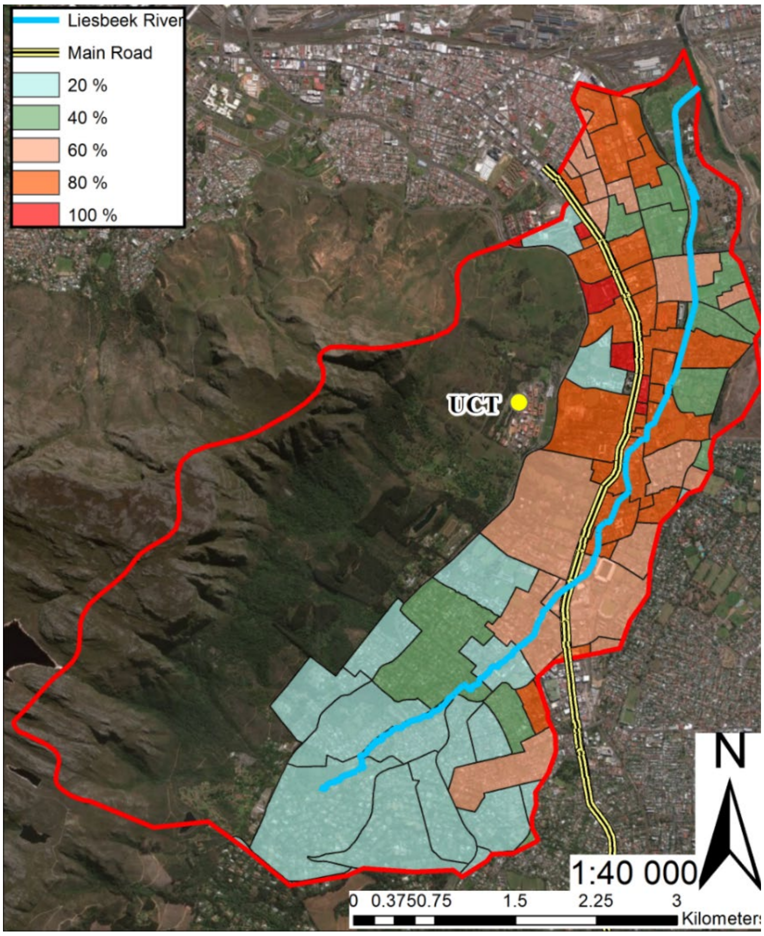

Figure A.5: Percentage of households renting properties

Owing in part to the presence of the University of Cape Town (UCT) within the catchment, as much as 80% of the residential accommodation in the middle to lower parts of the catchment is rented – mostly by students – as shown in Figure A.5. This is important as it raises questions as to the social acceptability of WSD technologies, such as rainwater harvesting, within the catchment – there is likely to be much less incentive for people renting properties to make savings compared with property owners. As noted by Fletcher *et al.* (2008), the success and the mitigation of the risks associated with WSD is dependent on the knowledge and commitment of the user, which in this case would often be the person renting the property, not the owner. Whether people who pay rentals that often include the supply of potable water would accept and use alternative water sources, such as rainwater, needs to be carefully considered through an in-depth social study.

A1.3 Rainfall and evaporation

The CoCT has a Mediterranean climate characterised by mild, wet winters and dry, warm summers (Rohli & Vega, 2011). The average rainfall in the CoCT is 515 mm/yr. (WMO, 2014); however, rainfall and evaporation are highly variable across the CoCT owing to the presence of mountainous topography within the City's boundaries. The Liesbeek River catchment specifically, is affected by the presence of the Peninsula Mountain chain to the west. Within the Liesbeek River catchment, the maximum annual rainfall (1500 mm/yr.) is more than double the minimum (600 mm/yr.) – see Figure A.6. While less significant, evaporation also varies – in this instance, between 1300 mm/yr. and 1550 mm/yr. across the catchment – see Figure A.6b. This large variation in rainfall and evaporation has the potential to significantly affect the viability of WSD technologies within the catchment.

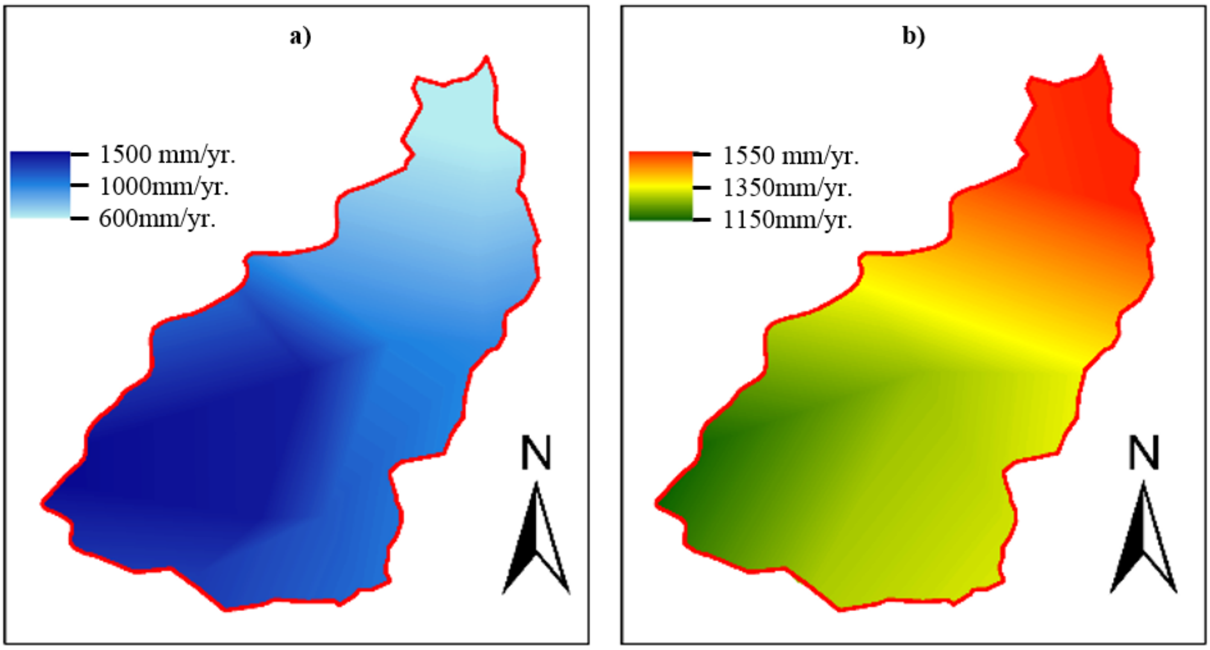

Figure A.6: a) Annual average precipitation and b) annual average evaporation across the Liesbeek River catchment

A1.4 Water demand

The preliminary water balance indicated that the Liesbeek catchment used approximately 6320 Mℓ of potable water annually; 2% of Cape Town's total annual water consumption. Figure A.7 shows the breakdown of total water demand in the catchment by land-use. The chart highlights the volume of water used by each land-use category, as well as their relative contributions to the total catchment water demand. 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 used about 3340 Mℓ/yr, nearly 53% of the catchment's total water demand. The relative proportion of domestic water in relation to the total catchment water demand was similar to the 59% estimated for the entire Cape Town metropolitan area (CoCT, 2011). The non-domestic water requirements in the catchment were significantly lower; the commercial, hospital and education sectors used 841 Mℓ/yr, 818 Mℓ/yr, and 747 Mℓ/yr respectively, and community facilities had the lowest annual water demand with 579 Mℓ/yr.

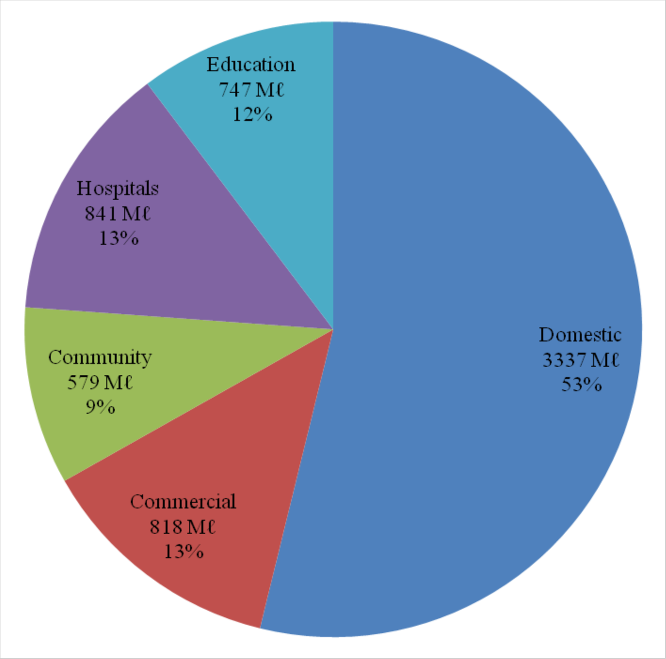

Figure A.7: Total water demand in the Liesbeek catchment according to land-use

Hospitals make up a significant proportion of the non-domestic demand, despite the fact that there were only three major hospitals in the entire catchment: Groote Schuur, Mowbray Maternity, and Valkenberg. The high demand was a result of the Groote Schuur hospital, which used nearly 643 Mℓ of potable water every year, 10% of the catchment's total water demand.

Domestic water demand varied significantly across the catchment, as shown in Table A.2. The water consumption per household was relatively low in the south of the catchment; this section of the catchment consisted almost entirely of low density general residential properties. The heavily urbanised areas in the centre of the catchment show significantly higher water demand in comparison to the residential suburbs. The high demand can 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. Non-domestic land-uses generally accommodate greater numbers of water users on a daily basis, leading to higher water consumption rates. The individual contribution of domestic households appears to be fairly low, however given the number of residential properties in the catchment, domestic water use makes up the majority of the catchment's water demand.

The distribution of outdoor water use is 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 are far smaller and do not have large gardens meaning that outdoor water demand is fairly low. Some of the larger properties in the catchment show little or no outdoor water demand; these properties were known to have boreholes on-site and it was assumed that these properties satisfied any outdoor water requirements by means of borehole water. This was particularly common for schools and sports grounds which require large quantities of water to irrigate fields.

Table A.2: Per-capita indoor water demand by suburb

Suburb	**Estimated indoor AADD (*l*/cap.day)**
Bishopscourt	260
Claremont	280
Mowbray	220
Newlands	260
Observatory	180
Rondebosch	210
Rosebank	240

A1.5 Dry weather flow in the river

The CoCT owns and maintains a number of continuous flow monitoring stations in rivers across Cape Town. These have been in operation for many years. Two of these flow monitoring stations (Lies03gS and Lies03hS) are located in the Liesbeek River. Unfortunately, although the stations were installed many years ago, they have not been maintained on a continuous basis and so data were only available for a period of 13 months (September 2012 to October 2013) at one of the stations (Lies03hS) whilst another station (Lies03gS) was clearly giving false data (constant readings). As a result, only Lies03hS was available for the calibration of the flow model. Fortunately, this gauge was located in the lower reaches of the catchment – see Figure A.8.

Using *PCSWMM*'s monthly and daily 'pattern' analysis tool, estimated monthly dry weather flow (Table A.3) was calculated from the observed flow data for days without precipitation. The dry weather flow included groundwater inflows, infiltration and inflows from the stormwater sewer network – which was observed to include swimming pool backwash water, car washing, runoff from cleaning at construction sites, and intermittent discharges for industry (South African Breweries) located on the banks of the river. The calculated flow was weighted across the nodes used to model the main Liesbeek River channel in *SWMM*, and assigned to the nodes as external inflows.

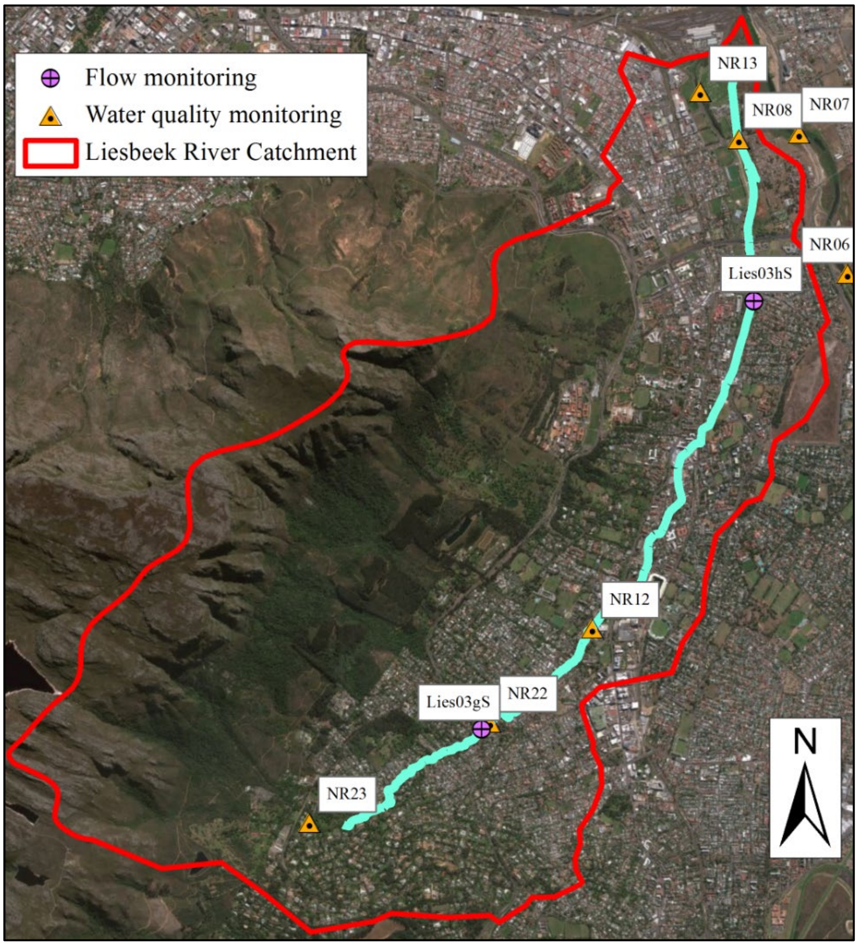

Figure A.8: Water quality and flow monitoring stations

Table A.3: Average monthly dry weather flow in the Liesbeek River at Lies03hS

Month	**Flow (m^3/s)**	**Month**	**Flow (m^3/s)**	**Month**	**Flow (m^3/s)**	**Month**	**Flow (m^3/s)**
January	0.246	April	0.333	July	0.797	October	0.583
February	0.112	May	0.313	August	1.004	November	0.374
March	0.081	June	0.869	September	1.127	December	0.345

A1.6 Potential effects of climate change

The analysis of rainfall and evaporation was undertaken considering the predicted changes in the average monthly data between the period 1979-2012 and the period 2050-2099, suggested by a selection of downscaled climate change models. A total of 31 climate change scenarios (see Fisher-Jeffes (2015) for details) that represented intermediate and high-emission scenarios were considered. A number of trends were evident and determined to be relevant to this research; they are highlighted in the following figures.

Figure A.9 illustrates the current average monthly rainfall for the Observatory rainfall station and the potential changes as a result of climate change, expressed as a percentage of current rainfall. It is evident that there are more significant changes for some months than others. Generally though, it is reasonable to expect: a decrease in rainfall for January to May; the rainfall for November, June and August to remain roughly unchanged; and July, October and December to experience slightly increased rainfall. On the other hand, the climate change modelling for the Kirstenbosch rainfall station (Figure A.10) indicates that, in general, it is reasonable to expect a decrease in rainfall for January, March, April and May; February to remain roughly unchanged; and June to December to experience slightly increased rainfall. The red line in Figures A.9 to A.11 denotes the average annual rainfall for each station.

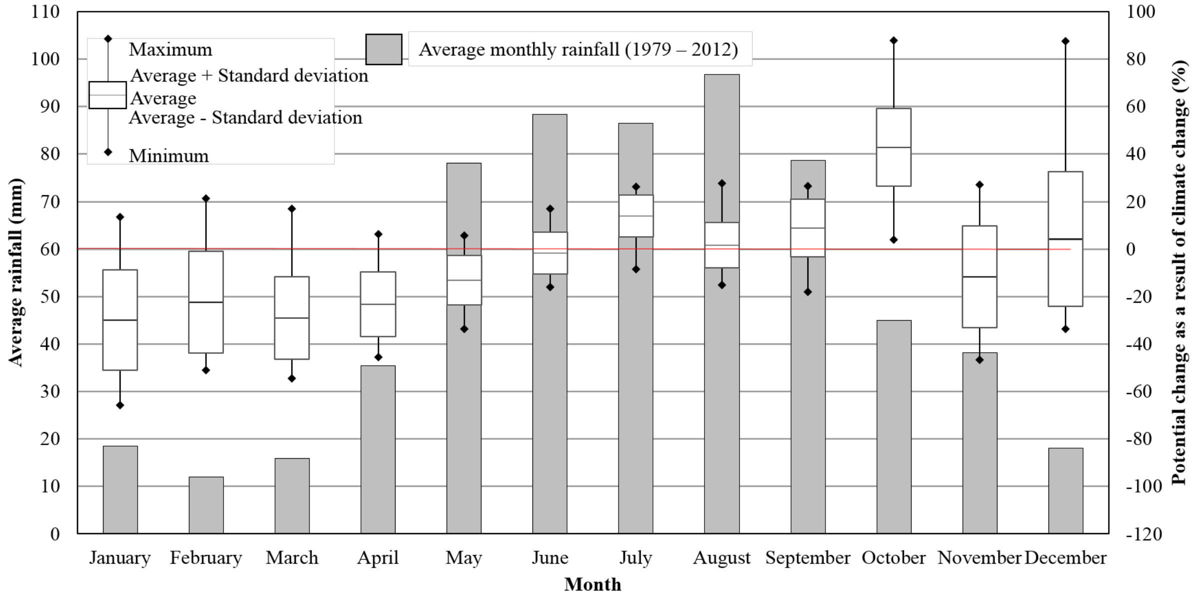

Figure A.9: Potential impact of climate change on rainfall (Observatory)

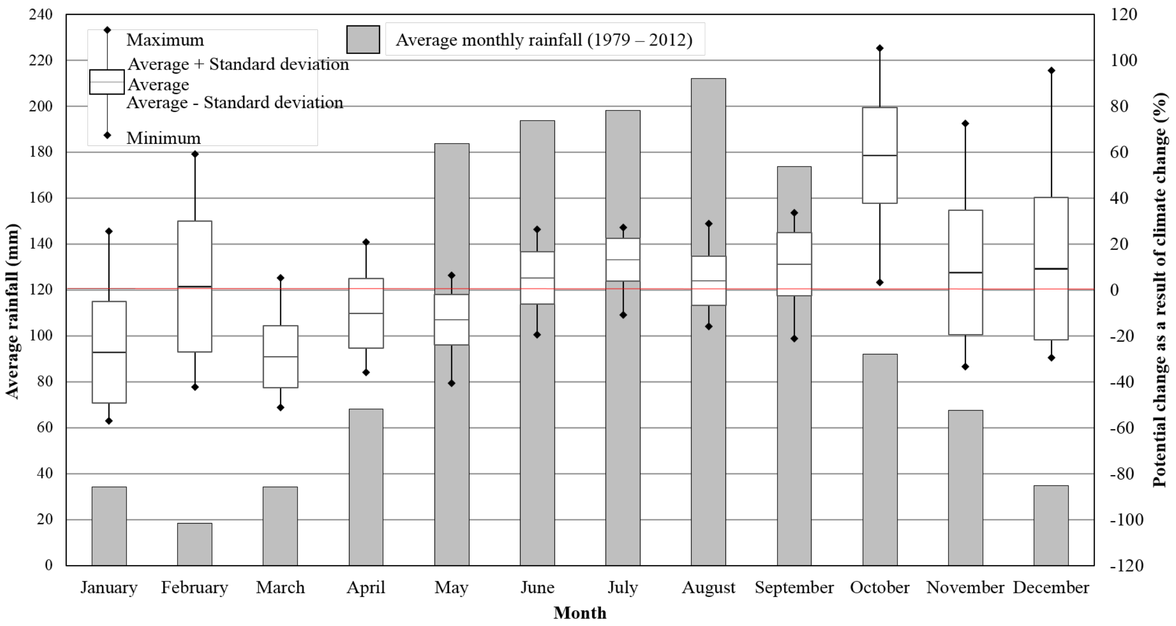

Figure A.10: Potential impact of climate change on rainfall (Kirstenbosch)

Figure A.11 illustrates the current average monthly evaporation at Observatory and the potential changes as a result of climate change (as a percentage of current evaporation). Unlike rainfall, there is a clear trend that evaporation will increase over the whole year. A similar trend is to be seen for the Kirstenbosch station.

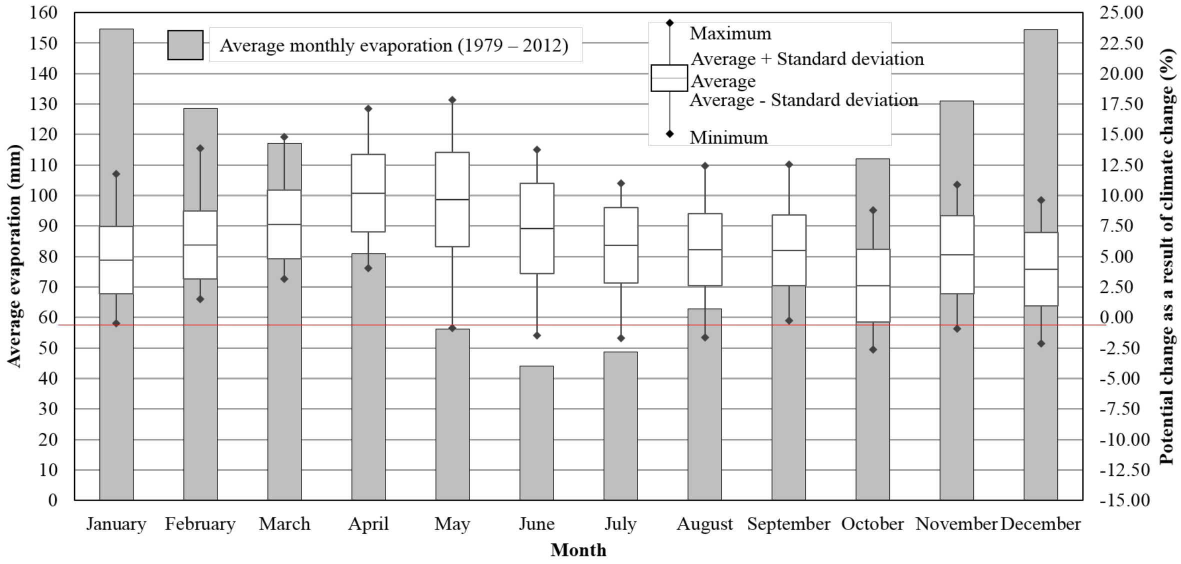

Figure A.11: Potential impact of climate change on evaporation (Observatory)

The potential impact of climate change is significant as decreased rainfall and increased evaporation have the potential to reduce runoff volumes, which could significantly impact the performance of a number of WSD systems including, *inter alia*, rainwater harvesting, stormwater harvesting, sustainable drainage systems, and greywater harvesting.

A2 Impact of modelling methods

A2.1 Modelling site scale WSD technologies: RWH

The analysis of the impact of modelling WSD systems at a site scale has at this stage only considered RWH; however, the outcomes can be used to inform how other site scale WSD systems (e.g. greywater) should be modelled.

A2.1.1 Selecting an appropriate time step

The selection of an appropriate time step had a number of important implications for this research, including the accurate modelling of a single RWH system in isolation, and the accurate modelling of RWH in the catchment as a whole. TableA.4 presents the catchment-scale results using a daily time step model. It is interesting to note the relatively minor difference in demand met (1%), cost per kilolitre (-0.9%) and volumetric reliability (1.4%) calculated using the daily and hourly time step models. There is, however, a significant difference in the percentage of dry periods calculated using the different time step models. This difference is the result of modelling at a finer time scale. For example, if half a day's demand could be met, but not the whole day's, the daily model would indicate that the demand was not completely met, and hence, the system ran dry. The hourly model could, however, indicate that, over the course of the day, the demand for 12 periods might well be met, as well as those 12 periods in which demand was not met and the system was dry. The differences in percentage collected are a result of modelling evaporation at a finer time scale, potentially allowing for the wetting and drying of the roof within a day. The system thereby realises greater losses and reduced collection.

Table A.4: Comparison of modelled performance using daily and hourly time step models at the catchment scale (using storage sizes in optimised daily time step model)

Performance parameter	Daily time step model	Hourly time step model	Difference (%)
Demand met (Mℓ/yr.)	601	596	1.0
Total storage volume (m^3)	37,965	37,965	0.0
Volumetric reliability	0.35	0.34	1.4
% dry periods	56	52	7.5
% collected	44	46	-3.1
Cost per kilolitre (2013ZAR/kℓ)	50	50	-0.9

It is important to recognise that the differences reported in TableA.4 are at the catchment scale and that, at the individual property scale, the differences in performance can be a lot more significant. Figure A.12 illustrates the range in results of modelling using two different time steps at the system scale. It is evident that there can be significant variations in the modelled performance at the system scale. For example, the performance of small systems (e.g. 0.5 kℓ) was typically underestimated. Due to the sizes of these systems, they have little impact on the catchment-scale results, but there could potentially be significant impacts on the cost of operating the system for the individual RWH system owner, since an underestimation of demand met will result in an overestimation of the cost per kilolitre.

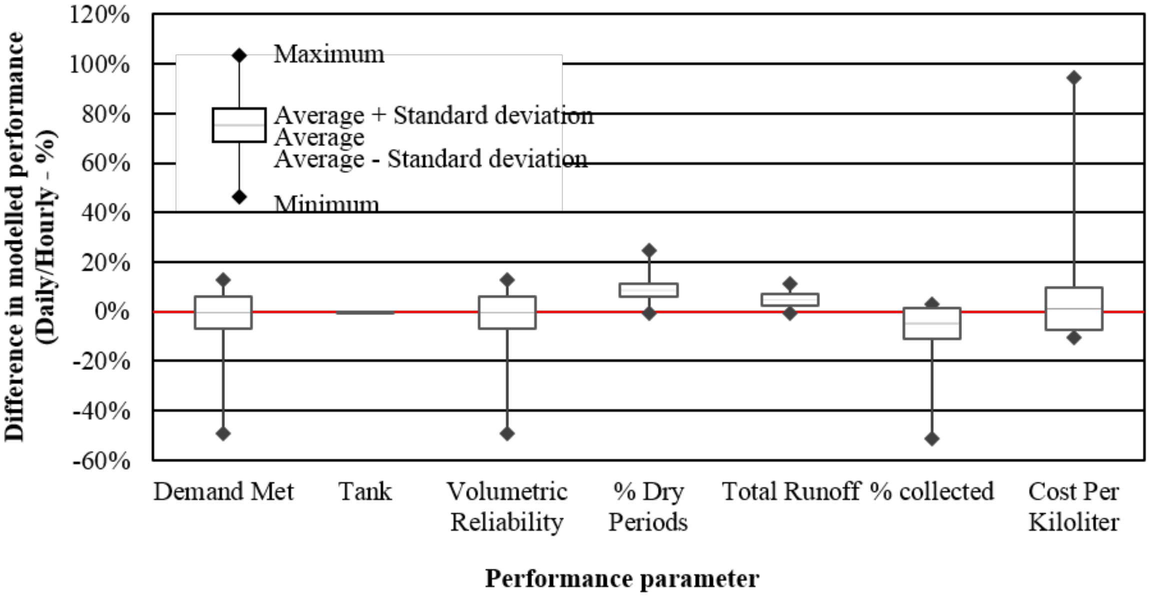

Figure A.12: Comparison of modelled performance using daily and hourly time step models at the property scale (using storage sizes in optimised daily time step model)

Differences in the modelled performance of a RWH system using the hourly and daily time steps could potentially be minor. TableA.5 presents the catchment-scale results (for water used for toilet flushing, washing machine, shower / bath, pool, and garden irrigation) based on the results of the daily / hourly time step models.

Table A.5: Comparison of modelled performance using daily and hourly time step models at the catchment scale (using storage sizes optimised by model)

Performance parameter	Daily time step model	Hourly time step model	Difference (%)
Demand met (Mℓ/yr.)	601	585	2.9
Total storage volume (m^3)	37,965	34,750	9.3
Volumetric reliability	0.35	0.34	3.2
% dry periods	56	53	6.1
% collected	44	45	-1.4
Cost per kilolitre (2013ZAR/kℓ)	50	51	-1.8

It is interesting to note the reduction in storage volume (9.3%) as well as the slight increase (compared with TableA.4) in difference in demand met and volumetric reliability, percentage collected and cost per kilolitre between the hourly and daily time step models. On the other hand, the selection of a larger or smaller time step can have a significant impact (up to 200%) on the individual system's storage. This, in turn, impacts all other performance parameters, as illustrated in Figure A.13.

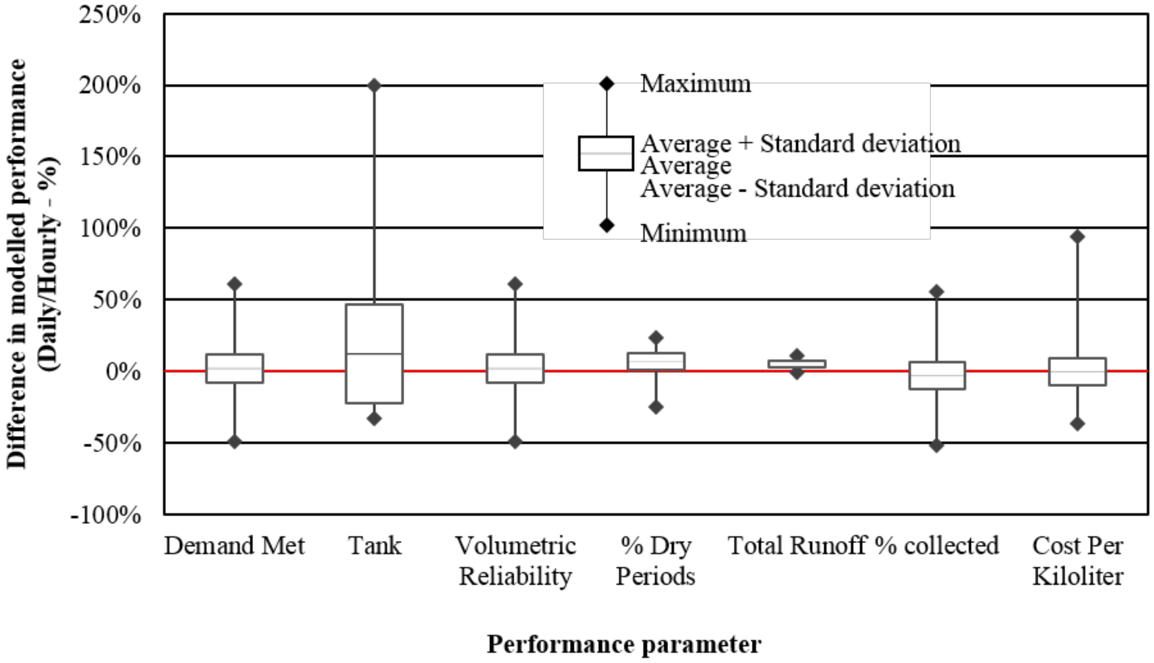

Figure A.13: Comparison of modelled performance using daily and hourly time step models at the system scale (using storage sizes optimised by model)

A2.1.2 The use of linear extrapolation

A number of studies have indicated that linearly extrapolating site-scale results for RWH could lead to potentially significant errors in the modelled performance. In line with Neumann *et al.* (2011), both the geometric mean and arithmetic means – at suburb and catchment scale – were used to estimate the average parameters for modelling a single RWH system. The performance results (e.g. demand met, volumetric reliability, etc.) were then linearly extrapolated in two ways:

i) The performance results were linearly extrapolated from the property scale to the catchment scale – termed extrapolating to the catchment scale.

ii) The performance results were linearly extrapolated from the property scale to the suburb scale according to a typical system for each suburb. The performance results from the different suburbs were then aggregated to provide catchment scale performance results. This was termed extrapolating to the suburb scale.

It was decided to investigate the impact that scaling to the suburb scale would have, as it was evident that there were significant variations in the parameters (e.g. roof area) between suburbs. It was assumed that socio-economic conditions within each suburb were homogeneous and, thus, the RWH systems would be more similar in use and operation and could potentially minimise the errors that accrue in extrapolation. Figure14 presents the error in volumetric reliability that results from linearly extrapolating to the catchment scale for Scenarios 1 through 10 using a daily time step, and for Scenario 10, modelled using an hourly time step – based on the assumption that the modelled performance, with each property modelled separately, reflects the most accurate modelling possible.

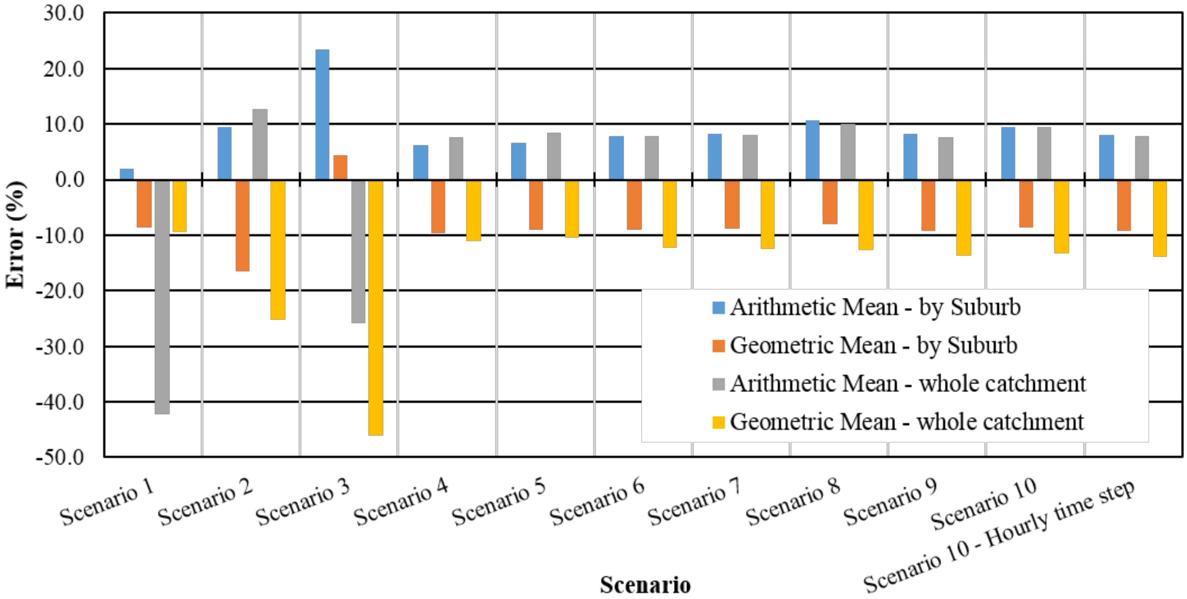

Figure A.14: Error in volumetric reliability as a result of linearly extrapolating a RWH system's performance to the catchment scale

It is evident that the use of the arithmetic mean typically results in an overestimation, while the use of the geometric mean results in an underestimation of the volumetric reliability. Also, extrapolating to the suburb scale and then aggregating to the catchment scale typically provides a better estimate of a system’s volumetric reliability than extrapolating directly to the catchment scale, whether using the arithmetic or geometric means of the input data.

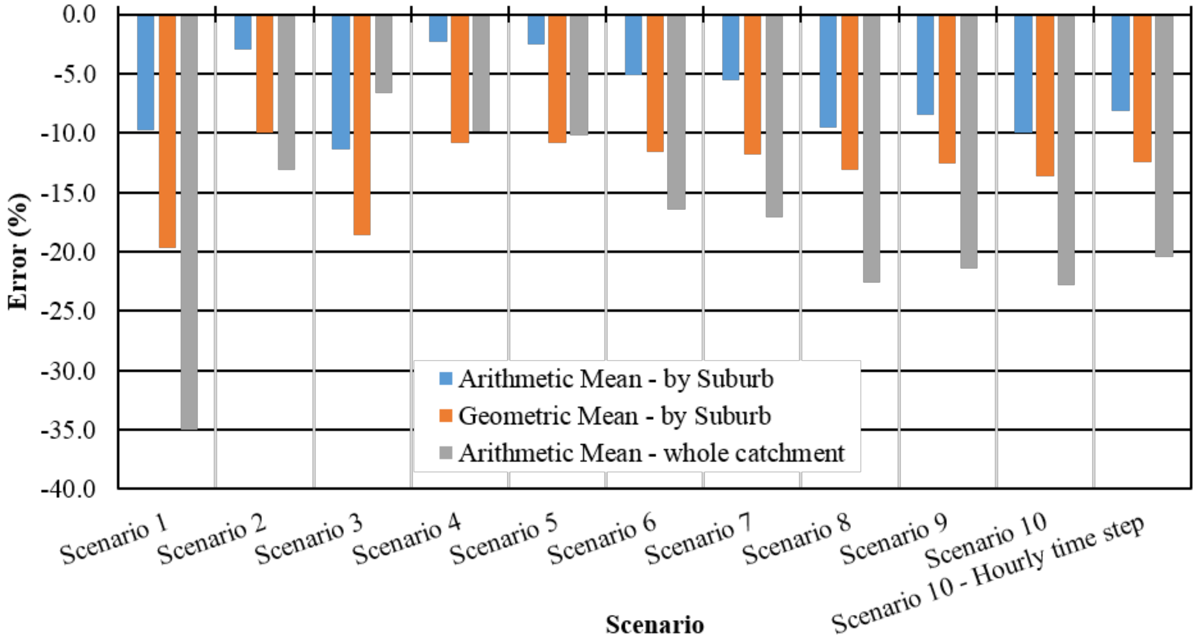

Figure A.15: Error in spillage as a result of linearly extrapolating an RWH system’s performance to the catchment scale

FigureA.15 presents the error in spillage that results from linearly extrapolating performance results to the catchment scale. It appears that linearly extrapolating the site scale results to the catchment scale can lead to a significant underestimation of spillage (3.5-35%, typically 7-18%). Using the geometric mean values to extrapolate to the catchment scale – not shown in FigureA.15 – resulted in errors exceeding 75%. The errors presented in both FigureA.14 and FigureA.15 are within the ranges of those presented in other studies.

A2.2 Modelling centralised WSD technologies: SWH

Whilst the analysis of the impact of modelling WSD systems at a local and regional scale has at this stage only considered SWH, the outcomes can be used to inform how other site scale WSD systems should be modelled. There is also limited guidance regarding the use of either the 'yield after spillage' (YAS) and 'yield before spillage' (YBS) operating rules when modelling SWH systems.

A2.2.1 Selecting an appropriate time step and storage algorithm

The selection of an appropriate time step has a number of important implications for this research, including the optimisation of an SWH system, the accurate modelling of a single SWH system in isolation and the accurate modelling of SWH in the catchment as a whole.

It is generally accepted that the YAS algorithm is most appropriate for modelling RWH systems and provides conservative results. There is, however, limited guidance when modelling SWH systems. Roebuck (2007) noted that for a larger system (to service communal buildings) the use of the YAS approach was not fully vindicated. Mitchell *et al.* (2008) noted that the storage capacity and time step were important considerations when selecting whether to use YAS or YBS. They suggested that for a time step <6 hrs and a storage volume of 16 kℓ/ha, the choice of YAS/YBS would have little impact. In this study on the Liesbeek River catchment, the storage size ranged from 100-1000 kℓ/ha. TableA.6 and Table A.7 show the results, at a catchment scale, of modelling 30 different SWH systems in the Liesbeek River catchment using the YAS and YBS algorithms. It is evident that the differences are negligible, with only the difference in percentage of dry periods using the daily time step, exceeding 1%.

Table A.6: Comparison of modelled performance using the YAS and YBS operating rules at hourly time steps

Performance parameter	YAS	YBS	Difference (%)
Demand met (Mℓ/yr.)	1023	1024	-0.08
Total storage volume (m^3)	386100	386100	0.00
Volumetric reliability	0.52	0.52	-0.07
% dry periods	0.29	0.29	0.31
% collected	0.26	0.26	-0.02
Cost per kilolitre (2013ZAR/kℓ)	16	16	0.07

Table A.7: Comparison of modelled performance using the YAS and YBS operating rules at daily time steps

Performance parameter	YAS	YBS	Difference (%)
Demand met (Mℓ/yr.)	1018	1028	-0.93
Total storage volume (m^3)	386100	386100	0.00
Volumetric reliability	0.52	0.53	-0.89
% dry periods	0.31	0.30	4.34
% collected	0.26	0.27	-0.60
Cost per kilolitre (2013ZAR/kℓ)	17	16	0.91

The difference between using the YAS or YBS methods was also compared using daily and hourly time steps. Table A.8 shows the variation in the modelled performance at the Liesbeek River catchment scale. Figure A.16 and Figure A.17 show the variation in results at a system scale. As expected, the YBS estimates a higher yield and consequently higher volumetric reliability, while the YAS provides a more conservative estimate. The YBS in conjunction with the daily time step model provides a provides a better estimate (smaller difference when compared with the YAS with either YAS or YBS in conjunction with a hourly time step model which is assumed to be more accurate than the daily time step model) of the percentage of dry periods to be experienced. It is also evident that the range in error at the system scale is relatively small – except for the percentage of dry periods that has been explained above. Either method would present reasonable results within the range of uncertainties expected with rainfall, runoff and demand modelling.

Table A.8: Comparison of the modelled SWH performance using the YAS and YBS operating rules at the catchment scale using daily and hourly time steps

Performance parameter	YAS (Daily time step) vs. YBS (Hourly time step) (%)	YBS (Daily time step) vs. YBS (Hourly time step) (%)	YAS (Daily time step) vs. YAS (Hourly time step) (%)	YBS (Daily time step) vs. YAS (Hourly time step) (%)
Volumetric reliability	-0.47	0.42	-0.39	0.50
% dry periods	8.48	3.96	8.13	3.64
% collected	-0.22	0.38	-0.20	0.40
Cost per kilolitre (2013ZAR/kℓ)	0.49	-0.42	0.42	-0.49

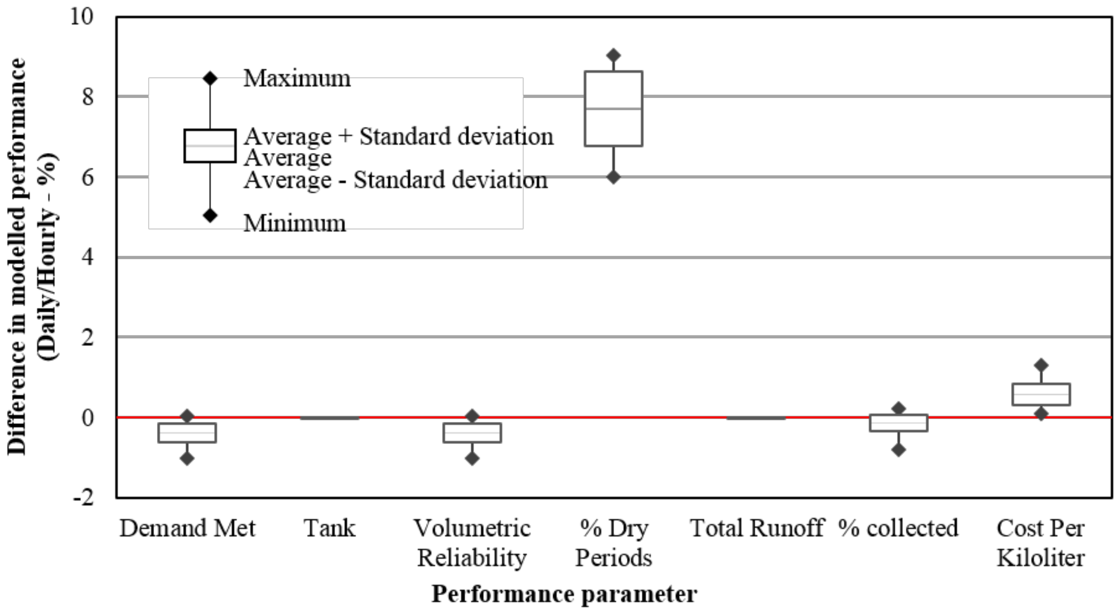

Figure A.16: Comparison of the modelled performance using daily and hourly time step models using the YAS storage algorithm at the system scale (storage sizes optimised in the daily time step model)

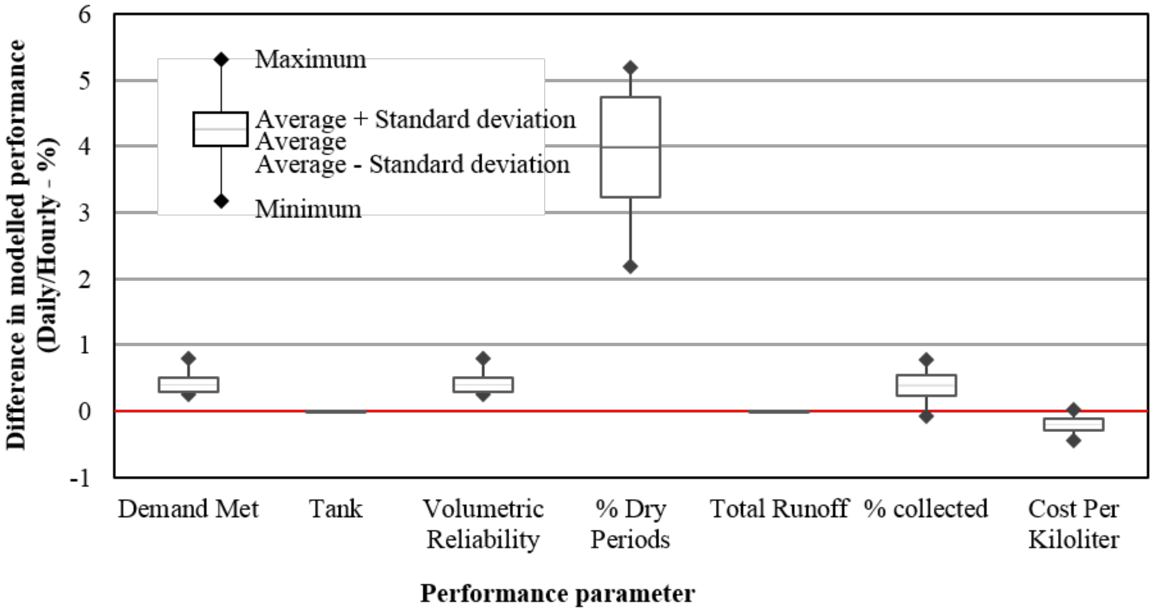

Figure A.17: Comparison of the modelled performance using daily and hourly time step models using the YBS storage algorithm at the system scale (storage sizes optimised in the daily time step model)

A2.2.2 Spatial lumping of SWH systems

Neumann & Maheepala (2013) suggested that '*the input variables of a number of stormwater harvesting systems spread across a catchment can be linearly combined (or summed) into a single system without introducing significant errors provided that the individual harvesting* *systems are well designed*'. They further suggested that the errors they found (2.4%-5% in demand met) were within the range of uncertainties associated with rainfall runoff and demand modelling.

In this study, the Liesbeek River catchment was divided into 30 SWH sub-catchments (FigureA.18), and the results of simulating SWH in these catchments independently and in a lumped manner (summing all demand, storage size, runoff, etc.) were compared using Scenarios 21, 23 and 25 (described in Table A.9). Note that the errors found in this study for demand met, the percentage for dry periods, and the percentage collected are larger than those reported in Neumann & Maheepala (2013). There are a number of possible reasons for this, including the significant variation in demand as well as climate variation across the catchment. However, the specific reason is of little consequence; rather, that an error of up to 9.7% is possible is an indication that caution is required, especially when it comes to economic analyses that rely on the volume of demand met to determine the viability of a system from an economic perspective.

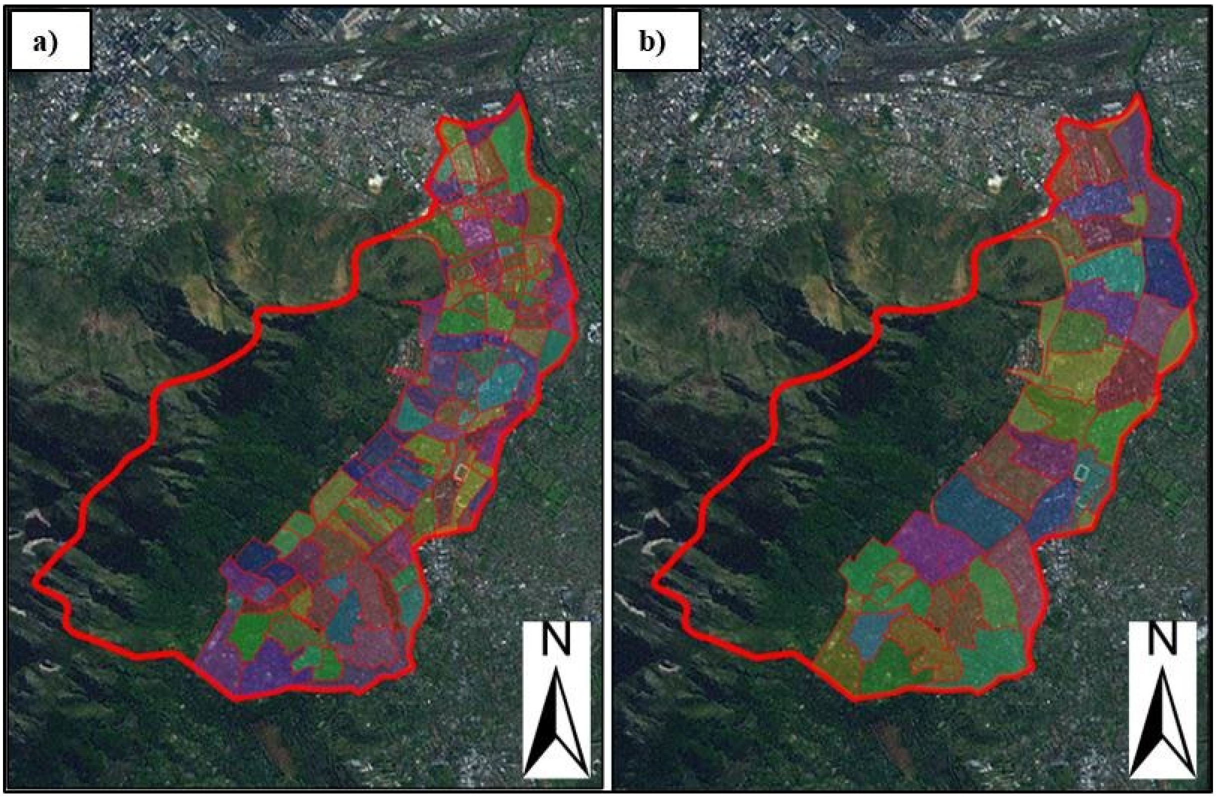

Figure A.18: Urbanised area of Liesbeek River catchment delineated into a) 130 subcatchments, and b) into 30 subcatchments as a result of combining subcatchments

Table A.9: Difference in performance parameters when modelling SWH systems separately and spatially lumping all the SWH systems together

Scenario	Enduse	Difference in Volumetric reliability (%)	Difference in Dry periods (%)	Difference in percentage of runoff collected (%)
Scenario 21	Gardens (at subcatchment scale)	6.7	-4.6	5.3
Scenario 23	Gardens and pools (at subcatchment scale)	8.9	3.8	8.2
Scenario 25	Gardens, pools and toilets (at subcatchment scale)	9.7	2.9	8.3

Appendix B

Testing Managed Aquifer Recharge on the Cape Flats Aquifer

B1 MAR site selection on the Cape Flats Aquifer (CFA)

An integrated hydrological model, MIKE SHE, was setup for the Cape Flats and calibrated for a four year period from 1980 to 1984. The model was calibrated to groundwater levels and streamflow. The benefit of this regional-scale modelling using an integrated hydrological model is that both groundwater and surface water process can be simulated. Thus, important groundwater information such as groundwater level and groundwater head elevation can be simulated as these factors are important for determining the feasibility of MAR. Additionally, due to the representation of surface water within the model, further useful information can be obtained from the model such as groundwater recharge. Groundwater recharge is important as it gives an indication of natural or current recharge for a particular site and where an MAR intervention would be most effective.

The site selection process for identifying areas suitable for testing MAR at a local-scale on the CFA requires information from a number of sources such as aquifer information from hydrogeological surveys and regional hydrogeological modelling results. Since this study aims to help mitigate flooding it is also important to consider where flooding is problematic on the Cape flats. The results from the regional MIKE SHE model provide the main basis for the selection of a local-scale site for testing MAR on the CFA – the most important of which are the maps of groundwater levels, groundwater head elevation and recharge. A significant limiting factor to MAR is finding locations where there is sufficient storage capacity within the aquifer for infiltrated or injected stormwater. By identifying locations where the groundwater level is at its greatest depth below the ground surface, it is assumed these areas are likely to have sufficient capacity for additional recharge. FigureB.1 shows those areas with the low groundwater levels yellow and orange, whereas those areas with high groundwater levels are indicated in blue.

The lowest levels within the Cape Flats Sands occur in the North East and in the South near Philippi and Mitchells Plain. In terms of flooding on the Cape Flats there are a number of low income areas that are at risk of seasonal winter flooding. Sweet Home, Kosovo, Phola Park and Kanana are listed by the City of Cape Town as areas that are affected most by seasonal winter flooding (Pharaoh, 2013). All these suburbs fall within areas that are associated with high mean groundwater levels indicated by the blue areas in FigureB.1.

The hydraulic gradient must also be considered for MAR interventions as the hydraulic gradient determine the flow of groundwater. The hydraulic gradient of the CFA (Figure B.2) shows a decreasing trend from North to South and East to West, with the highest groundwater elevation found in the North East. This means that the aquifer to the North East of those suburbs affected by flooding is not ideal for stormwater MAR as they are ‘down gradient’ of the areas where storage could be maximised. However, the area to the South of the flood risk areas between Philippi and Mitchells Plain hold more potential as they are ‘down gradient’ and also have the required storage capacity.

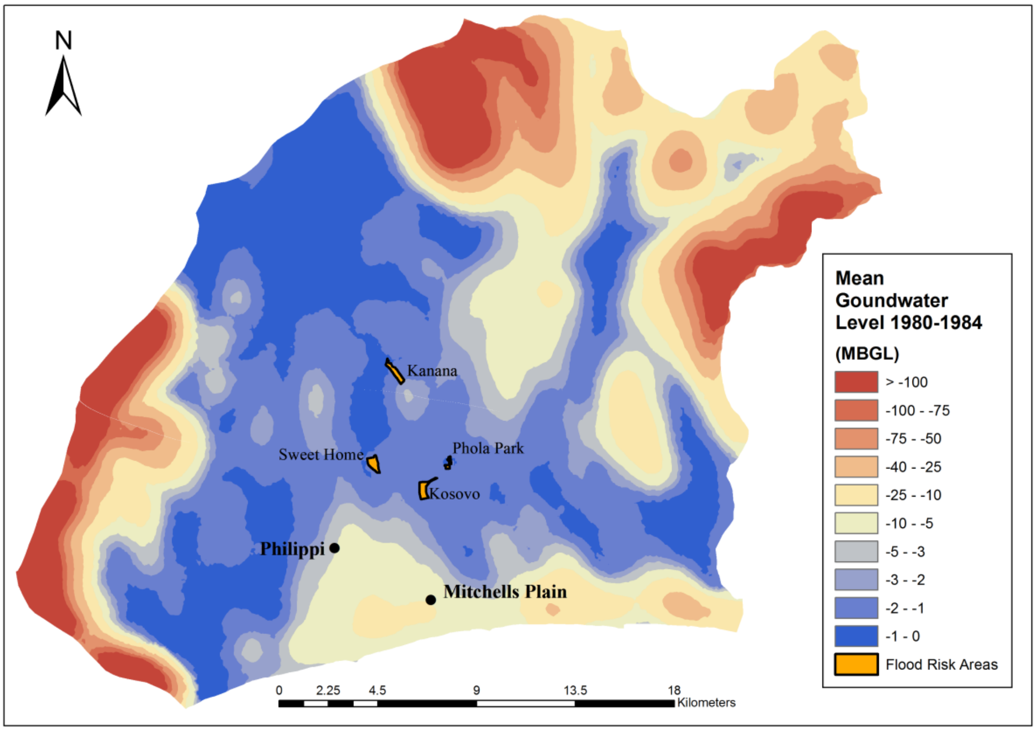

Figure B.1: Simulated mean groundwater levels (meters below ground level) for the Cape Flats from 1980-1984

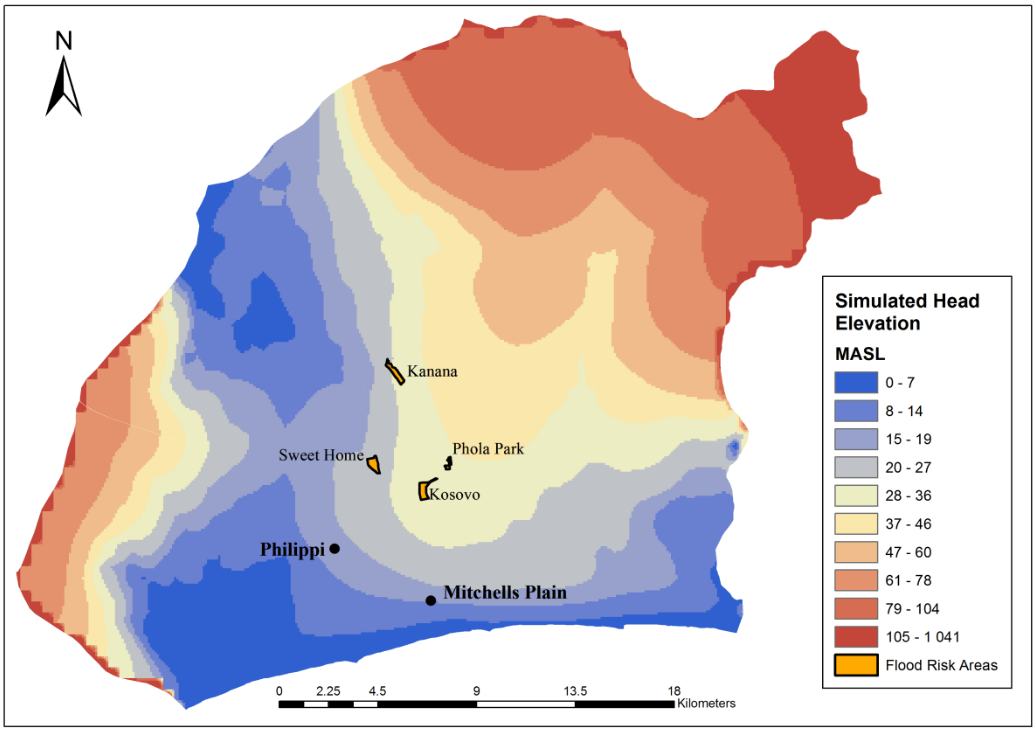

Figure B.2: Simulated head elevation (meters below ground level) for the Cape Flats from 1980-1984

Further support for the selection of a site near Philippi and Mitchells Plain is the fact that the recharge in this area is high (0.5-1 mm/day) or very high (>1 mm/day) (Figure B.3). This means that there is sufficient available land for recharge to take place and that this location has the required soils for infiltration stormwater to recharge the aquifer. Additionally, the area around Philippi and Mitchells Plain has been studied extensively in the past and much of the hydrogeological investigations performed in the late 1970s and early 1980s were concentrated around Mitchells Plain and Philippi (Henzen, 1973; Gerber, 1980; Tredoux *et al.,* 1980). The CFA around Mitchells Plain and Philippi produces the highest borehole yields (>5 ℓ/s) due to the high hydraulic conductivity and transmissivity values (Gerber, 1980). Furthermore, Tredoux *et al.* (1980) tested the concept of wastewater recycling on the CFA applying MAR principles. The study showed many promising aspects in terms of the infiltration and reclamation of treated wastewater in the CFA. However, further research on the CFA lost momentum as attention was shifted onto the Atlantis aquifer, a MAR project initiated at a similar time to that of the CFA.

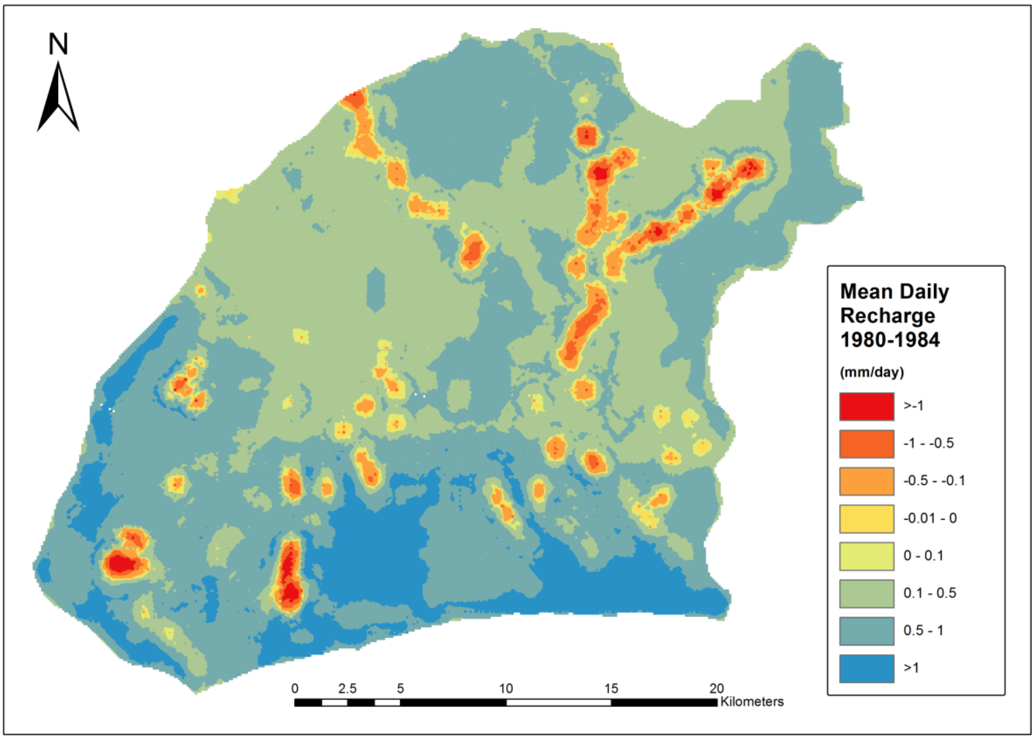

Figure B.3: Simulated mean daily recharge for the Cape Flats from 1980-1984

B2 Local-scale groundwater modelling and scenarios

Based on the information from the regional-scale modelling using MIKE SHE, additional information from literature and hydrogeological surveys of the CFA and the proximity to areas that have a high risk of urban flooding, the region around Philippi and Mitchells Plain was evaluated as the most suitable for MAR. At the most Northern boundary, the proposed site includes the informal settlement areas of Sweet Home, Kosovo, Never and Phola Park, as these areas are prone to winter flooding linked to elevated groundwater tables (highlighted in blue in

Figure B.4). The areas in the South of the study site are the parts of the CFA that have been evaluated as suitable for MAR based on the aquifer's storage capacity and high hydraulic conductivity (highlighted in red in Figure B.4).

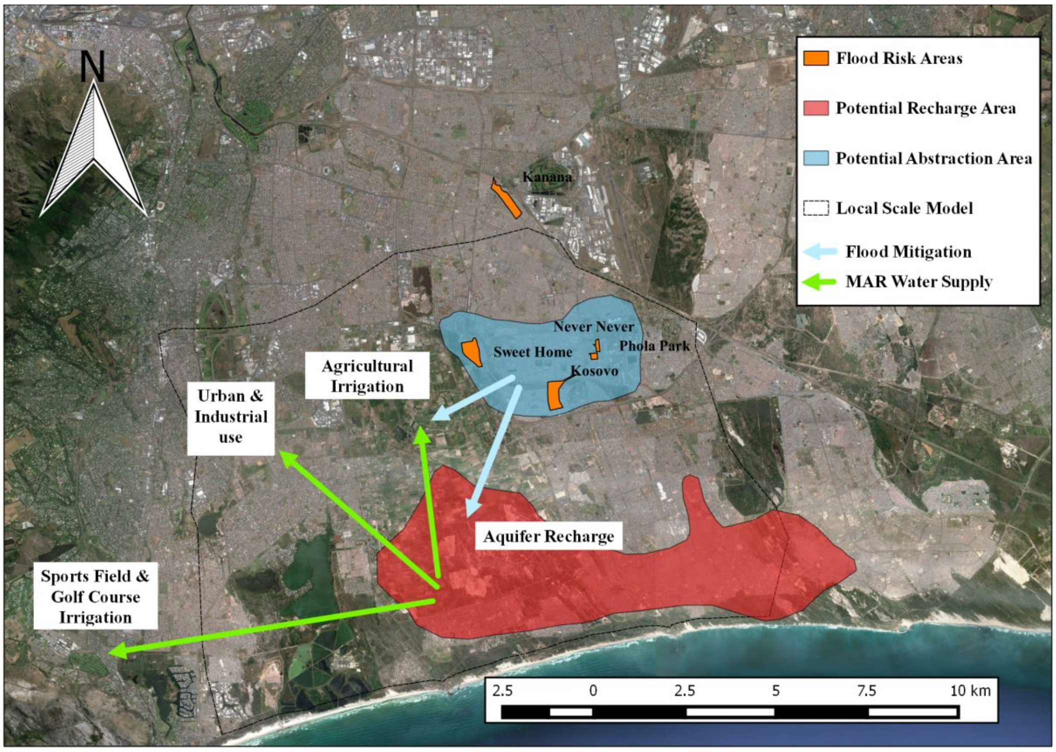

Figure B.4: Local-scale model area used to test MAR on the CFA and the movement of water for flood mitigation and water supply from MAR

The aim in these local-scale scenarios was to investigate the option of reducing winter flooding by lowering the water table by increasing groundwater abstractions during summer, which will help prevent the water-logging of the soils. The abstraction of water from the aquifer below the residential areas of Sweet Home, Kosovo, Never and Phola Park could be used for irrigation in the neighbouring farmlands of the Philippi Horticultural Area (PHA) or used to improve the supply capacity of the CFA around Philippi and Mitchells Plain through MAR using infiltration ponds. The process of infiltration may also provide a means of water treatment as there is a risk of groundwater contamination in areas close to informal settlements. By increasing the amount of recharge in the most productive areas of the CFA it might be possible to improve the assurance of supply from the aquifer and improve the water quality, which is prone to high salinity after prolonged abstraction. The recharged water could then be used for a number of fit-for-purpose uses such as urban agriculture, industrial water supply, irrigation of recreational areas – or even pumped to the Blackheath or Faure Water Treatment Works for blending and treatment to potable water standards. There are a number of assumptions that are required to assess the feasibility of MAR on the CFA. First, it is important to select a draw down level that is sufficient enough to reduce flooding, based on the rate at which the aquifer recharges and the extent of the influence of the cone of depression as a result of groundwater abstractions. Secondly, in the areas where the aquifer is recharged, an upper level must be specified to prevent flooding and to ensure the integrity of underground structures such as the foundations of buildings.

B3 Local groundwater flow simulation using a site-specific conceptual and numerical model for the Cape Flats Aquifer

A detailed local-scale study of the CFA is currently being finalised (Gxokwe, in progress) on evaluating the contribution of hydrogeology on the effectiveness of WSD in the management of urban water systems. The study has the following main aims, and interim results:

i) To assess groundwater-surface water interactions within the CFA region using principal aquifer setting, hydrochemistry and environmental isotopes analysis – with the aim of establishing the occurrence of sites of groundwater-surface water (GW-SW) interaction to monitor the influence of the interaction on the effectiveness of WSD.

A positive linear relationship between surface topography and groundwater table elevation was observed, meaning that groundwater flow follows topography. 3D piezometric surface maps were developed to highlight areas where groundwater flow nets intersect surface water bodies; and based on these plots, several potential sites of groundwater surface water interaction were identified – in the Kuilsriver, Elsieskraal River, and Vygekraal River areas. Hydrochemistry and stable isotopic analysis was then undertaken to confirm whether GW-SW interaction does occur at the identified sites. The underlying assumption was that similarities in the hydrochemistry and stable environmental isotopes between groundwater and surface water will show interaction. Electrical conductivity (EC) monitoring showed similarities in EC trends between various surface water sites and groundwater points serving as evidence of possible interactions taking place in those areas. Analysis of the major ion chemistry through tri-linear plots showed that groundwater in these areas was of the Calcium bicarbonate ($CaHCO_{3)}$ type for the period of February to April, which is characteristic of fresh, shallow and recently recharged groundwater with temporary hardness. Surface water for the period February to July appeared to possess the $CaHCO_3$ and Sodium chloride (NaCl, characterising marine and ancient groundwater) types. For the month of June the dominant groundwater and surface water types were found to be Calcium sulphate ($CaSO_{4)}$ type. Similarities in water types between groundwater and surface water therefore suggest interaction between the two resources for the months of February, April, June and July – thus validating that groundwater interaction occurs within the identified sites. Similarly, analysis of stable isotopes showed that there were similarities observed in isotopic signatures during the months of April, June and July.

ii) To estimate aquifer parameters with an emphasis on transmissivity and storativity of the CFA using Theis and Cooper Jacobs matching solutions in order to establish zones to implement injection and abstraction.

Test boreholes were selected within the upper, middle and lower part of the aquifer based on their spatial distribution. Pump tests were then conducted to estimate transmissivity and storativity in all the selected boreholes. High transmissivity zones were observed around Philippi and intermediate transmissivity zones were observed towards the northern part of the aquifer covering the Bellville and UWC wellfields and some southern parts covering Lentegeur

Hospital wellfield and Westridge stadium borehole. The ideal location to implement the managed aquifer recharge (MAR) suggested as part of WSD would likely be within areas of high transmissivity – in this case, Philippi. Storativity gives an indication of the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer. High storativity values indicate that a unit can take in or release high volumes of water. The implementation of MAR as stipulated by WSD is thus only feasible in areas of high storativity. In this case, the Philippi area would be feasible to implement MAR, thus confirming what is suggested based on transmissivity values.

iii) To simulate a groundwater flow system using site-specific conceptual and numerical flow models in order to predict the influence of WSD implementation on the behaviour of the aquifer.

A regional conceptual model for the CFA has been developed and the numerical modelling is currently being finalised. Based on the conceptual model groundwater follows surface topography from high elevation areas to lower elevation areas. The hydrogeological cross section presented in Figure B.5 shows the groundwater flowing from high elevation areas in the north-east to low elevation areas on the south western side of the catchment.

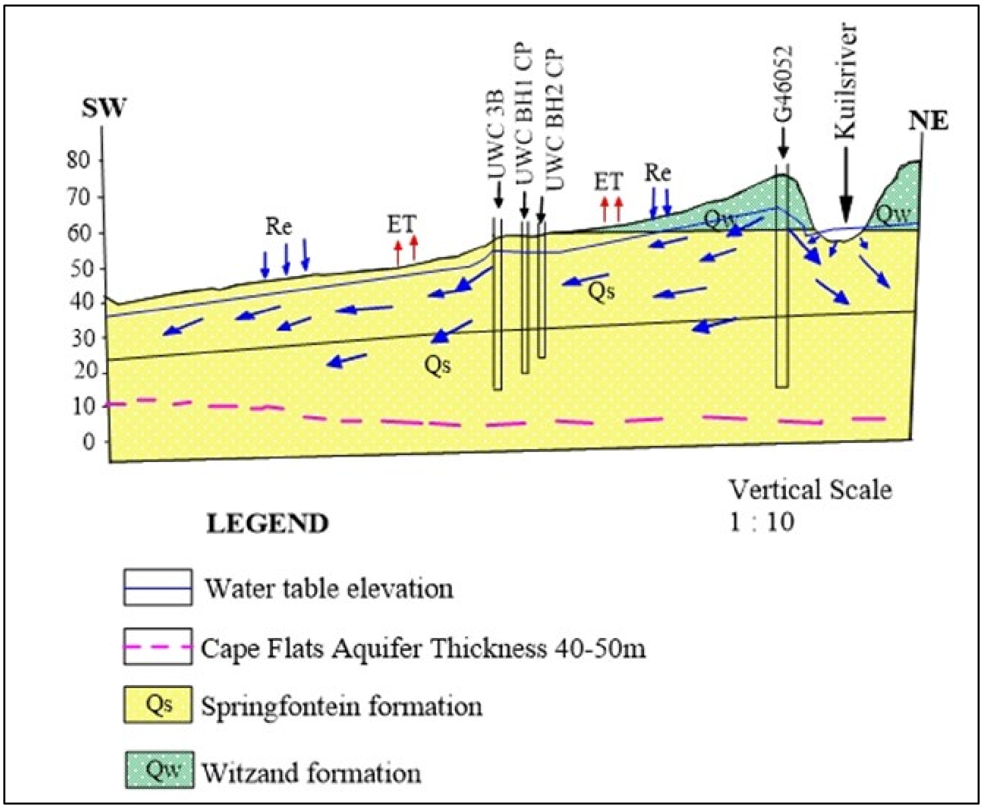

Figure B.5: Hydrogeological cross-section of CFA

The water table is shown with the blue line as very shallow, ranging from 2-4.5 m. Recharge occurs from the surface of the aquifer as shown by blue arrows and from other sources such as leakage of sewage systems and potable water supply mains, as well as interactions with other surface water bodies.

Appendix C

‘Liesbeek Life Plan’

C1 WSD objectives for the Liesbeek River catchment

This section briefly outlines an ongoing WSD design process in the Liesbeek River catchment, Cape Town, and is included here as a working example of the type of planning / design process and associated stakeholder engagement that is required to develop WSD objectives in a particular precinct in a city.

The City of Cape Town has managed the Liesbeek River catchment since the 1920s, primarily through interventions aimed at reducing the risk of flooding to private properties and infrastructure. Nearly 70% of the river corridor is now canalised and formally attached to a network of stormwater pipelines that discharges runoff directly to the river (Figure C.1). The combination of residential properties 'creeping' onto the Liesbeek floodplain and the dominant engineering paradigm of the day, have thus contributed to an ecologically degraded river system, parts of which function largely as a stormwater drain.

Figure C.1: Liesbeek River

The 'Liesbeek Life Plan' is a collaborative effort between the community organisation, Friends of the Liesbeek, and the Urban Water Management research unit at UCT. The primary aim of this collaboration is to work together in a community of practice to develop a framework plan to guide the building of ecological and social resilience in the Liesbeek River catchment. Phase 1 of the project started in late 2014 and opened a dialogue between researchers, members of the public, local authority officials and practitioners in which attention was drawn to re-conceptualising the design and form of the Liesbeek River. Four sites were chosen for the consideration of water sensitive interventions and a concept plan was developed (see Figure C.2 for an example of the designs at one of the sites).

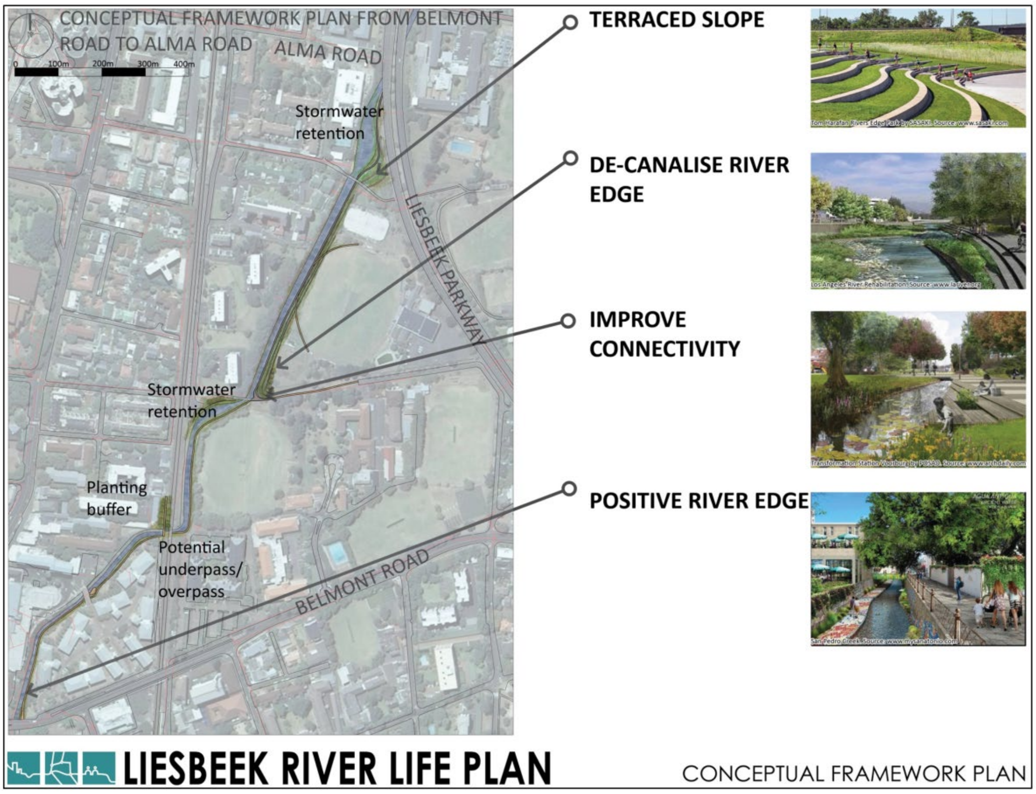

Figure C.2: Example of concept plan for area along Liesbeek River between Belmont Road and Alma Road

The concept plan is geared towards assessing the potential for the implementation of WSD options; specifically aimed at alleviating flooding, improving river quality, increasing biodiversity, and enhancing the amenity value of the river corridor. This is achieved mainly through the use of SuDS components at the local and regional-scale, including: filter strips, swales, bio-retention areas, infiltration trenches, detention / retention ponds, and constructed wetlands. Additional opportunities for intervention in terms of creating multi-functional public spaces and improving river connectivity have also been explored.

The concept plan was completed at the end of 2014, and was used to initiate further consultation with the various stakeholders and City of Cape Town officials. One of the main outcomes of the Liesbeek Life Plan (LLP) has been the development and inclusion of citizens' contributions to the river restoration process – as such, it adds another important dimension to this study (WRC Project K5/2412) as well as providing an excellent opportunity for the sort of social learning envisaged through the WSD Community of Practice programme (WRC Project K5/2413).

Phase 2 of the project began in September 2015 and involved a detailed description and interpretation of a set of conceptual plans and the incorporation of existing data (e.g. flow, water quality, social survey data, land use data, and planning ordinances). There are two current efforts underway to support this process – (i) monitoring, with instrumentation, the bioremediation treatment of stormwater in a constructed wetland; with the aim of generating data before and after interventions so as to demonstrate the performance of the system; and (ii) the appointment of an education officer to work with schools and community-based groups in an effort to build the case for education around stormwater.

In keeping with the WSD implementation focus and core rationale – i.e. supporting equitable and participatory decision-making of local communities in water resources management – the intention of the education programme was to connect a range of stakeholders in the Liesbeek catchment and establish an informal learning network that provides spaces for potential emerging Community of Practice participants to coalesce. The programme presents new opportunities for cross- and inter-sector engagement and learning about, among others, history, heritage, ecology, engineering, geography, land use changes and society; and also learning for the Liesbeek Life Plan itself, which includes actions and community involvement around river restoration, water quality monitoring and stormwater management.

The education programme will continue in 2017, but the focus has shifted to the development of ideas and implementation projects for the LLP that emerged from the interactions and network relationships of the 2015/2016 programme. Events and activities will be co-ordinated more specifically to support the projects. At this stage five interconnected LLP educational projects with potential to be significant research platforms for this study have been identified and either are being finalised or already underway. The projects focus on designing and implementing:

- Public signage along the Liesbeek
- Strategic workshops using the Common Cause framework
- A 3-year WSD project for architecture students
- Proposals for river stewardship involving corporates situated along the Liesbeek
- A learning partnership to upskill LMP team members

Project #1: Public educational signage

The development of fixed public educational signs along the Liesbeek is a key LLP objective. Signs are an essential form of public awareness and communication. For this project a series of five or six signs are being designed to tell a story of the section of the lower Liesbeek River between Durban Road in Mowbray and Observatory Road in Observatory, and to draw public attention to, among others:

- The retention properties and remediation potential of bio-filters such as the constructed stormwater pond opposite the River Park office complex and the Valkenburg wetland on the Two Rivers Urban Park (TRUP) estate.
- The historical and cultural value of this section of the Liesbeek.

Project #2: Strategic implementation of Common Cause in the LLP

In 2016 the LLP education programme arranged two public workshops introducing the Common Cause methodology to interested Liesbeek stakeholders. A third introductory workshop was also held specifically for committee members of the Friends of the Liesbeek (FOL), the co-collaborators in the LLP along with the University of Cape Town. The workshops were facilitated by Common Cause South Africa, a member of the global Common Cause Foundation network. This methodology has potential to be instrumental in stimulating and sustaining collaborative learning processes because it works at the level of values to address some of the underlying structural causes of our social, ecological and economic injustices.

Common Cause draws on extensive collaboration with leading social psychologists from different countries, which acknowledge that values are a driving force behind many human attitudes and behaviours. Values are expressed in most of what people say and do, and advertising, media, entertainment, business and political practices particularly, are often criticised for reinforcing undesirable values. Common Cause states that so-called intrinsic or compassionate values underpin a deeper concern for social and environmental issues, particularly bigger societal, or so-called ‘wicked’ or complex systems problems. Emphasising these values in a variety of ways motivates people and organisations to become more engaged in these big issues of our time. Compassionate values are inherent in everyone, but society often reinforces more selfish or extrinsic values; and this can occur at the expense of individual well-being, societal justice and cohesion, and environment. Giving voice to and strengthening compassionate values helps to widen and deepen responses to a broad range of social and environmental challenges. Based on the success of the initial workshops (e.g. positive feedback from participants with requests ‘to go deeper’ around implementation), the 2017 education programme is preparing a series of four LLP strategy and implementation workshops over the next 6 months facilitated by Common Cause SA using the Common Cause methodology. The objective is to assist the FOL committee and relevant LLP stakeholders, to develop:

- A new vision for FOL in terms of its deeper values,
- A set of organisational values, or underlying operational principles for FOL, and
- A set of high-level implementation strategies and activities for the LLP.

It is expected that FOL / LLP will use the above output (drawn from the four workshops) to develop more detailed implementation plans, targets and key performance indicators.

Project #3: Corporate river stewardship

A number of corporate companies situated in the Liesbeek catchment have indicated their interest in collaborating with FOL through a river stewardship model as their contribution to the LLP. River stewardship broadly refers to a strategic initiative that aims to inspire and co-ordinate active protection of all or part of a river system. There are a number of successful river stewardship programmes in South Africa that feature cross-sector collaboration between business (the stewards) and NGOs (the implementing agents). FOL is currently negotiating with three companies in the Liesbeek catchment to incorporate a river stewardship programme as part of annual corporate social responsibility (CSR) initiatives. The blueprint for the programme is a monthly contract (i.e. retainer income), where FOL supplies the resources (e.g. labour and equipment through its LMP) to maintain a mutually agreed section of the Liesbeek, and also arrange two or three annual events that involve the respective company staff and their families in practical river-based activities. The staff events are intended to be arranged around key environmental dates (e.g. World Water Day, World Environment Day, and World Water Monitoring Day) and centred on the preparation work done by FOL. Company staff will be involved in basic activities such as river cleaning, clearing of alien invasive vegetation, indigenous planting as well as more advanced activities such as water-quality testing (i.e. miniSASS) and possibly even filming events. It is anticipated that this interaction could lead to further involvement and collaboration such as representation on respective committees or boards.

Project #4: WSD for Architecture students

This project presents an opportunity for cross-sector WSD collaborative learning specifically in the field of architectural and landscaping design. It brings together 2nd year Architectural students from UCT and companies situated along the Liesbeek in the River Park office complex in Mowbray. The aim of the project is to create greater connection and flow for people between the office complex and the river. Currently, people working in the complex are largely disconnected from the river because security fencing prevents easy access. The river area is also overgrown with alien vegetation and is known to encourage undesirable elements. This has led to a number of companies in the complex expressing interest in upgrading the area and wanting to understand more about the maintenance of urban waterways and the potential of WSD to improve them. This section of the Liesbeek in front of the offices has considerable potential to be redesigned to improve the general amenity value of the riverbank (e.g. paths for short walks, shaded areas for sitting, and possibly even a pedestrian bridge over the river), as well as to introduce WSD interventions such as upgrading the weir to improve water flow and stabilising the river banks to prevent erosion. However, there also are certain obstacles to any redesign work here including navigating the requirements of environmental bylaws and impact assessments. As such this area provides an interesting opportunity for collaborative interaction and learning between the various stakeholders, i.e. businesses, local government and the university.

For the design students at university, this project presents a real world example to test the application of theory, and gain valuable experience from interacting with public and private sector organisations. For the interested businesses and the River Park office complex as a whole, including the commercial property managers, this project is a low cost opportunity to investigate (and design) improvements to the area. For the local government authority in the City of Cape Town, this project represents an opportunity to engage in a low intensity public-private sector partnership that aligns with its goals of sustainable human settlements.

Project #5: Learning partnership between FOL and Omni HR Consulting

At one of the first LLP education programme events in 2016 (a business networking event) a partnership was forged between FOL and a human resources consulting business and SETA accredited training provider. With their offices situated in the River Park complex overlooking the Liesbeek, the company was invited to engage with FOL around the LLP and discuss options for collaboration around common interest and expertise. The outcome was an agreement to provide *pro-bono* training for the river workers employed by FOL.

FOL operates a team of eight full-time river workers who perform a range of river maintenance tasks for the Liesbeek Maintenance Project (LMP). The LMP is a core function of FOL mandated by the City of Cape Town to provide additional capacity to fulfil the responsibilities of a number of municipal service departments including Parks & Recreation and Biodiversity Management. Although performing the obligations of local government, the LMP is operated and managed by FOL and resourced with private funding. FOL is legally responsible and liable for the health and safety of its workers, and also considers the general personal development of its workers as part of its good governance practices.

In partnership with Omni HR Consulting, each member of the LMP team has been placed on a one-year learnership programme to complete the NQF level 2 National Certificate in Environmental Practices. Omni views the partnership with FOL as an exciting opportunity to grow the skills base in the critical water management sector while contributing their services to the local community. The learnership, which began in November 2016 and will continue for a full year throughout 2017, recognises the existing skills and experience each LMP member has gained from their work on the Liesbeek and formally credits this towards their qualification. The team is given time off on workdays to attend classes at Omni's training facilities.