A FEASIBILITY STUDY TO EVALUATE THE POTENTIAL OF USING WATER SENSITIVE DESIGN PRINCIPLES TO STRENGTHEN WATER PLANNING FOR THE WATERBERG INDUSTRIAL COMPLEX

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WATER RESEARCH COMMISSION

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Report to the
Water Research Commission

by

P Dama-Fakir[1], G Bonthuys[1], G Singh[1], P Wille[1], T Coleman[1] and C Jainisch[2]

[1]Golder Associates Africa
[2]BiomimicrySA

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Obtainable from
Water Research Commission
Private Bag X03
Gezina 0031
PRETORIA

orders@wrc.org.za or download from www.wrc.org.za

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EXECUTIVE SUMMARY

The focus on water management has changed from traditional methods where water supply, water treatment and stormwater management were considered separately, to more integrated approaches taking sustainability into consideration.

The Water Reconciliation Strategies collated by the Department of Water and Sanitation (DWS) identified various water-stressed catchments in South Africa. The need for optimization of reuse options, water efficiency and conservation and water demand management are highlighted in several water management studies carried out in South Africa. One such area is the Limpopo Water Management Area (WMA) North which experiences low rainfalls and high evaporation. Applying the principles of WSD holds potential to reduce the risk of water shortage in the area by reducing the need to abstract water from resources while also protecting the area from flash flooding.

The present study investigates the potential of implementing the WSD options in the Waterberg District Municipality within the Limpopo WMA considering the existing infrastructure, planned development, institutional arrangements, existing partnerships and taking retrofitting current infrastructure into consideration.

The project team incorporated Biomimicry Life's Principles in the approach to water management systems. This included:

- Adapt to changing contexts – through the use of variability, redundancy and decentralised water management systems.
- Integrate development with growth – through the use of modular systems and ensuring good communication between various authorising bodies.
- Be locally attuned and responsive – by including simple feedback loops to manage and adapt systems. A system that is able to change over time with feedback is key.
- Be resource efficient – by fitting form to function, leveraging on gravity, working within the ecological footprint, recycling water and materials were possible and designing multi-functional systems.
- Design for a healthy urban ecosystem – The water management system can contribute to healthy functioning of local ecosystems such as wetlands, as well as healthy hydrological function in general.
- Design for wellbeing – Water management systems that can contribute to ecosystem services that leverage ecological infrastructure to contribute to a sense of place – will support wellbeing and be a great place to live.

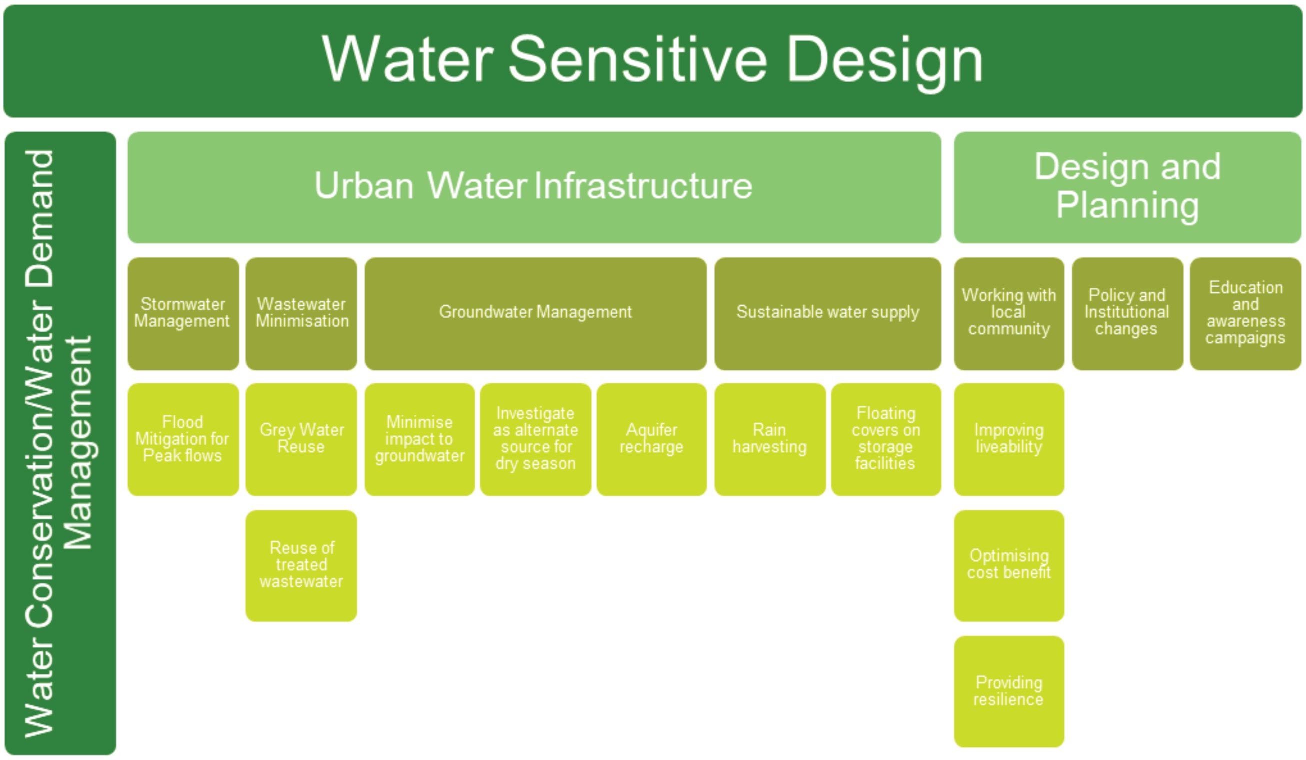
The Waterberg region falls within the subtropical high-pressure belt. The region has warm summers and moderate, dry winters and experiences summer rainfall (Golder, 2017). The lowest rainfall depths are typically experienced in the month of June and the highest depths experienced during January. Rainfall typically occurs in the form of short duration, intense convection thunderstorms. Droughts are endemic to the more semi-arid and arid regions and occasional flooding may occur during the summer months due to the convection thunderstorms and tropical disturbances (Limpopo SOE, 2004 as cited in Golder, 2017). The Mean Annual Evaporation (MAE) is more than three (3) times that of the Mean Annual Precipitation (MAP), with evaporation varying between 1 800 mm per annum and 2 000 mm per annum (Exxaro Services, 2013 as cited in Golder, 2017).

Lephalale was selected as the focus area due to its high growth projections and current challenges with surety of water supply. The area is supplied by Mokolo Dam. The MAP for the area is between 437 mm/a

and 483 mm/a. Water balance predictions indicate that shortfalls of up to 31 Ml/day can be experienced in 2040 if water consumption rates continue as present and growth projections are met.

One of the key challenges in the area is the need for Flue gas Desulphurisation at the new power stations being established there. Reducing air pollution is equally important and research is required on alternative less water intensive treatment options.

Water Sensitive Design (WSD) requires a paradigm shift from the current linear approach to water management to a more cyclic, integrated approach. Responsible teams for water supply, stormwater management, wastewater management and energy supply need to work together to ensure safe, affordable water for all.



WSD activities (adapted from Armitage et al., 2014).

Watershare is a worldwide network of water research organisations and utilities dedicated to applying global expertise to master local water challenges. The following available Watershare® tools applicable to WSD:

- City Blueprint
- Wastewater Treatment Selection (WASS)
- Water-Use Info
- Urban Water Optioneering Tool (UWOT)

Limitations identified on the Watershare® Tools were around data requirements and flexibility to meet some of the unique challenges faced in South Africa.

An assessment on roof gardens was carried out as an option to manage peak events. Results indicated that the gardens would require additional water for maintenance and measures such as permeable paving will be more effect for managing peaks.

Analysis using a rainfall harvesting tool developed for the area indicated that whilst the payback period improved with shopping centres, large developments and rainfall harvesting was not as attractive a solution in Lephalale as it would be in an area with more frequent rainfall.

Water saving devices proved to be effective and should be encouraged. Bulk purchases will result in reduced Capital costs. Developers can be encouraged to use the installation of water saving devices as a marketing tool for new property developments.

Industry and mining should consider floating covers for pollution control facilities. This will reduce the evaporative losses from return water systems thus reducing the top-up water requirements. Recent developments on floating covers include solar cells that provide a dual benefit of reduced evaporation and energy production

Greywater reuse was found to be feasible for new developments but not in established suburbs. The risk of cross-connections is high and changes to bylaws in terms of signing off on plumbing connections and training is essential in order to reduce the risk of contamination of drinking water sources.

Local wastewater treatment plants will need to be upgraded to meet the increased flow anticipated. The option if reusing treated wastewater in the mines and industry should be considered. This will offset potable consumption being used as makeup water in the dry season.

A change in mindset is required in South Africa as a whole. Under drought conditions, the population is able to use water wisely and responsibly. A compendium of successful water saving initiatives applied in Cape Town over the 2017/2018 water shortage can be a useful document for South Africans.

Proposed solutions for water management need to be site specific and cannot be replicated in different catchments.

A key lesson learnt in the study is a balance between flexibility and accuracy is key when developing options analysis tools.

ACKNOWLEDGEMENTS

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- Dr Jo Burgess – Water Research Commission
- Dr John Zvimba – Water Research Commission
- Dr Kirsty Carden – University of Cape Town
- Johnny Harris – Isidima Design and Development
- Charles Linstrom – Exxaro Resources
- Jacky Burke – SRK

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CHAPTER 1: INTRODUCTION AND OBJECTIVES

The focus on water management has changed from traditional methods where water supply, water treatment and stormwater management were considered separately, to more integrated approaches taking sustainability into consideration. Currently, there is a movement towards considering the urban water cycle allowing for adaptability, ensuring water security whilst protecting the resource and incorporating multifunctional design approaches. These include:

- Roof gardens which lead to flood attenuation, recharge, reuse, conservation and purification of water;
- Sustainable urban Drainage (SuDs) systems where runoff in urban areas is adapted and mimic that of natural systems; and
- Stormwater attenuation and treatment wetlands which serve as a water purification facility whilst creating a habitat for various birds and animals, adding to the biodiversity of an area and increased aesthetic appeal.

Water Sensitive Design (WSD) is a land planning and engineering design approach which integrates the ecosystem's water cycle, accounting for stormwater, groundwater, wastewater management and water supply, into urban design (Wong, 2006) to improve environmental sustainability, aesthetic and recreational appeal and can lead to long term economic and social benefits. The use of WSD initiatives can also increase the fixing of carbon and will reduce the carbon footprint of anthropogenic developments.

The Water Reconciliation Strategies collated by the Department of Water and Sanitation (DWS) identified various water stressed catchments in South Africa. The need for optimization of reuse options, water efficiency and conservation and water demand management are highlighted in several water management studies carried out in South Africa. One such area is the Limpopo Water Management Area (WMA) North which experiences low rainfalls and high evaporation. Applying the principles of WSD holds potential to reduce the risk of water shortage in the area by reducing the need to abstract water from resources while also protecting the area from flash flooding.

The present study investigates the potential of implementing the WSD options in the Waterberg District Municipality within the Limpopo WMA considering the existing infrastructure, planned development, institutional arrangements, existing partnerships and taking retrofitting current infrastructure into consideration. A further aim of the project is to assess the applicability of a range of tools provided by Watershare®, an international knowledge management model for the water sector, to assist in WSD in the area. This report addresses the baseline assessment for the Waterberg catchment and more specifically the Lephalale region where planned urban and industrial development puts further strain on the water resource

CHAPTER 2: APPROACH AND METHODOLOGY

One of the key factors influencing Water Sensitive Design (WSD) is the context. In terms of context, the following needs to be understood:

- Climate;
- Population;
- Water requirements;
- Development plans/Urban planning,
- Long term population and development projections

Water Sensitive design initiatives are constantly changing and evolving to meet the current and future needs and a literature review on Water Sensitive Design initiatives, including the South African Guideline document and other available literature was carried out.

Whilst individual water sensitive design applications can be replicated, the overall integrated solution will be site specific. In order to assess the potential of applying water sensitive urban design principles to improve the efficient use of water, a baseline assessment of the area and baseline water balance for the catchment is a key input to the assessment.

A baseline assessment of the site was carried out. Key aspects investigated included climate and climate variability, projected water consumption for different sectors, urban development plans for the area and planned industrial developments. A baseline water balance was prepared for the study area using the available hydrological data and information contained in the water reconciliation strategy. The catchment water balance was checked against the WRSM model (Bailey and Pitman, 2015). Future projections for water consumption were applied to the model and the impact on the supply was assessed for different water sensitive designs.

2.1 INCORPORATING BIOMIMICRY PRINCIPLES

The biomimicry and ecological engineering methodologies were applied in identifying potential WSD initiatives for the catchment. The Biomimicry Life's Principles approach for water management systems can be summarised as follows:

Adapt to Changing Contexts

Water management systems need to be designed to appropriately respond to dynamic conditions with regards to changing stormwater flows, population growth and behavior, industrial growth, etc. A critical component of this will be to embody resilience through variation, redundancy and decentralisation of water management systems. In order to accomplish the necessary resilience and adaptability, it is recommended that designs should incorporate multiple approaches, decentralized approaches and consider the natural environment. Conventional methods tend to be more centralized and focused on achieving one function. The ecological approach promotes retrofitting to the natural environment and incorporating the principles of multifunctional designs. Resilience is also dependent on the ability of a system to self-renew after a disturbance. Ecological water systems are likely to be able to do this as damaged plants can recover, while damaged pipes would need repair or replacement.

Integrate Development with Growth

Integrated systems design and planning requires that ecologists, hydrologists, urban planners and local/regional authorities work together to design systems, particularly water management systems. Design principles serve as high-level recommendations, but it will be required that more detailed planning be done in a collaborative way upfront rather than checking requirements at the end. It is highly recommended that interdisciplinary teams, using full-cost accounting methods work together to design the appropriate water management systems. In addition, cross-pollination of principles from natural systems and urban water management, and a willingness to investigate and support unconventional systems by the public and regulator is necessary. Modular systems are most suitable to adaptability and integrating development with growth. This means a preference for systems where functional components are in modules that integrate together to perform functions so that components can be replaced or adapted without losing the full system. In addition, the system can match the water related functional needs as the development grows. Designing for circular systems will be critical. Investigate systems that can be disassembled and reassembled, decouple resource consumption from growth, and those that contribute to natural cycles.

Be Locally Attuned and Responsive

A water management system that is integrated within the physical, social and planning context is more likely to be well-adapted to context and therefore more resilient. Designs that learn from and seek to nurture, restore or mimic the natural systems context, are more likely to be well-adapted to context and therefore more successful in the long-term. Ecological Performance Standards provide guidance for healthy well-adapted functions in context. Making use of readily available energy (including gravity, renewable energy or an abundant workforce) and working with natural water flows instead of trying to control against them is a more resilient response. Systems designed with short, simple feedback loops to manage and adapt systems in dynamic contexts will be more resilient. Surface-based stormwater management using vegetative cover such as SUDS systems provides visual feedback as to the state of the system, compared to pipes underground. Replicating strategies that work in context such as SUDS systems and abstracted stormwater management principles from local natural organisms/ecosystems will leverage existing responses. A system that is able to change over time through feedback will be key.

Be Resource Efficient

A key component of resource efficiency is fitting form to flow. Design the urban space around natural water flows rather than imposing water flows on an already defined urban plan. Leverage gravity and avoid fighting water’s natural flows. Fit forms to multi-function. Recycling nutrients in storm/wastewater back into soil regeneration and recycling the water itself are opportunities to turn urban development into development that supports critical ecosystem services rather than depleting them. Leverage multi-functional ecological infrastructure for water management across the site with additional multiple benefits such as contributing to carbon sequestration, temperature regulation and wellbeing.

Design for a Healthy Urban Ecosystem

Nurturing and restoring healthy ecosystem function will require more than protecting some areas – it will require that all urban development areas contribute to healthy function. The water management system can contribute to healthy functioning of local ecosystems such as wetlands, as well as healthy hydrological function in general. In addition, when leveraging ecological infrastructure, other healthy functions can be nurtured and restored such as restoring C, N and P cycles, while also preventing sediment loss.

Design for well-being

A resilient urban development will also contribute to human wellbeing. A development that can appropriately respond to dynamic changes in water flows is important for health, safety and wellbeing. Water management systems that can contribute to ecosystem services, that leverage ecological infrastructure to contribute to a sense of place – will support wellbeing and be a great place to live.

2.2 APPROACH

The study approach can be summarised as follows:

- Water challenges applicable to the catchment were identified through the baseline assessment phase. This included a literature review and a baseline water balance.
- The ecological and biomimicry design principles were considered when identifying potential water saving and water management initiatives.
- Available tools were used to assess WSD initiatives in the catchment. Additional tools were developed where necessary in order to assess these initiatives.
- Recommendations were made on a way forward.

CHAPTER 3: WATERBERG INDUSTRIAL COMPLEX – BASELINE ASSESSMENT

3.1 CATCHMENT LOCALITY

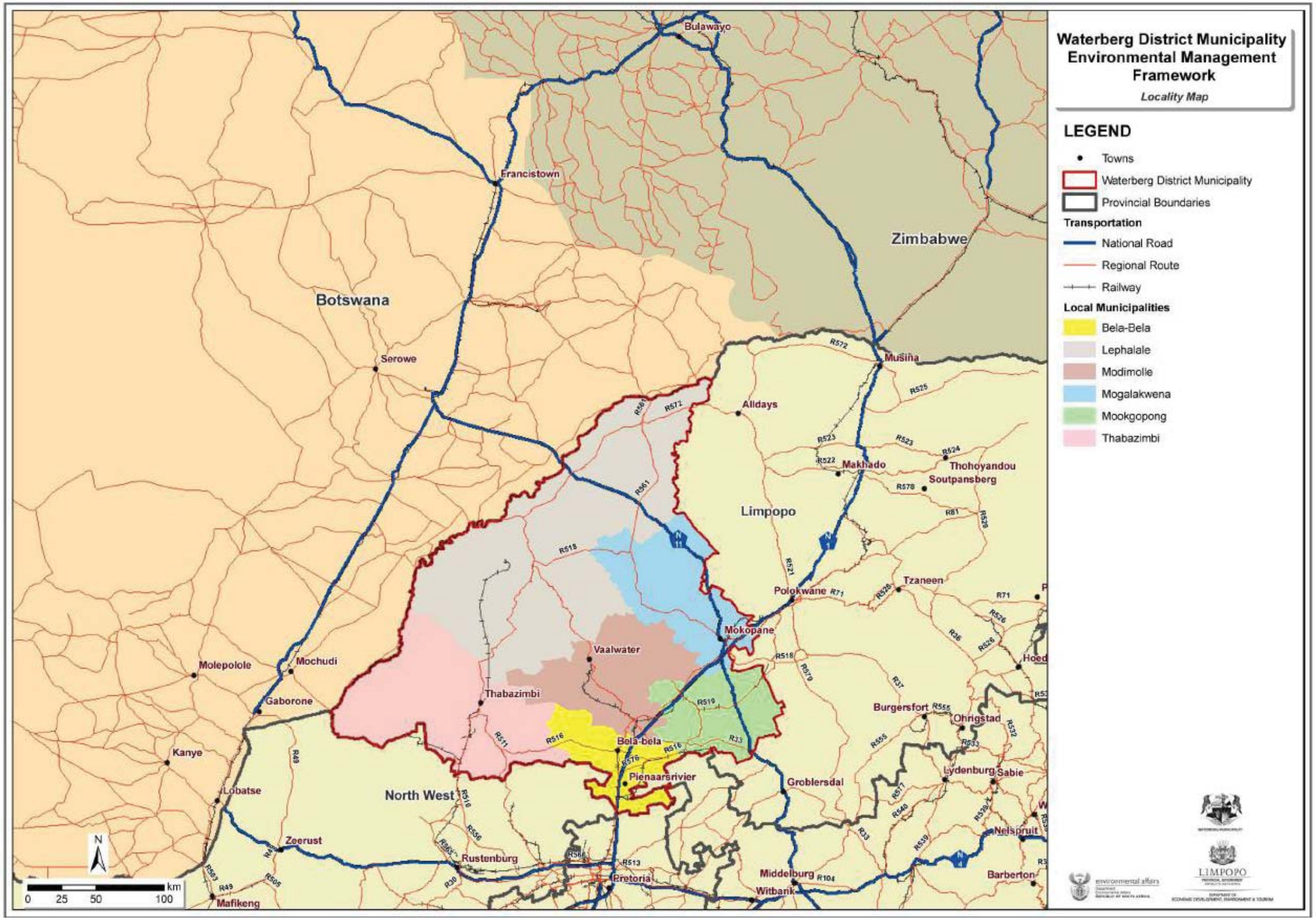
The Waterberg District Municipality (DM) is a political demarcation on the western portion of the province of Limpopo, South Africa (Figure 1), consisting of Bela-Bela Local Municipality (LM), Lephalale LM, Modimolle-Mookgophong LM, Mogalakwena LM and Thabazimbi LM. The area is approximately 44 913 km^2 and consists mainly of commercial farms, game farming, rural settlements and small towns (Waterberg District Municipality, n.d.). The district municipality comprises of six local municipalities namely Lephalale, Mogalakwena, Modimolle, Thabazimbi, Bela-Bela and Mookgophong (Figure 2). The largest contribution of the GDP of the district is mining (approximately 57.5%) (Water District Municipality, n.d.). There are plans to extend the mining to meet the demands for coal from the expanding power-generating industry in the area. This is driven by the construction of the coal fired power station, Medupi, near Lephalale (ibid.). Another significant contributor to the GDP of the district is agriculture, approximately 28.8% (ibid.). The farming areas most prominent are Lephalale and Mogalakwena. The district has a population of 679 336 with a density of 15.13 per km^2 (Census, 2011). The DM falls within the Limpopo Primary Catchment Area.

3.2 PRIORITY AREA OF FOCUS

From spatial planning of the province of Limpopo, in which the Waterberg District falls, Lephalale is recognized as the provincial growth point (Lephalale Local Municipality, 2016). The provincial growth point includes the towns of Lephalale with the urban developments of Marapong, Onverwacht and Ellisras as nodes. The area is recognized as a provincial growth point due to its sizeable economic sector, its regional and provincial service delivery functions and its large number of social facilities. The urban growth in the area is spurred by the mining and the power generating industries of the nearby Grootgeluk Mine and the Medupi Power Station. The future plans for the area include expanding the mining and power generating industries hence, growing the urban infrastructure. Thus, the Lephalale region serves as the ideal location for the feasibility study on the application of WSD in the Waterberg District.

The spatial layout of the Lephalale municipality includes the Marapong township to the north, the industrial areas of Medupi Power Station to the west and the Matimba Power Station near Marapong. Onverwacht is the largest expanse of formal residential development while Lephalale is recognized as the major town with most of the commercial and institutional facilities in the area (Figure 3).

The industry most prominent in the Lephalale region is the coupled mining and power generating industries. Grootgeluk Mine is a large coal mine under the Lephalale Municipality. The coal supply feeds the Medupi and Matimba Power Stations. A new mine and power station, namely Thabametsi Mine and Power Station, is proposed adjacent to Grootegeluk Mine (Figure 3).


Waterberg District Municipality
Environmental Management Framework
Locality Map
LEGEND
Towns
Waterberg District Municipality
Provincial Boundaries
Transportation
National Road
Regional Route
Railway
Local Municipalities
Bela-Bela
Lephalale
Modimolle
Mogalakwena
Mookgopong
Thabazimbi
Botswana
Zimbabwe
Limpopo
North West
Bulawayo
Francistown
Serowe
Molepolole
Mochudi
Gaborone
Kanye
Lobatse
Zeerust
Mafikeng
Rustenburg
Pretoria
Witbank
Middelburg
Groblersdal
Thabazimbi
Vaalwater
Bela-bela
Pienaarsrivier
Mokopane
Polokwane
Alldays
Musina
Makhado
Thohoyandou
Soutpansberg
Tzaneen
Burgersfort
Ohrigstad
Lydenburg
Sabie
Nelspruit
Barberton
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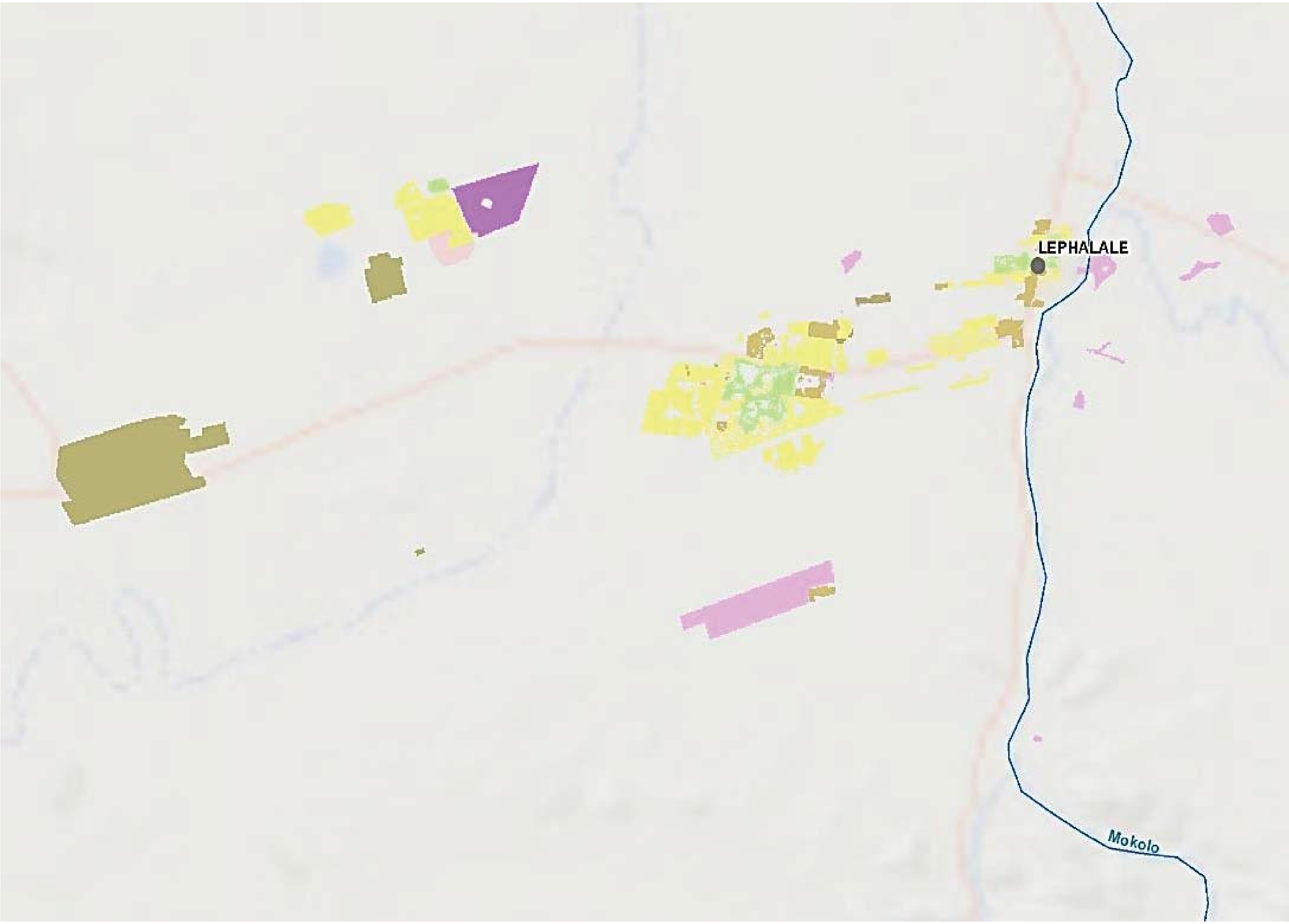
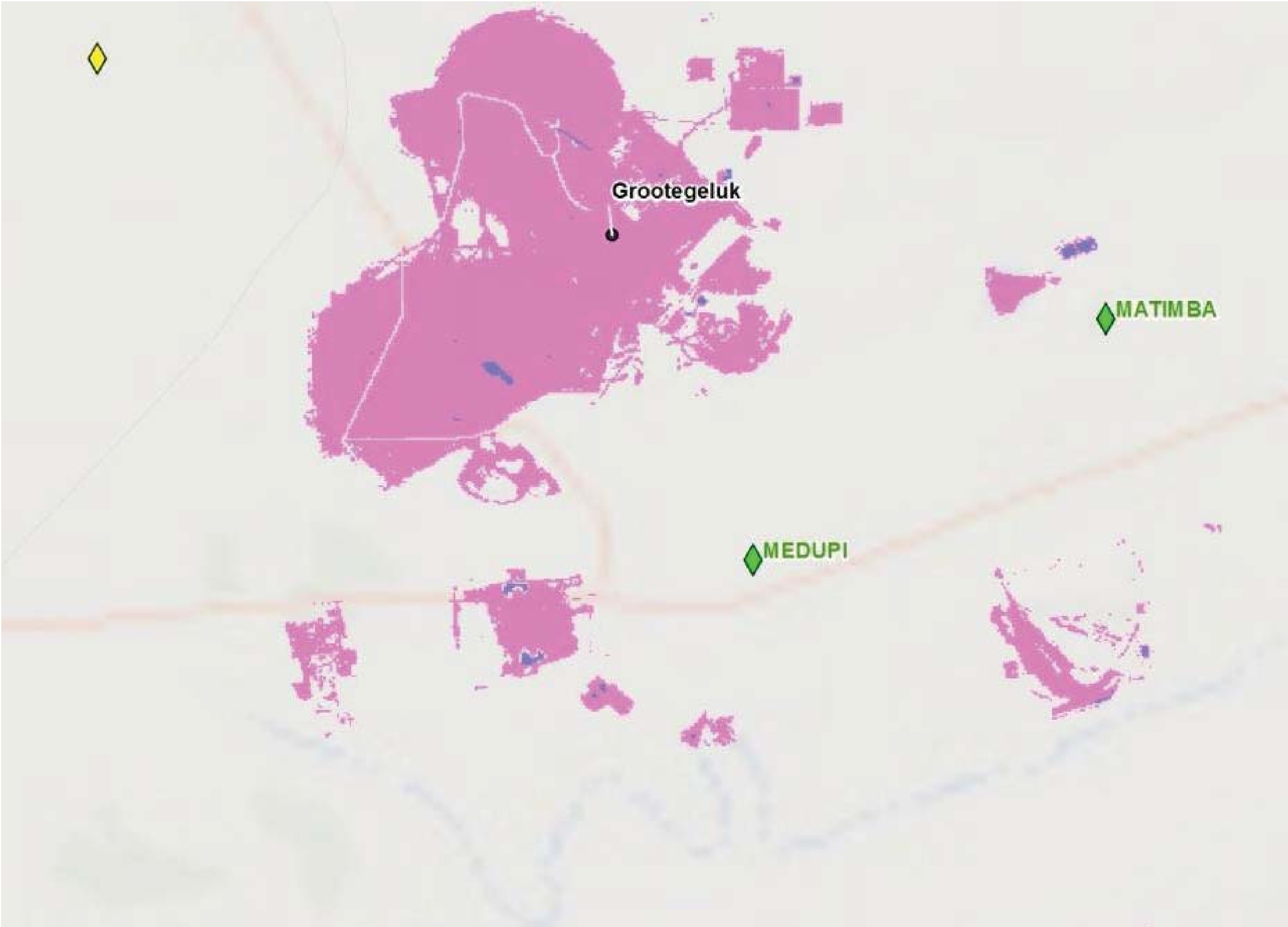

LEPHALALE
Mokolo


Grootegeluk
MATIMBA
MEDUPI

3.3 BIOPHYSICAL ENVIRONMENT

Most of the catchment area of the Waterberg DM falls under the central Bushveld Bioregion, which falls under the Savanna biome (Department of Environmental Affairs, n.d.). Smaller areas are classified under the Mesic Highveld Grassland Bioregion, a subsect of the Grassland biome (ibid.). Lowveld Riverine Forest, Springbokvlakte Thornveld, Central Sandy Bushveld and Makhado Sweet Bushveld are some of the vegetation in the area that requires conversation (ibid.). There are 43 mammal species of conservation concern in the Waterberg district, of which thirteen falls under the Red List of critically endangered species (ibid.). Protected natural areas include the Marakele National Park, Entabeni Nature Reserve and the Dnyala Nature Reserve. The environmental framework highlights that degradation of the natural environment is present and is mainly due to the existing cultivation, urbanisation and mining in the area.

3.4 CLIMATE

3.4.1 Overview

The Waterberg region falls within the subtropical high-pressure belt. The region has warm summers and moderate, dry winters and experiences summer rainfall (Golder, 2017). The lowest rainfall depths are typically experienced in the month of June and the highest depths experienced during January. Rainfall typically occurs in the form of short duration, intense convection thunderstorms. Droughts are endemic to the more semi-arid and arid regions and occasional flooding may occur during the summer months due to the convection thunderstorms and tropical disturbances (Limpopo SOE, 2004 as cited in Golder, 2017). The Mean Annual Evaporation (MAE) is more than three (3) times that of the Mean Annual Precipitation (MAP), with evaporation varying between 1 800 mm per annum and 2 000 mm per annum (Exxaro Services, 2013 as cited in Golder, 2017). The Köppen-Geiger climate classification index of the Lephalale region is Bsh; a hot semi- to arid environment (Figure 4: CSIR Köppen-Geiger map based on 1985 to 2005 South African Weather Services data on a very fine 1 km x 1 km grid (Conradie, 2012).) (Conradie, 2012).

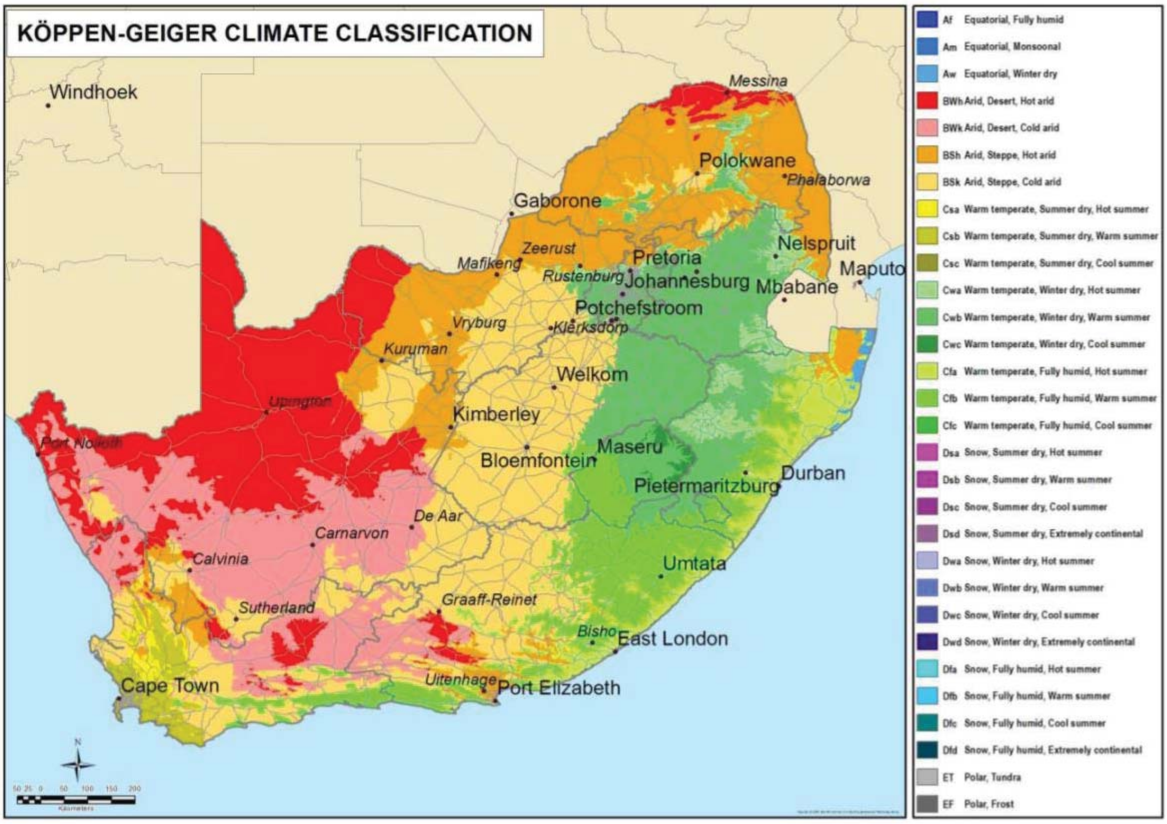


Figure 4: CSIR Köppen-Geiger map based on 1985 to 2005 South African Weather Services data on a very fine 1 km x 1 km grid (Conradie, 2012).Hydrological catchments

Figure 4) (Moatshe and Schulze, 2011). This is further broken down to 45 quaternary catchments.

The Waterberg District is managed under the Limpopo Water Management Area as well as the Crocodile (West) and Marico Water Management Area. Most rivers in the District drain to the Northwest direction towards the Limpopo River. Major dams in the District include the Mokolo Dam, the Doorndraai Dam and then Glen Alpine Dam.

The Lephalale town falls within the Mokolo hydrological catchment (quaternary catchment A42) and its primary water source is the Mokolo River. The Mokolo Dam was constructed to provide water to the power station and coal mines located near Lephalale. The dam has a full supply capacity of approximately 146 million m^3. The natural MAR at the dam site is estimated at 240 million m^3/a. The current groundwater resource is estimated at 11 million m^3/a and this is used to supply irrigation and domestic rural use.

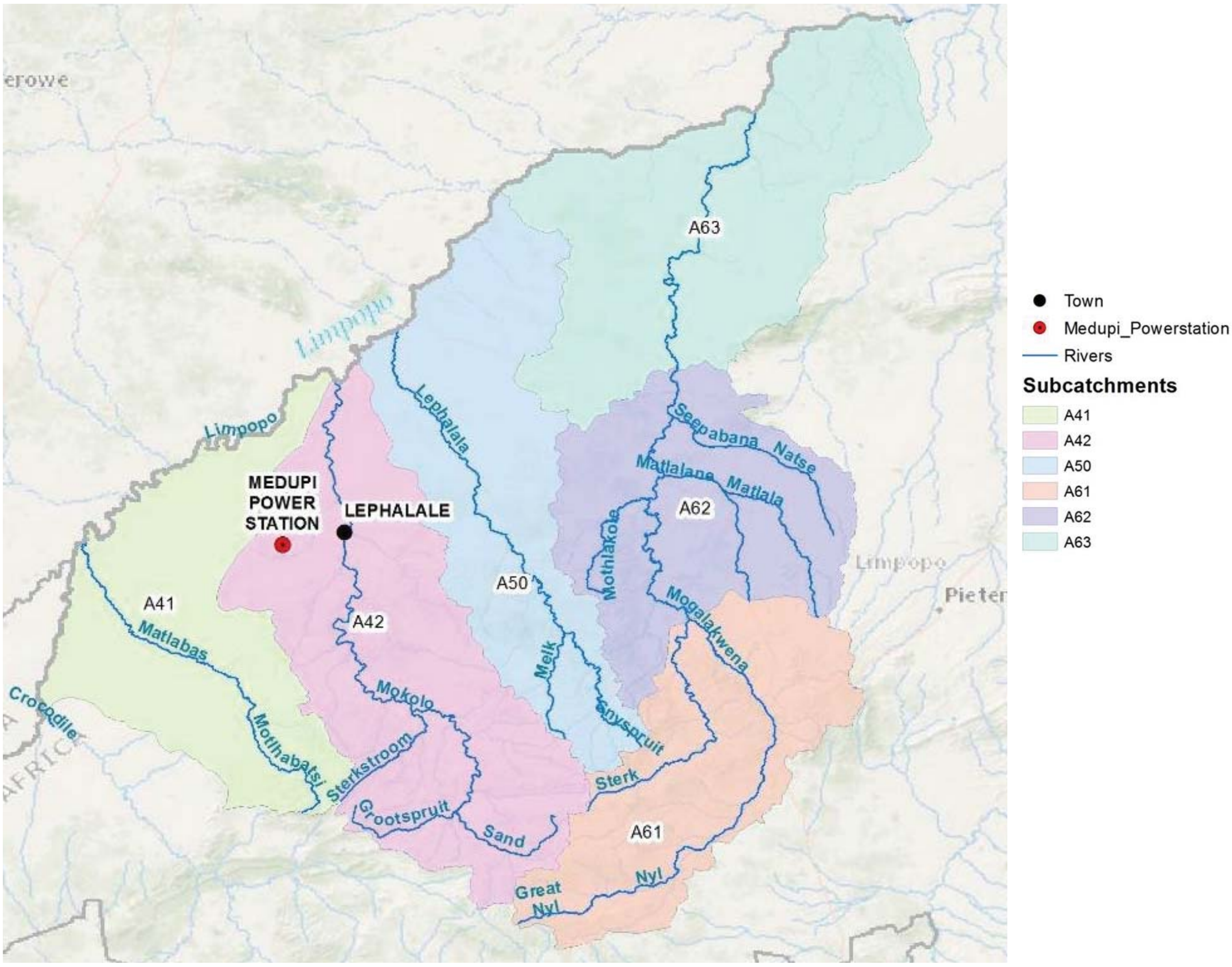


Figure 5: Catchments of the Waterberg District Municipality

Table 1.

Table 1: Average summer and winter minimum and maximum temperatures (Golder, 2013)

Season	Minimum (°C)	Maximum (°C)
Summer	11	40
Winter	0	28

In Lephalale, temperatures reach highs of approximately 35°C over the summer months and reduce to approximately 24°C over winter. It rarely gets colder than 8 degrees in the area and is considered a hot environment (Figure 6).

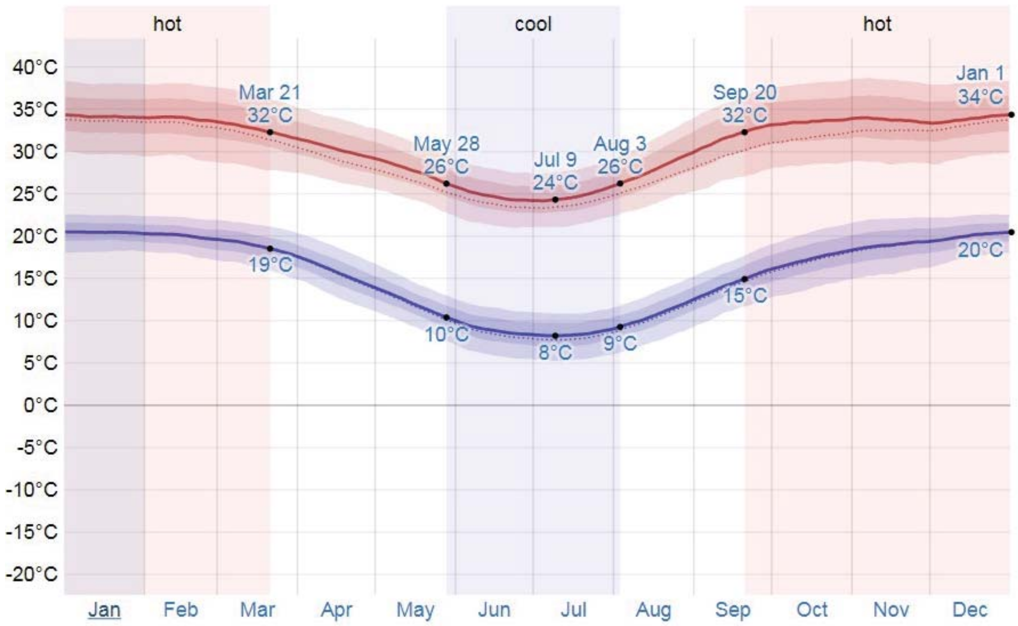


Figure 6: Average high and low temperatures for Lephalale (Weather Spark Beta, 2017).

3.4.2 Rainfall

The Waterberg District receives most of its rainfall in summer. The MAP of the Waterberg district ranges from < 200 mm to > 600 mm with the majority of the district catchment receiving between 400 and 600 mm of rainfall a year (Moatshe and Schulze, 2011). The area south-east of the Waterberg region receives more rainfall than the surrounding area. The least amount of rainfall occurs on the northern end of the delineated area (Figure 7). Available rainfall data from weather stations near Lephalale was used to generate the MAP (Table 2) and monthly rainfall patterns for the case study catchment area (Figure 7). From the Ellisras weather station data, the MAP was calculated as 463 mm (Figure 8).

Table 2: Average summer and winter minimum and maximum temperatures (Golder, 2013)

Station Name	Station Nr.	Years of data	Altitude (mamsl)	Longitude	Latitude	MAP (mm)
Grootgeluk	0674100W	95	908	27.34	23.40	483
Ellisras	0674400W	96	837	27.44	23.41	460
Grootfontein	0674429W	96	853	27.45	23.39	437

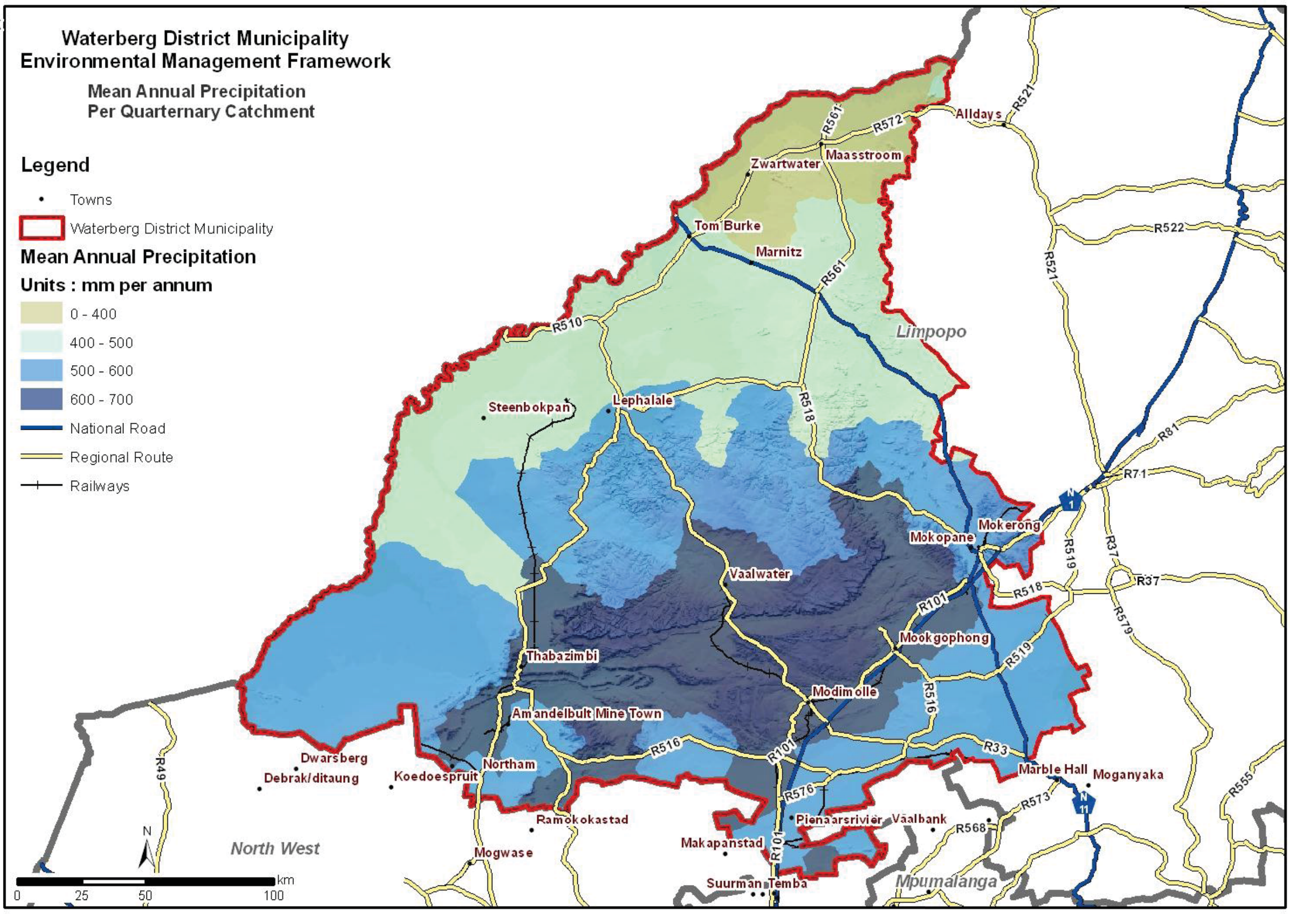
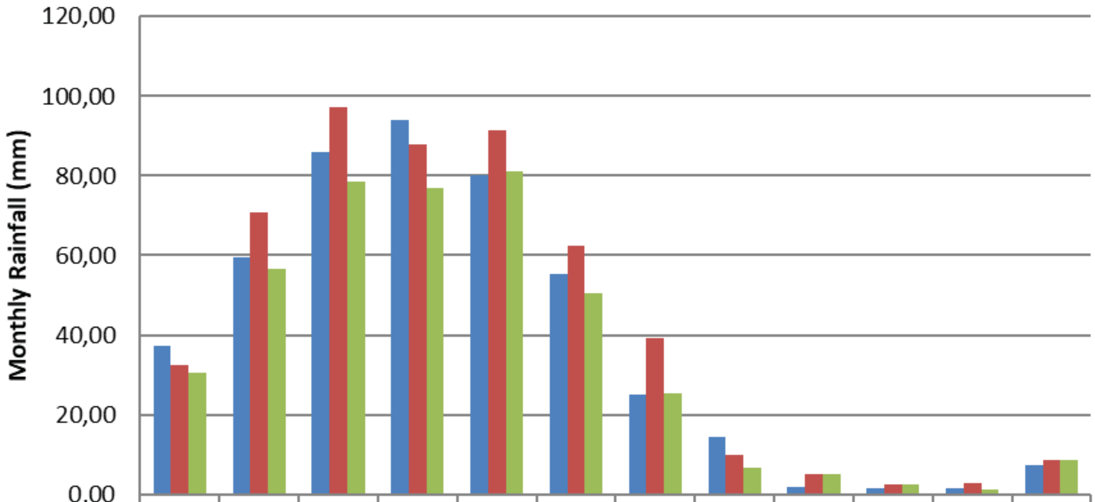


Figure 7: MAP of the Waterberg District (Dept. of Environmental Affairs, 2011).



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Grootgeluk	37,20	59,60	85,82	94,06	80,03	55,47	25,09	14,34	1,79	1,55	1,45	7,23
Ellisras	32,49	70,69	97,26	87,93	91,31	62,44	39,25	9,87	5,09	2,53	2,80	8,56
Grootfontein	30,35	56,57	78,42	77,06	81,07	50,45	25,39	6,63	4,89	2,56	1,09	8,75

Figure 8: Average high and low temperatures for Lephalale (Weather Spark Beta, 2017).

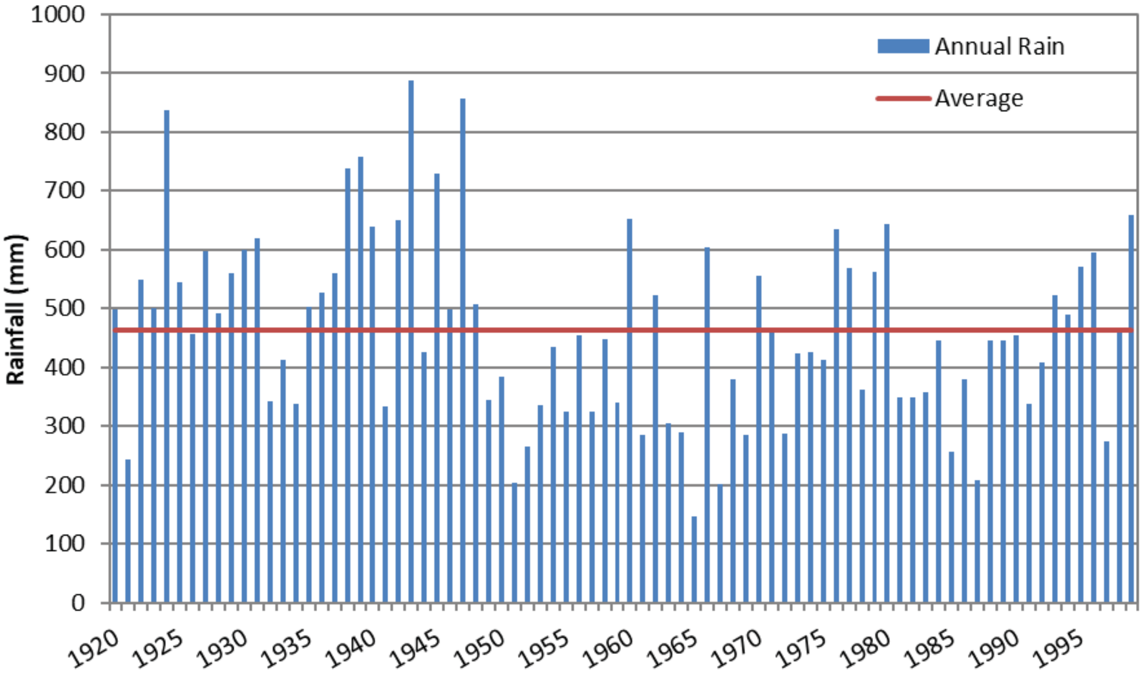


Figure 9: Average rainfall data for Lephalale (Weather Spark Beta, 2017).

3.4.3 Evaporation

The mean annual evaporation (MAE) in the Waterberg District is much higher than the MAP which results in the arid conditions of the area. For Lephalale, the MAE is 1908 mm (Figure 10).

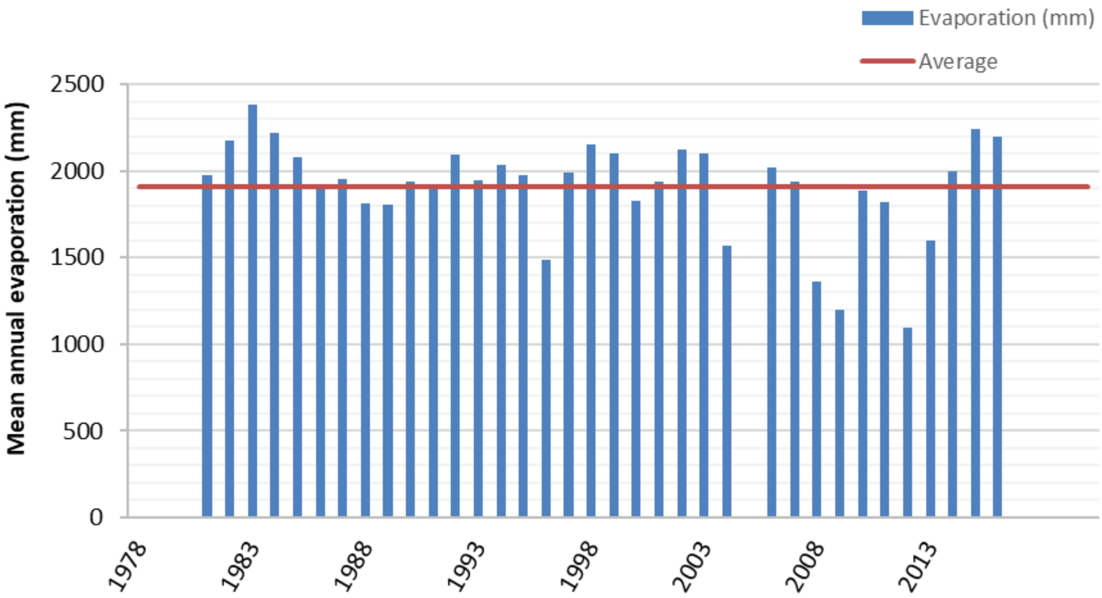
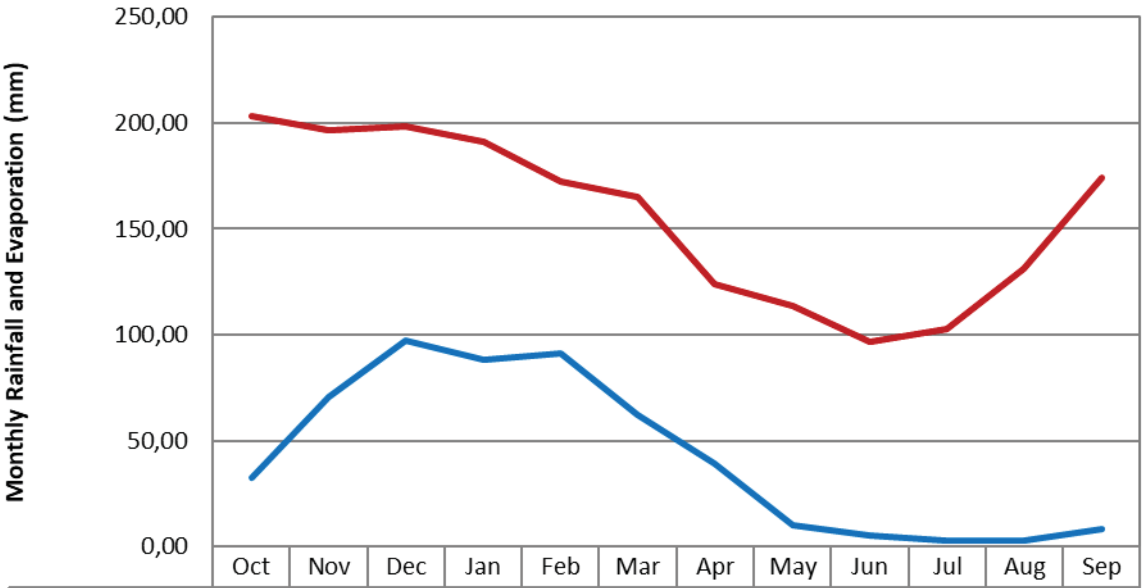


Figure 10: Mean annual evaporation of the Lephalale area (2017).

A monthly average comparison between the evaporation and the precipitation in Lephalale is shown in Figure 11 below. For all months of the year, evaporation is significantly higher than rainfall.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Ellisras	32,49	70,69	97,26	87,93	91,31	62,44	39,25	9,87	5,09	2,53	2,80	8,56
Evaporation	202,97	196,55	198,53	191,21	172,49	165,15	124,07	113,49	96,37	102,59	131,31	174,04

Figure 11: Comparison of monthly average rainfall and monthly average evaporation of the Lephalale area (2017).

3.4.4 Wind

The location of the weather stations used to derive the analysis the wind conditions of the Waterberg District area are given in Figure 12. The topography of the Waterberg District has a strong influence on the wind field. The wind direction and strength of six towns in the Waterberg region are presented in wind roses (Figure 13). The roses summarize the occurrence of winds at a location, representing their strength, direction and frequency. Calm conditions are defined as wind speeds less than 1 m.s-1. Each directional branch on a wind rose represents wind originating from that direction. Each directional branch is divided into segments of different colours which are representative of different wind speeds. (Dept. of Environmental Affairs, 2011).

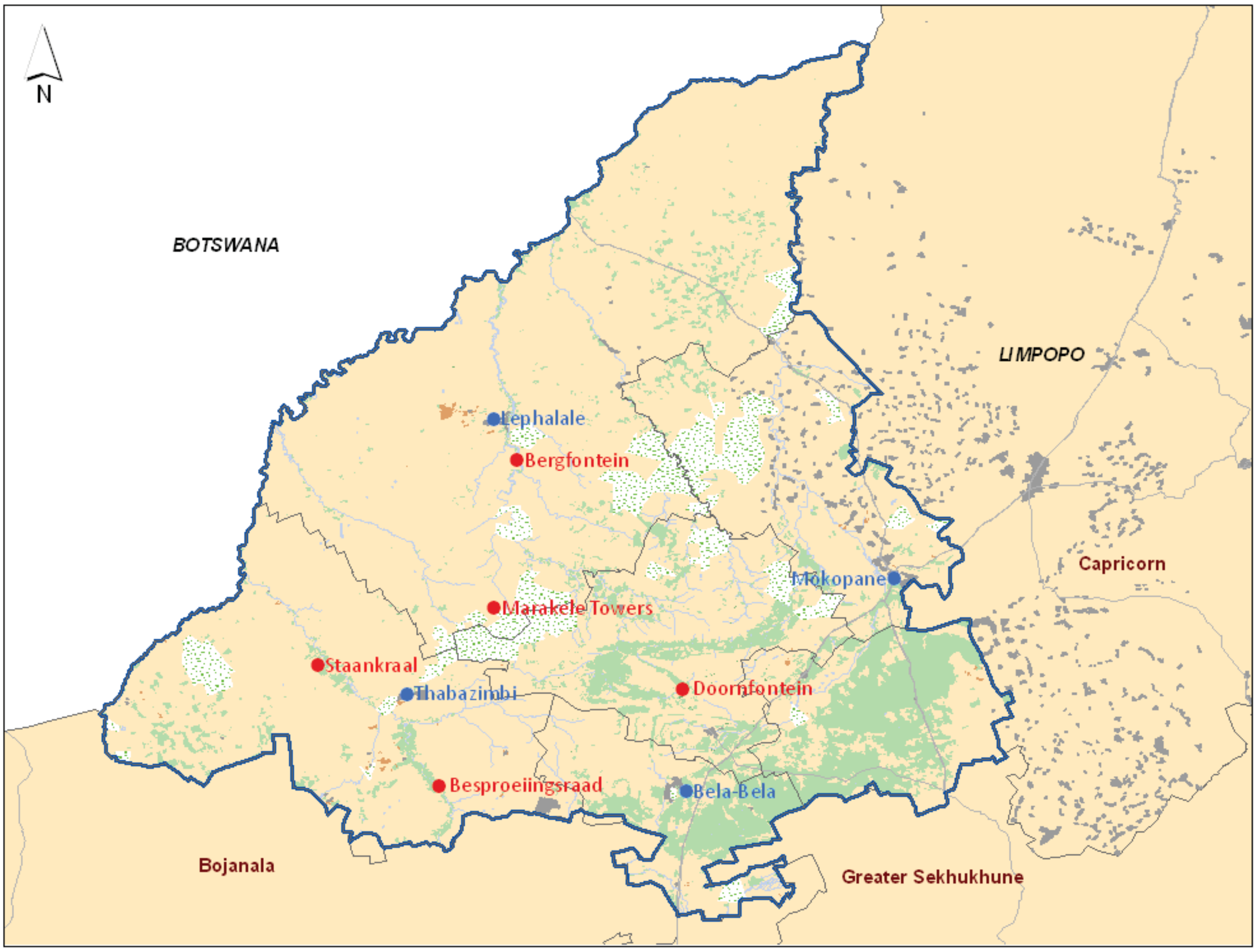


Figure 12: Weather stations in the Waterberg District (2017).

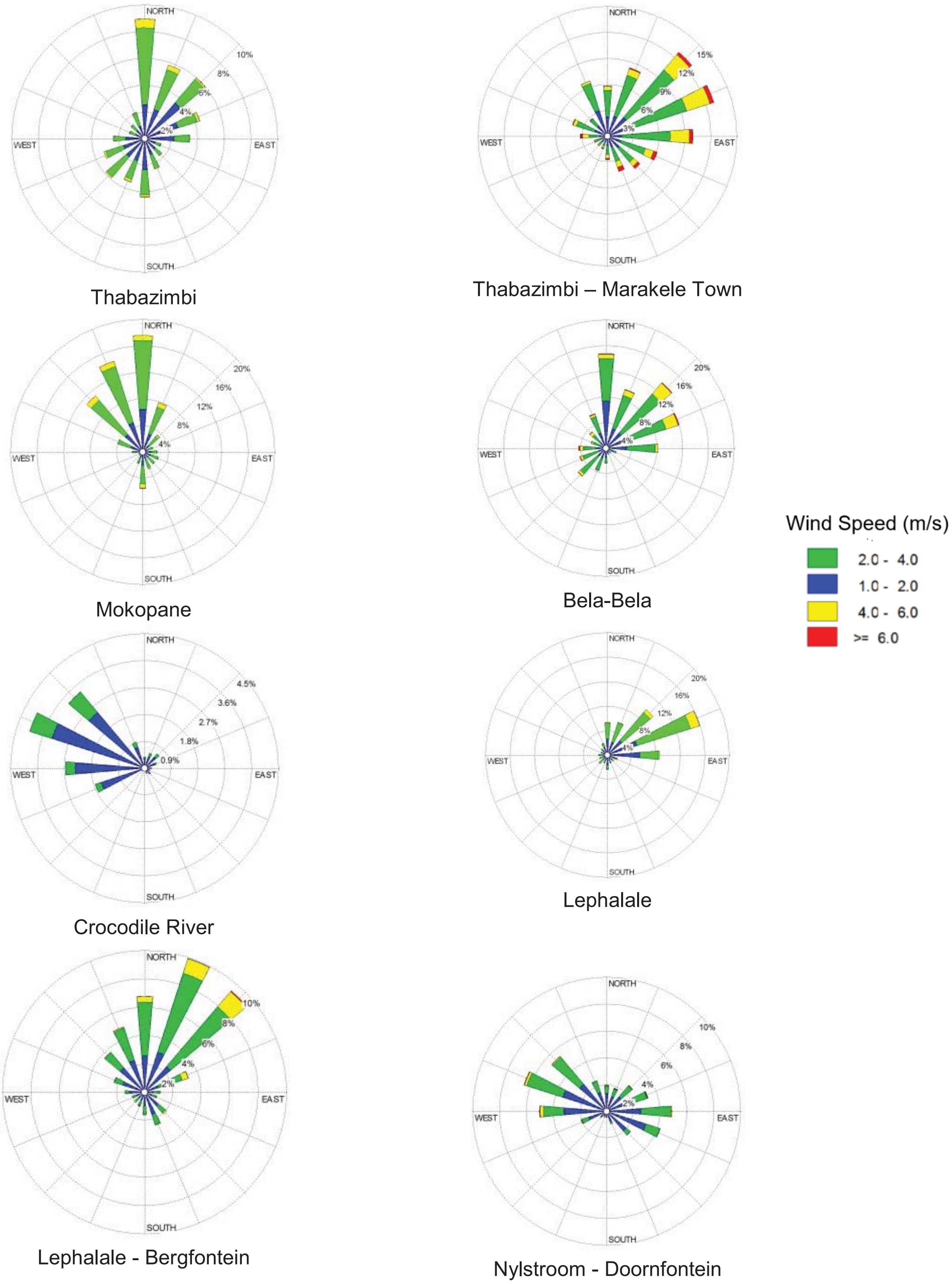


Figure 13: Wind roses for the different locations in the Waterberg District (Dept. of Environmental Affairs, 2011).

3.5 ANTHROPOGENIC DEVELOPMENT (2017)

The population of the Waterberg district is approximately 679 336 with a density of 15.13 per km^2 (Census, 2011). Mogalakwena and Lephalale local municipalities have the largest populations in the district (Table 3). Education levels are considered to be fairly low in the district with the working population earning in the salary ranges of either R 1000-R4000 per month or R 6400-R12800 per month income brackets (Department of Environmental Affairs, n.d.). Settlements tend to be dispersed except for the larger towns in the east and south. Densification is occurring in the centres of Lephalale, Mokopane, Thabazimbi and Bela-Bela (ibid.). Influences on settlement include mining activity, major transport corridors and tribal land demarcations (ibid.).

Table 3: Populations of the six local municipalities that make up the Waterberg District (StatsSA, Community Survey 2016, IDP draft, 2017).

Local municipality	Number of settlements	Population	%
Mogalakwena	178 villages 2 townships 1 town	325 291	43.62
Lephalale	38 villages 1 town 2 townships	140 240	18.81
Modimolle/Mookgophong	27 (Modimolle) 6 (Mookgophong)	107 699	14.44
Thabazimbi	1 town 1 township	96 232	12.90
Bela-Bela	7 farms and small holdings	76 296	10.23

Currently, the largest contributor to the GDP of the district is mining and agriculture. The agricultural sector employs the largest proportion of the population (Department of Environmental Affairs, n.d.). The power generation industry drives the extensive coal mining in the region primarily with the Matimba Power station in Lephalale and the Medupi Power station which has partially been commissioned. These has increased the demand for coal in the area. The iron, platinum and coal mining in the area has spurred the development of the district's largest towns. Positive growth is currently observed in three of the local municipalities, with Modimolle recording the largest growth (Department of Environmental Affairs, n.d.).

The main means of transportation is the road network comprising of the well-maintained national roadway, the N1, and linking regional roads R510 and R516. (Department of Environmental Affairs, n.d.). Rail links do exist between Lephalale and Thabazimbi, however, it currently cannot support the coal transportation demands which places more dependency on road-transportation for the mining industry. Small airfields are present in the larger towns of Thabazimbi, Lephalale, Bela-Bela, Modimolle and Mokopane however, they do not support commercial flights (ibid.).

Three developmental elements have been listed of national importance in the Integrated Development Plan (IDP) for the district. These are the currently constructed Medupi Power Station that will contribute to the national power generation, the Waterberg coal fields and Platinum Mines which drive the mining sector in the area and the heavy haul corridor from Lephalale to the south (Waterberg District Municipality, 2017).

3.6 INSTITUTIONAL ARRANGEMENTS

The institutional structure of the Waterberg DM is presented in the IDP (Waterberg District Municipality, 2017). The structure is shown in Figure 14.

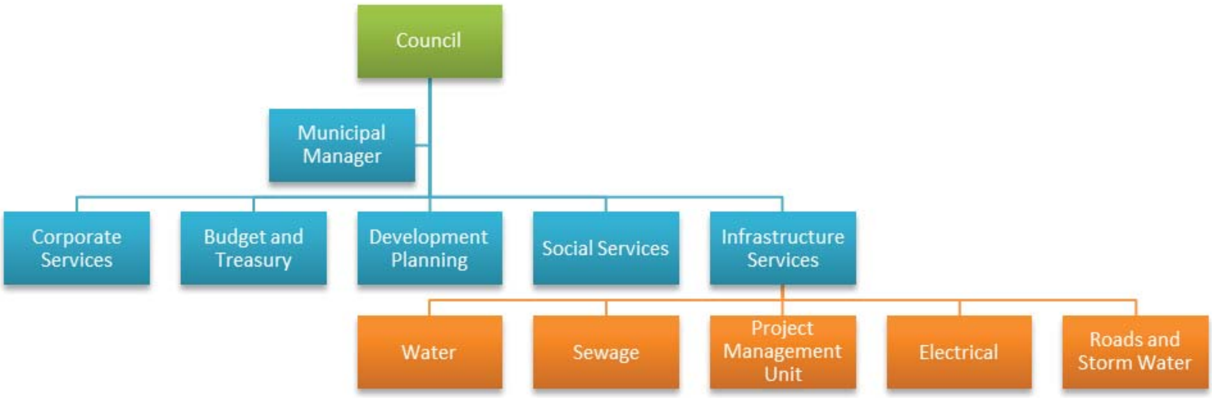


Figure 14: Waterberg District Municipality institutional structure (Waterberg District municipality, 2017).

As with most DMs, water, sewage, roads and stormwater are managed as separate units. It is important that these units meet on a regular basis to ensure alignment with policies and by-laws. Similarly, the development and planning group should ideally work closely with the infrastructure services group to ensure that infrastructure needs are incorporated at the planning stage.

3.7 WATER-RELATED CHALLENGES

Current water challenges for the Waterberg district are identified in the draft IDP of the district municipality, these include (Waterberg District municipality, 2017):

- Inadequate bulk water supply
- Ageing infrastructure
- Poor quality of drinking water
- Inadequate bulk water supply
- Inadequate funding
- Illegal connections, theft and vandalism

Most rural communities in the Waterberg District use boreholes and bulk water storage supply as their primary source of water. Coupled with the ageing infrastructure, the access to water of an adequate quality is becoming difficult to achieve, especially in Bela-Bela and Modimolle. There is also concern of poor mining and industrial water management which has the potential to impact the underground water quality. This is especially the case in Lephalale and Mogalakwena. (Waterberg District municipality, 2017). There is also inadequate water supply within the Mokolo catchment to meet the growing needs of the mining and industrial sector (energy generation) in the Lephalale area.

The listed challenges lead to a loss of revenue, inadequate service delivery, inefficient water use, as well as the inability to reach the Millennium Development Goals targets that have been agreed on a national level. Further, the challenges discourage potential and existing investors in the district (Waterberg District

Municipality, 2017). Possible solutions considered by the District officials include the upgrading of the region's water supply and the use of Municipal Infrastructure Grants (MIG) funding from the Department of Water and Sanitation (DWS) to invest in water resource protection (ibid.). The 2014 Blue Drop Assessment, a means of assessing drinking water quality at water treatment plants in South Africa (Department of Water Affairs, 2012), of the area found that the performance of the majority of the water treatment plants in the Limpopo Province ranged from very poor to critically poor. (Waterberg District Municipality, 2017).

3.7.1 Flooding in Waterberg

Recent flooding in the District is a concern to the District Municipality with the area of Lephalale being most at risk of flooding when the Mokolo and Phalala Rivers break their banks. The Thabo-Mbeki Township, Mamojela Park informal settlement and Magol farming communities are near the floodplain and are vulnerable to flooding. The Jabulani informal settlement of Thabazimbi Local Municipality has experienced flooding due to a mine dam overflowing during heavy rains. (Waterberg District Municipality, 2017). Other areas that have experienced flooding include the flooding of the R101 regional roadway, damaging the road significantly, and the township of Mahwelerane where children had to be assisted by a rescue team to cross over a flooding stream to access the nearby school. (Waterberg District Municipality, 2017)

3.7.2 Climate Change

Climate variability will impact a large proportion of the Waterberg population who live in vulnerable informal settlements and are at risk from climate change especially due to their low resilience to extreme climate events. Concerns of disease and inadequate housing infrastructure are raised in the IDP. Climate change will also impact the agriculture sector reducing the economic growth of one of the primary contributors to the GDP in the District. Climate change is predicted to intensify issues such as flooding, human health and environmental degradation in the District. Adaptation measures to climate change need to be developed for the District.

Lephalale is the largest polluter in the district due to its industrial development which is responsible for 95.9% of greenhouse gas emissions of the area. Vehicular movement also contributes to the greenhouse gas emissions of the town. Due to this, the Lephalale municipality has been identified as an air quality hot spot.

The key environmental issues which will be further affected by climate change in the District are listed in Table 4.

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Table 4: Key Environmental Issues in the Waterberg District (Waterberg District Municipality, 2017)

Key Environmental Issues of the Waterberg District Municipality	
Waterberg District	• Mining • Deforestation • Governance • Veld fires

Key Environmental Issues by Local Municipality	
Modimolle	• Governance • Waste management • Alien invasive species • Spatial Development Framework (SDF): no environmental sensitive areas – new developments are allowed in wetlands • Housing in flood planes or landfill sites
Mookgophong	• Waste management • Governance • Deforestation • Alien species invasion
Bela-Bela	• Governance • Waste management • Deforestation
Lephalale	• Air pollution – mining • Ground water availability • Deforestation • Governance
Thabazimbi	• Mining • Waste management • Governance
Mogalakwena	• Mining • Alien Invasion • Deforestation

Concerns have been raised on the impact of climate change on the water resources of the district. Climate change impacts may result in erratic, unpredictable changes in the hydrological cycle affecting the availability of water for irrigation and drinking. Higher air and water temperatures can contribute to the increased incubation and transmission of water-borne diseases. Higher water temperatures will further impact temperature-sensitive fish populations. Lower oxygen concentrations in water sources has the potential to increase the fish mortality rate.

Increased flash flooding raises significant concerns to the ecosystem and human settlement, threatening the functionality of stormwater systems due to blockage and increased flood peaks and flood frequency. The increase in flood peaks could result in significant bank erosion and encroachment towards nearby settlements. Flooding will also further disperse pollution to areas downstream. Conversely, more frequent and intense drought may occur affecting the reliability of supply from water supply systems. The more frequent periods of lower flow will reduce the assimilative capacity of the river systems which could result in the deterioration of the water quality due to the reduced dilution of wastewater discharges and irrigation return flows placing larger strain on treatment works and ecosystems who receive this water.

3.8 LONG TERM PLANNING

The environmental management framework of the Waterberg District (Department of Environmental Affairs, n.d.) describes the development plan for the area. The Water Requirements and Return Flows of the Limpopo region have been forecast based on projected development in the region (Mhlanga and Robertson, 2015). The development of the area is forecast based upon the expected economic development and human settlement which supports these economic activities (Department of Environmental Affairs, n.d.). The development is also governed by the climate, physical opportunities and limitations (ibid.).

The Environmental framework recognises mining and agriculture as the two primary activities which spurs development in the district (Department of Environmental Affairs, n.d). The platinum and coal mining activities near the towns of Lephalale and Mokopane has significant potential to further drive development of the towns. The Matimba and Medupi coal-fired power stations are driving the coal mining industry in the Lephalale area. With Medupi Power station presently under construction, the demand remains relatively low, however, once in operation, it is predicted the demand will increase substantially (Mhlanga and Robertson, 2015). There is also a possibility of establishing and expanding platinum mines near Mokopane. The negative impacts of mining expansion include the reduction of the natural landscape as well as the loss of farmland. (Department of Environmental Affairs, n.d.). Mining infringes on the District eco-tourism economic sector and is considered a serious threat/challenge in the Biosphere Reserve Area (Waterberg District Municipality, 2017).

In terms of agriculture, the largest developmental region occurs on the “Springbok Flats” in the south-east of the district. Game and cattle farming is also popular in the Steenbokpan area. Lephalale Municipality has proposed the expansion of agricultural activities which will require the expansion of the region’s irrigation schemes. Another agricultural hub is the Modimolle town which also plans on expanding the industry. (Department of Environmental Affairs, n.d.). Development projects and opportunities have been identified and include the Waterberg Agriculture training project, community game farm projects and organic vegetables projects to name a few. (Department of Environmental Affairs, n.d.). The Mookgophong municipality also intends on building their already dominant agriculture industry with the expansion of citrus, spices and granadilla production, hydroponics and game farming. An important consequence of the expanding agriculture is the loss of biodiversity. This is further worsened by poor land management of farming leading to overgrazing and habitat destruction (ibid.).

The integrated development plan for the district acknowledges the importance of water infrastructure to develop the region and have listed major water projects to ensure the adequate and reliable supply of water for economic and social sectors. These include the listed projects (Waterberg District Municipality, 2017):

- Mooihoek/Tubatse Bulk Water Scheme
- Sekhukhune Bulk Water Scheme
- Moutse Bulk Water Scheme
- Mogalakwena Bulk Water Supply
- Mametja Sekororo Regional Water Scheme
- Nebo Bulk Water Supply

- Sinthumule Kutama Bulk Water Supply
- Giyani Water Services, and
- Giyani Bulk Water Supply Drought Relief

3.9 WATER RECONCILIATION

The water demand of the Waterberg District was investigated by Mhlanga and Robertson (2015) under the 'Limpopo Water Management Area North Reconciliation Strategy' project. The water requirements for the northern Limpopo water management region in which the Waterberg District falls was the focus area. The study took account of the potential development of the mining, industry and power generation sector in the area as well as agriculture and domestic water use projections.

The 2010 irrigation level is considered the current water demand for the region until 2040. The findings of the study show that irrigation is the largest water use sector using 465 million cubic meters per annum (Mhlanga and Robertson, 2015). In total, the water requirements for the Northern Limpopo Water Management region is 644 million m^3/annum as shown in Figure 15. The total water requirements for the Waterberg Region is 307 million m^3/annum and is summarised in Table 5.

The power generation, mining and industry are currently low water use sectors and irrigation dominates the water use in the region. From the predictions, irrigation will remain the largest water requirement sector in the area. However, predictions show that the power generation, mining and industry will be a significant water use by the year 2040. The water requirement is projected to increase from 17.0 million m^3/annum at the 2010 development level to 192.9 million m^3/annum in 2040 as presented in Figure 15. The Mokolo River Catchment has the largest demand from the power generation and mining industries. The two power stations, Matimba and Medupi, are large drivers for the growth in water demand. The water for the two power stations will be supplied by the Mokolo Crocodile Water Augmentation Project (Phase 2) (Table 6). The mining industry also places a large demand on future water use for the area as tabulated in Table 6. This large mining and power generation development also drives urbanization in the region resulting in a higher domestic urban water demand proportional to the mining and power generation industry.

Table 5: Summary of total water requirements in the Waterberg Region (Mhlanga and Robertson, 2015).

Matlabas River catchment: Water requirements (million m^3/a)				
Sector / type	**2010**	**2020**	**2030**	**2040**
Irrigation	4.7	4.7	4.7	4.7
Domestic	0.0	0.0	0.0	0.0
Mining, industrial and power generation	0.0	6.0	6.0	6.0
Livestock	2.3	2.3	2.3	2.3
IAP and commercial forestry	0.0	0.0	0.0	0.0
Total Matlabas water requirements	**7.0**	**13.0**	**13.0**	**13.0**
Mokolo River catchment: Water requirements (million m^3/a)				
Sector / type	**2010**	**2020**	**2030**	**2040**
Irrigation	40.2	40.2	40.2	40.2
Domestic	4.6	5.2	6.1	7.0
Mining, industrial and power generation	18.3	35.8	86.3	110.4
Livestock	2.1	2.1	2.1	2.1
IAP and commercial forestry	0.0	0.0	0.0	0.0
Total Mokolo water requirements	**65.2**	**83.3**	**134.7**	**159.7**

Lephalala River catchment: Water requirements (million m^3/a)				
Sector / type	**2010**	**2020**	**2030**	**2040**
Irrigation	69.8	69.8	69.8	69.8
Domestic	2.8	3.2	3.6	3.9
Mining, industrial and power generation	0.0	0.0	0.0	0.0
Livestock	2.4	2.4	2.4	2.4
IAP and commercial forestry	1.2	1.2	1.2	1.2
Total Lephalale water requirements	**76.2**	**76.6**	**77.0**	**77.3**
Mogalakwena River catchment: Water requirements (million m^3/a)				
Sector / type	**2010**	**2020**	**2030**	**2040**
Irrigation	99.4	99.4	99.4	99.4
Domestic	29.9	37.1	47.9	56.3
Mining, industrial and power generation	15.3	24.8	37.8	37.8
Livestock	11.5	11.5	11.5	11.5
IAP and commercial forestry	2.6	2.6	2.6	2.6
Total Mogalakwena water requirements	**158.7**	**175.4**	**199.3**	**207.6**
TOTAL WATERBERG DISTRICT	**307.1**	**348.3**	**424**	**457.6**

Additional water requirements at the power stations are summarised in Table 6.

Table 6: Water requirements for power generation to be supplied by MCWAP (million m^3/a).

Project	2010	2015	2020	2025	2030	2035	2040
Matimba Power Station	4.67	3.60	3.60	3.60	7.60	7.60	7.60
Medupi Power Station	0.66	6.00	10.40	15.40	15.40	15.40	15.40

Expansions planning in the mining industry will also lead to increased water demands as presented in Table 7.

Table 7: Mining future water requirements (million m^3/a) (Mhlanga and Robertson, 2015).

Catchment	2010	2015	2020	2025	2030	2035	2040
Matlabas	0.00	0.00	7.97	7.97	7.97	7.97	7.97
Mokolo	11.20	14.11	35.77	61.99	86.34	89.92	110.42
Lephalale	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mogalakwena	1.59	4.20	14.73	19.84	25.87	25.87	25.87
Total	**16.99**	**19.04**	**85.17**	**125.8**	**163.66**	**172.84**	**193.34**

The total water requirements of the Limpopo North Water Management region are shown in Figure 15.

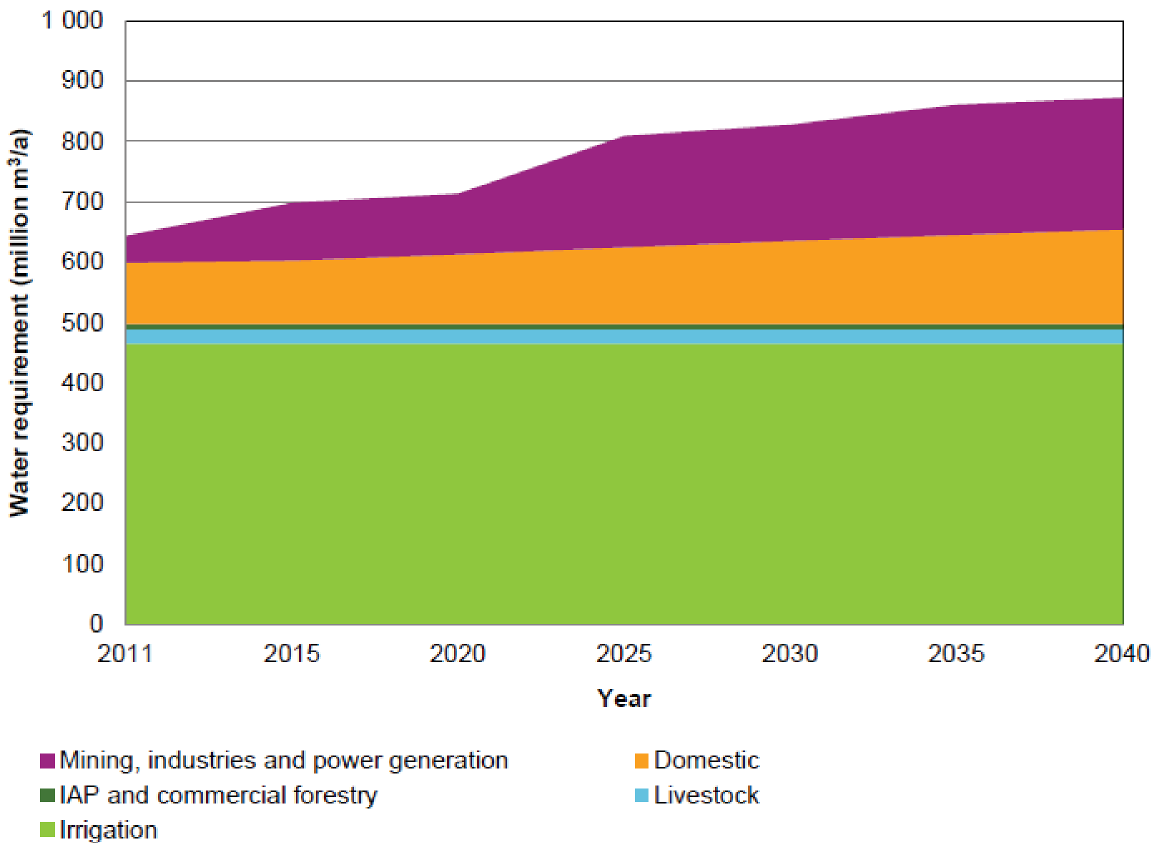

Figure 15: Water requirements of the Northern Limpopo Water Management region.

The study concludes that the water requirements for the Limpopo North Water Management area are projected to rise by approximately 30% in 2040. Given the uncertainty of the impacts of climate change, the water required by the area to achieve the expected growth may be larger. Erratic climatic conditions, such as droughts and heavy rainfalls, may lead to an instability in water supply. This motivates for the use of water sensitive urban design to be implemented in the area to improve water use efficiency to reduce water wastage and conserve water to buffer the effects of climate change and the increased demand on water supply in the area.

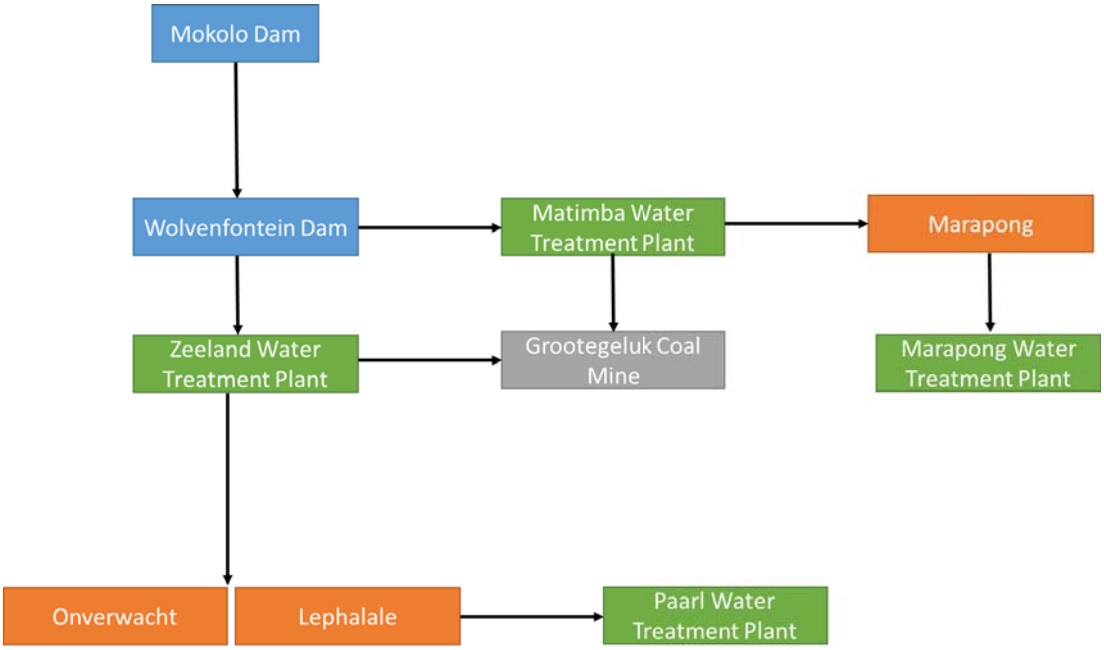

Figure 16: Water supply, consumption and distribution summary for the study area

3.9.1 Water availability and supply

The following water quantities of the available water have been reported by the 2016-2017 IDP (Lephalale Local Municipality, 2016).

Boreholes

- Bulk water abstracted from boreholes for 4 rural supply areas with a total of 138 municipal boreholes
- Potential abstraction reported, actual demand and yield not known
- Potential abstraction 1.5 million m^3/annum

Mokolo Dam

- 145.4 million m^3 capacity
- Historic Firm Yield 38.7 million m^3/a with recurrence interval of 1:224 years (DWS, 2015).
- 27 million m^3/annum yield allocated to Lepehale area.

Water supply from the Mokolo Dam

- Total: 27.6 million m^3/annum
- Agriculture: 10.4 million m^3/annum
- Matimba Power Station: 7.1 million m^3/annum
- Grootegeluk Coal Mine: 10.1 million m^3/annum
- Lephalale Municipality: 5.0 million m^3/annum (accounted in the Matimba and Grootegeluk demand)

3.9.2 Water treatment plants

Potable water

- Zeeland Water Treatment Plant: 7.3 million m^3/annum
- Matimba Water Treatment Plant: 8.4 million m^3/annum

Sewage Treatment Plants

- Three treatment plants: Marapong, Paarl, New Plant
- Overall 3.9 million m^3/annum capacity
- 2.5 million m^3/annum used
- Note that only 40% of households are connected to the sewer system

Water losses/consumed/unaccounted

- 0.8 million m^3/annum

3.9.3 Water Requirements breakdown

The breakdown of the domestic water requirements per land use has been calculated by i@Consulting (2017). The breakdown is indicated in Table 8. The calculations indicate that low density residential areas account for 88% of the total water demand. i@Consulting (2017) note that Lephalale Municipality by comparison consumes 7 times more per low density residential stand than the neighbouring Mogalakwena Municipality. The reason for the large demand was attributed to higher income in Lephalale, warmer climate, lower water costs and possible water meter errors.

Table 8: Water demand per land use i@Consulting (2017).

Land Use	Million m^3/annum
Educational	0.56
Government	0.07
Industrial	0.13
Institution	0.17
Municipal	0.13
Private open space	0.16
Public garage	0.06
Public open space	0.02
Low density residential	29.25
Medium to high density residential	0.99
Business	1.59
Total	**33.14**

3.10 FINANCIAL MANAGEMENT WITHIN THE WATERBERG DISTRICT MUNICIPALITY

The Waterberg DM is faced with financial challenges that makes it difficult to dedicate budget to the restoration and expansion of water infrastructure in the area. The financial management issues and challenges are discussed in the draft IDP of the Waterberg District Municipality (2017).

One of the issues raised was the lack of financial resources to provide water, electricity, sanitation, solid waste management and community facilities. Given the water requirement forecast for the area, this issue will only compound. Many municipalities of the Waterberg DM are currently in debt and the debt is increasing. Indigent populations are also large, and many are not registered and thus unaccounted for in strategic planning. Another challenge faced by the Waterberg DM is inadequate project management and supply chain management systems. There is also a lack of funding for capital expenditure to support economic growth in the district, coupled with aging infrastructure that requires renovation. Anti-corruption strategies are also not well implemented in the district area. Internal audits are poorly managed and external audits have negative reports; however, this challenge is improving. The district municipality is almost solely dependent on government grants.

3.11 INTERESTED AND AFFECTED PARTIES (IAPS)

The social aspects of the project will require engagement with interested and affected parties to ensure that any design approaches improve the livelihood of all stakeholders and consider cultural needs and perceptions present in the area. From a reference group meeting held for the initiation of the project, the following individuals and/or groups have been identified as Interested and Affected Parties (IAPs) (Table 9) in Lephalale. Further engagement with the listed IAPs will assist in highlighting key water-related issues and potentially highlight the causes, implications and mitigations for them.

Table 9: IAPs identified for the feasibility study of WSD in Lephalale.

Interested and Affected Parties (IAPs)	Role
Community residents	Critical
Existing industries (Glencore and Eskom representatives	Critical
Project managers of planned industrial and residential developments	Critical
Dept. of Water and Sanitation regional officers	Critical
Dept. of Environmental Affairs regional officers	Moderate
Dept. of Health regional officers	Minor
City Planning management officials	Critical
IDP committee for the Lephalale municipality	Minor
Provincial management officials	Moderate
Local/Municipal management officials	Moderate
Farming communities in the area	Moderate
Agricultural governing body (AgriSA)	Moderate
Any other water users	NA

CHAPTER 4: BASELINE WATER BALANCE FOR MOKOLO CATCHMENT

A hydrological catchment model was developed for the Mokolo Catchment. The model was developed to evaluate the inflow to and demand from the Mokolo Dam upstream of Lephalale, Grootegeluk Mine and Eskom's Matimba and Medupi coal fired power stations.

Runoff from the catchment was modelled using the Australian Water Balance Model (AWBM) and a stochastic rainfall simulator. The simulator was calibrated to ensure the rainfall sequences generated are statistically equivalent to the long-term historic record selected. The long-term rainfall data was sourced through the Daily Rainfall Data Extraction Utility (Kunz, 2004).

The runoff model was calibrated to historical data from the WR2012 study (Bailey and Pitman, 2015) modelled using the WRSM/Pitman Model. The development and calibration of the runoff model is summarised in Section 4.1 to Section 4.3 of the report. The complete catchment model (Section 4.4) was developed using GoldSim and applied in the evaluation of different WSD options for the Lephalale region and the water usage downstream of the Mokolo Dam.

4.1 WR2012 AND WSRM/PITMAN MODEL

The WR2012 study is the sixth comprehensive water resources assessment to be undertaken in South Africa (incl. Lesotho and Swaziland) (DWS, 2015). This study has along with its predecessors played a substantial role in providing key hydrological information to water resources managers in the South African water sector.

For the 1981 assessment, the 22 main drainage regions of South Africa were assembled under six groups which were dealt with in six corresponding report volumes, for each of which there are reports in two parts. For the 1990 Study (WR90), the same grouping of the main drainage regions was retained and dealt with again in six volumes, but for each of these the report was in three parts: a User's Manual, which is common to all six volumes, a set of Appendices and a Book of Maps. In the WR2005 study, there were three main documents used, an Executive Summary, a User's Guide and a Book of Maps (Middleton and Bailey, 2005).

The Water Resources Simulation Model 2000 (WRSM2000) was chosen as the model to be used on the WR2005 study. The WRSM 2000 was developed as a Windows based monthly hydrological system model that simulates the movement of water through an interlinked system of catchments, river reaches, reservoirs and irrigation areas.

Each water resource assessment study built on the previous study and the technology and knowledge gained from it. The WR2012 study built on the previous WR2005 assessment by using updated and new data and information as well as new tools and technology. As part of the WR2012 study a website has been developed that describes the water resources of South Africa, Lesotho and Swaziland. This website is a culmination of several water resource appraisals that have been carried out over the past four decades. The intention of the website was to provide all the data, information, GIS maps, water resource models, spreadsheets and tools with regards to the past and current South African water resources studies to allow water resource practitioners to investigate, analyse and plan their own water resources studies. All this information is available on the WR2012 website (DWS, 2015). A schematic of the website and menu system headings is shown in Figure 17.

• GIS maps; • WRSM2000 (Pitman) rainfall-runoff model; • WR2005 database; • Reports; • Quaternary data spreadsheets; • Patched observed streamflow data; • Catchment rainfall groups; Catchment based rainfall	• Point rainfall; • Naturalised streamflow; • Water quality; • Monitoring; • Land/water use; • Present day streamflow

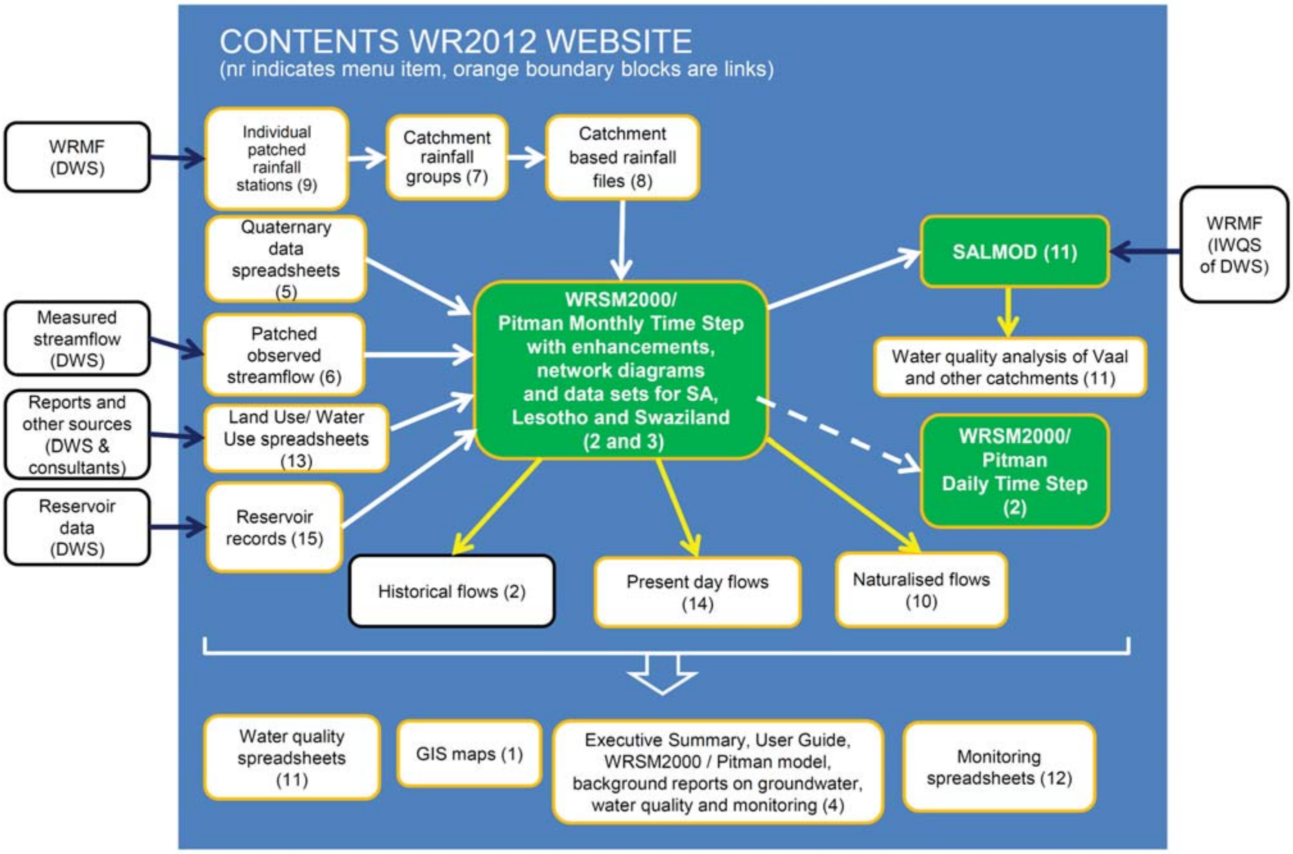

Figure 17: WR2012 Website schematic (DWS, 2015).

As can be seen from Figure 17, the WRSM/Pitman rainfall-runoff model was a key part of the WR2012 assessment. Outputs from the WRSM/Pitman model are used as the primary inputs to the Department of Water and Sanitation's water resources planning models.

The underlying theory of the WRSM/Pitman rainfall/runoff model was first described in Hydrological Research Unit (HRU) Report No. 2/73 "A Mathematical Model for Generating Monthly River Flows from Meteorological Data in South Africa", published in 1973 (Bailey and Pitman, 2015). Shows an adapted flow chart of the theory behind the original Pitman model from the 1973 HRU report.

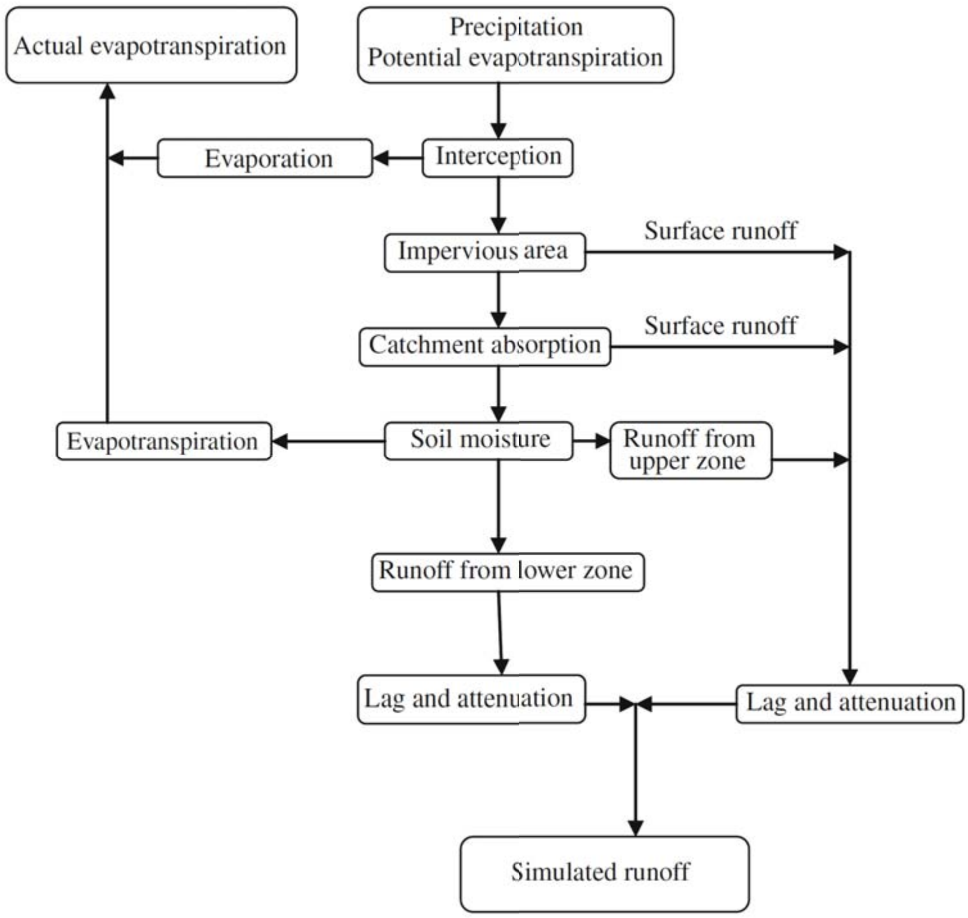

Figure 18: A flow chart of the original Pitman model (Ndiritu, 2009).

The WRSM/Pitman monthly time-step model was used to analyse all catchments in South Africa, Lesotho and Swaziland with data up to September 2010. As discussed, these networks and data sets are included on the WR2012 website for users to develop their own analyses.

4.2 RAINFALL ANALYSIS

The catchment-based rainfall datafiles from WR2012 are monthly datasets of percentage rainfall of the MAP of the specific catchment. For the Mokolo River Catchment, the WR2012 study developed 3 catchment-based rainfall files applicable to the nine sub-catchments or quaternary catchments of the Mokolo River Catchment. The nine sub catchments of the Mokolo River Catchment (A42A to A42J) are shown as part of the WRSM schematic in Section 4.3.1 and modelled within the WRSM application as runoff modules RU1 to RU9. Table 10 shows the relation of the Mokolo River sub-catchments to the WRSM runoff modules and the catchment-based rainfall datafiles from WR2012. Figure 19 shows a summary example of the A4C rainfall data file.

Table 10: Mokolo River catchments and rainfall datafiles

DWS Tertiary Catchment	DWS Quanternary Catchment	WRSM Runoff Module	Rainfall Datafile
A42	A42A	RU1	A4C
	A42B	RU2	
	A42C	RU3	
	A42D	RU4	A4D
	A42E	RU5	
	A42F	RU6	
	A42G	RU7	A4E
	A42H	RU8	
	A42J	RU9	

```
                          DETAILS OF RAINFALL STATIONS USED
      SECTION   POSITION   MAP(mm)   PERIOD OF RECORD   LATITUDE
LONGITUDE

       588         721       644       1917 TO 2009      24.31
27.55
       589         342       702       1910 TO 1939      24.42
28.12
       589         342       702       1941 TO 1952      24.42
28.12
       589         371       654       1950 TO 2004      24.41
28.13
       589         670       640       1913 TO 1938      24.40
28.23
       589         670       622       1941 TO 1942      24.40
28.23
       589         670       592       1944 TO 1967      24.40
28.23
       589         670       666       1970 TO 1993      24.40
28.23
       632          89       676       1948 TO 2009      24.29
28.03
       632         137       601       1918 TO 1948      24.17
28.05
       632         198       608       1964 TO 2009      24.18
28.07
       632         297       617       1911 TO 1973      24.27
28.10

                                RAINFALL INPUT AS PERCENT M.A.P.
 YEAR STNS.   OCT    NOV    DEC    JAN    FEB    MAR    APR    MAY    JUN
JUL   AUG    SEP    YEAR

 1920   5    23.44  11.43   7.10  20.17  19.58  34.72   5.36   5.77
0.00  0.00   0.00   0.04  127.62
 1921   5     9.33  34.18  21.45  13.29   9.66   8.06   0.45   2.44
0.71  0.00  12.73   1.01  113.31
 1922   5     9.68  14.82  14.38  50.99   8.80   6.65   1.95   1.80
0.30  0.05   0.00   1.55  110.96
```

Figure 19: A4C WRSM Rainfall Datafile extract.

For the stochastic rainfall simulator, historical daily rainfall data was sourced from the Daily Rainfall Data Extraction Utility (Kunz, 2004). This historical data was clipped to fit the exact period of record used for the WR2012 rainfall datafile (Figure 19), and a daily weighted average calculated for the different rainfall gauges used. These values were then summed to monthly totals. The rainfall input as percentage of MAP from Figure 19 was multiplied by the historical MAP from the WR2012 runoff modules to also obtain monthly rainfall totals for the nine different runoff modules. The monthly totals from historic daily rainfall data was compared to the monthly rainfall totals from the WR2012 catchment-based rainfall files and was found to have adequate correlation as shown in Figure 20.

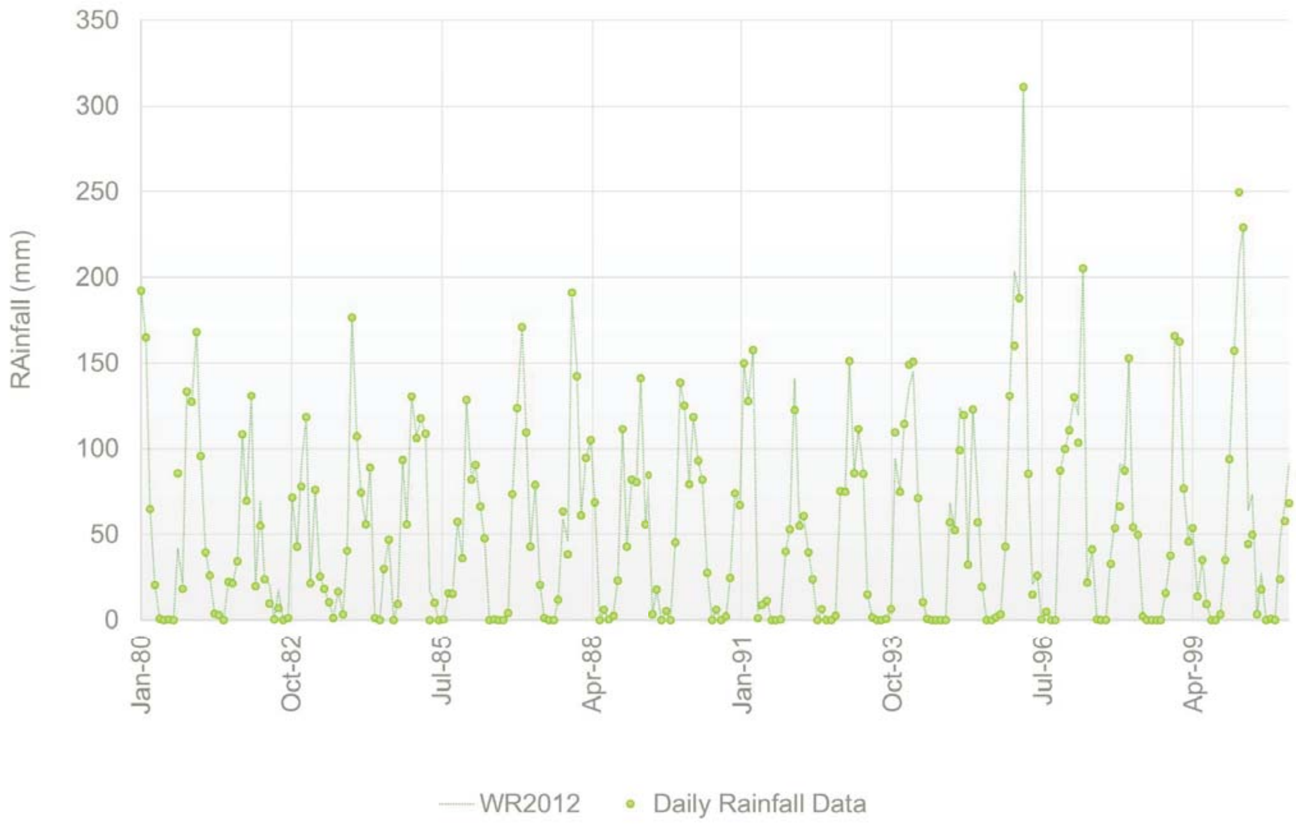

Figure 20: Rainfall data comparison.

As a result of the above correlation, the historical daily rainfall data was sourced from the Daily Rainfall Data Extraction Utility (Kunz, 2004) was used in the stochastic rainfall simulator and daily Catchment Water Balance Model.

4.3 RUNOFF MODELS

An integral part of the assessment of WMA's is the hydrological modelling of the associated water resources. The main water resource within the Lephalale region is the Mokolo River and more specifically the Mokolo Dam upstream of Lephalale on the Mokolo River.

An integral part of the evaluation of the effect of WSD on the Lephalale region includes a thorough understanding of the Mokolo River Catchment water balance. Central to the water balance is the rainfall-runoff relationship that would be modelled using the WRSM/Pitman model.

The rainfall-runoff relationships for several sub-catchments within the Mokolo River Catchment were modelled and used to evaluate the need for and possible effects of WSD. The following sections of the report discuss how the WRSM and WR2012 data was used to calibrate the AWBM to model the upstream runoff and inflow into the Mokolo Dam. Following the successful modelling of the inflow to the Mokolo Dam, a stochastic rainfall simulator was used to predict future rainfall and subsequent runoff both upstream and downstream of the Mokolo River. The Limpopo Water Management Area North Reconciliation Strategy (DWS, 2015) was then used to calculate future water demand estimates for the Mokolo Dam.

The development and calibration of the different runoff models and future water demand estimates culminated in the modified Mokolo River Catchment Water Balance (focussing on the Mokolo Dam operations) which is discussed in Section 4.4 of the report.

4.3.1 WRSM

The Water Resources Simulation Model 2000 (WRSM2000) was used as the model for the WR2012 water resource study for South Africa, Lesotho and Swaziland. Figure 21 shows a schematic of the WRSM model for the Mokolo River Catchment, A42.

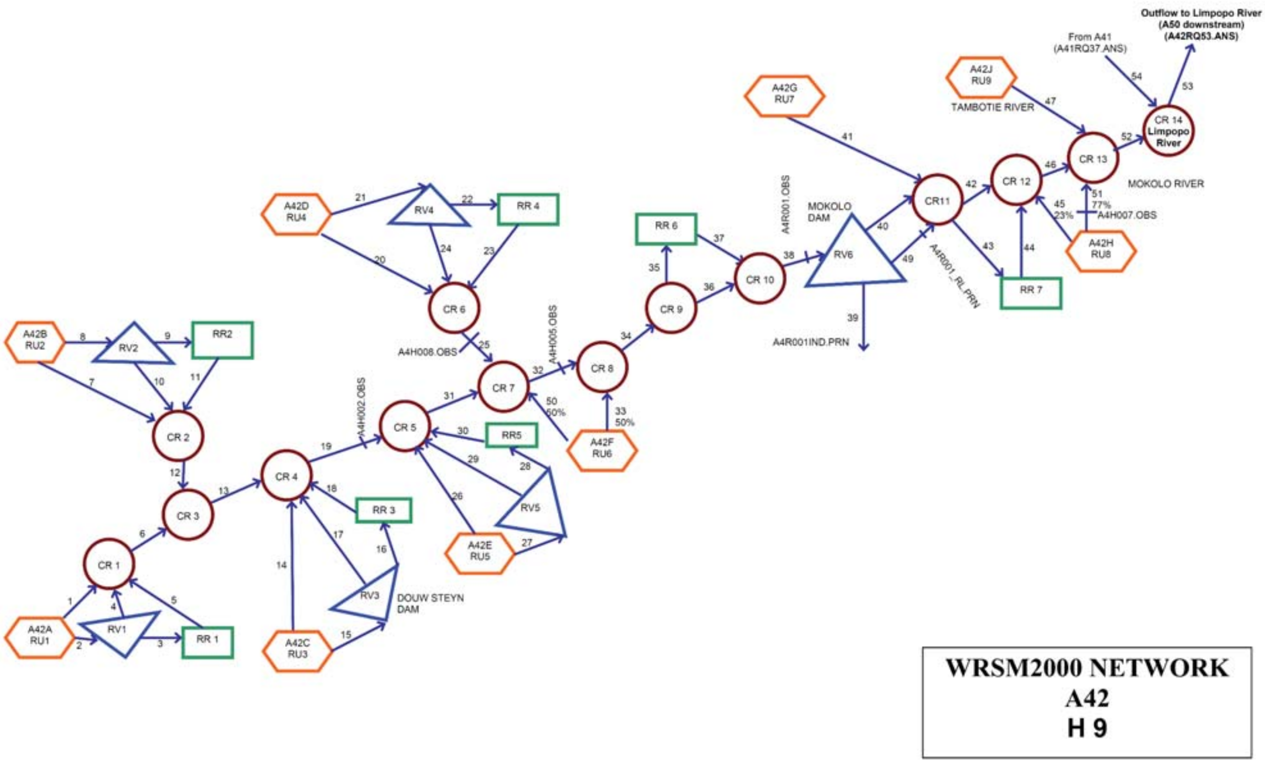

Figure 21: WRSM model schematic – Mokolo River Catchment – A42.

The hydrological characteristics and operation of the catchment is modelled through the following modules in the WRSM model as shown in Figure 21.

- 9 Runoff modules (RU's)
- 7 Irrigation modules (RR's)
- 6 Reservoir modules (Mokolo Dam and 5 other smaller upstream dams or reservoirs) (RV's)
- Several river reach modules (CR's)

The WRSM model uses the Pitman model as a basis for developing a rainfall-runoff relationship for the different runoff modules from the historical data from the WR2012 study. Figure 22 shows the historical net catchment runoff modelled for the RU1 runoff module (WRSM2000) with Figure 23 showing the calculated runoff compared to the historical observed runoff into the Mokolo Dam at the A4R001 river gauging station.

The AWBM discussed in the following section of the document was used to model the different runoff modules from the WRSM model and calibrated using the historical data for the WRSM model from the WR2012 study. This calibration is discussed in Section 4.3.3.

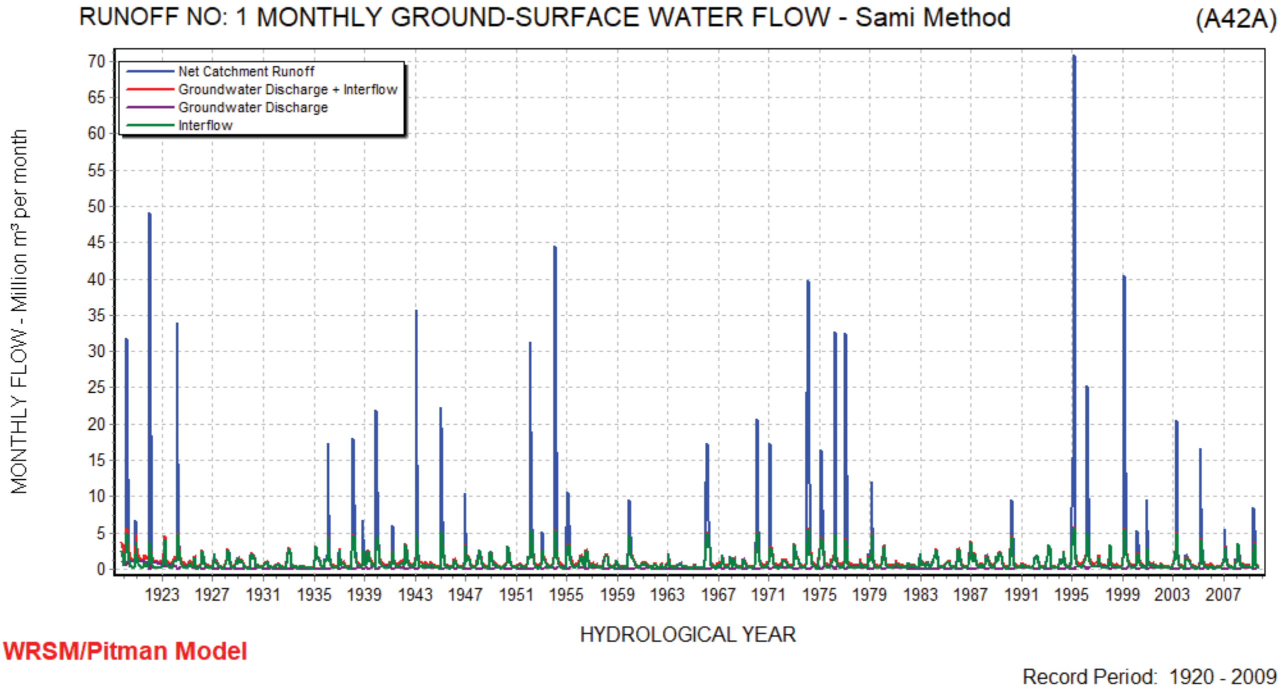

Figure 22: WRSM monthly hydrograph – RU1 – A42A.

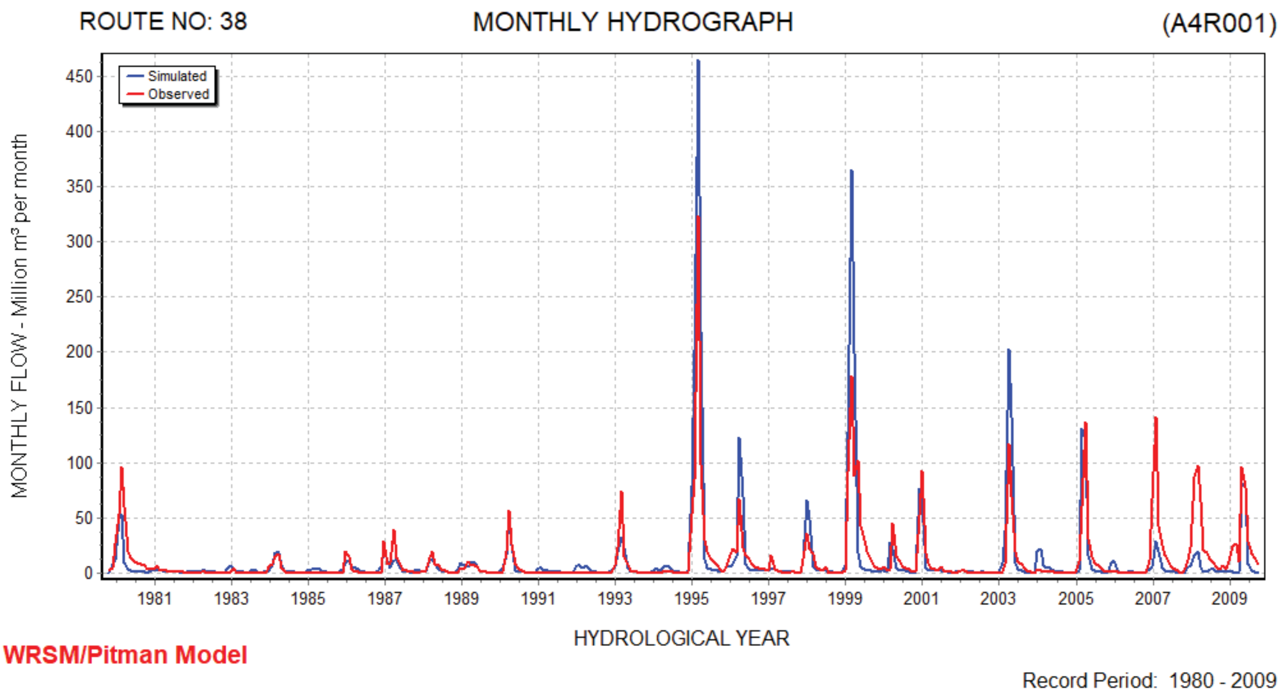

Figure 23: Historic and modelled Mokolo Dam inflow hydrograph – WRSM2000.

4.3.2 Australian Water Balance Model

Saturation Excess Overland Flow occurs when the soil becomes saturated, and any additional precipitation or irrigation causes runoff. It is essentially, the excess rainfall remaining after the surface storage capacity of a catchment has been replenished. Therefore, abstraction of rainfall and the amount of rainfall that is converted to runoff depends on the antecedent moisture conditions of the catchment. In addition to this there can also be spatial variability in the rainfall abstraction and the generation of runoff over the catchment. When developing catchment runoff models, it is possible to start with the simplest concepts of catchment behaviour and increase the complexity of the model by introducing variables such as antecedent wetness and spatial variability in order to develop a comparative structure for modelling the rainfall-runoff relationship (Boughton, 2004).

The most basic model of abstractions of rainfall over a catchment is the elementary bucket model shown in Figure 24. The capacity C of the bucket represents the surface storage capacity of the catchment in units of depth. Runoff from the model is also expressed in units of depth. The behaviour of the model assumes that all rainfall is abstracted, and no runoff occurs until the bucket is filled, following which all rainfall becomes runoff. If the catchment is completely saturated prior to the rainfall event, all rainfall becomes runoff, and the rainfall-runoff relationship is the 45-degree line from the origin. If there is zero antecedent wetness, then the relationship between the rainfall and the runoff is as shown in Figure 24a by line C. Any other degree of saturation of the catchment will be represented by a line somewhere between the origin and C (Boughton, 2004).

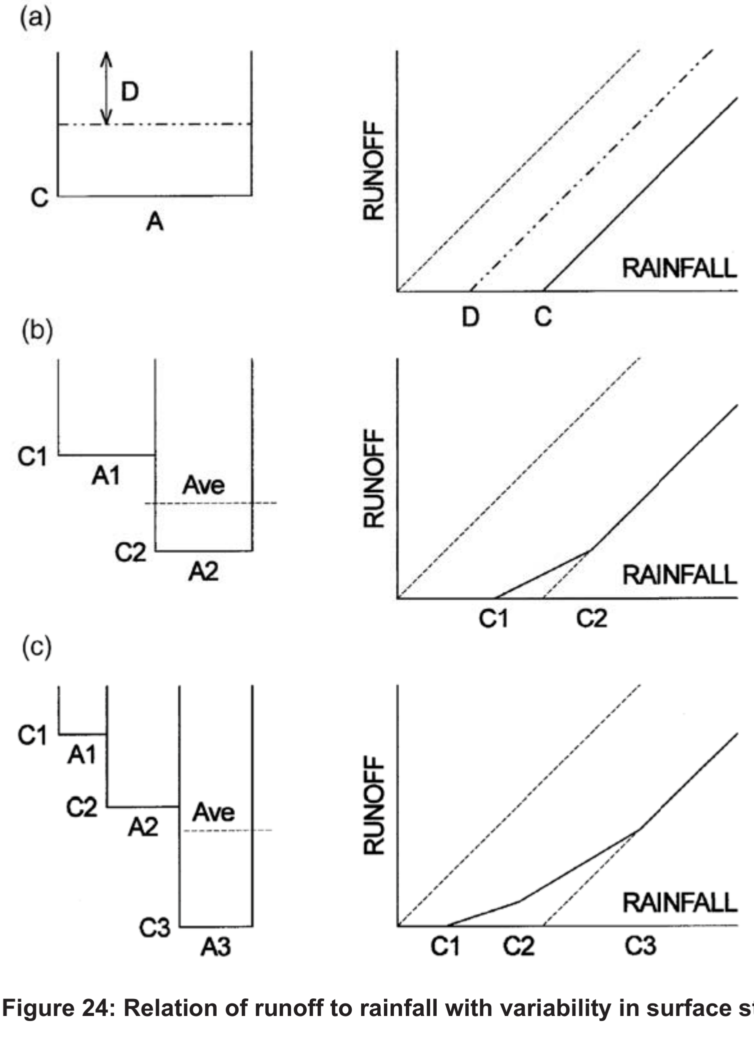

Figure 24: Relation of runoff to rainfall with variability in surface storage.

Figure 24b demonstrates the effect of spatial variability within the surface storage capacity of a catchment by considering two capacities C1 and C2 covering partial areas A1 and A2, respectively of the catchment. The sum of the partial areas of the catchment equate to the total catchment area. Runoff begins once rainfall is sufficient to fill the smaller storage capacity C1. Until the rainfall is sufficient to also fill the larger capacity C2, the rainfall-runoff relationship from the smaller store will be a line with slope 1 vertical to 1.0 horizontal. When rainfall exceeds the capacity of C2, the rainfall-runoff relationship is again a 45-degree line. If that 45-degree is extended backwards, it intersects the x-axis at the average storage capacity. The more capacities and partial areas are used to model the catchment the closer the rainfall runoff relationship becomes to a smooth curve and a better fit to the rainfall runoff data. However, an increase in the number of parameters reduces the reliability in the calibration of each parameter as each parameter adds more interaction between parameters and reduces the definition of each. Therefor the number of capacities used with the method described remains a pragmatic choice. With the development of the AWBM three partial areas and capacities (Figure 24a) were found to provide enough flexibility to fit to rainfall and runoff data with the parameters few enough to permit positive calibration (Boughton, 2004).

The AWBM model works on the premise of the three partial areas with different capacities contributing to the total catchment. At each time step, rainfall is added to each of the surface stores and evapotranspiration is subtracted as shown in Figure 25. If there is an excess of rainfall at any of three partial areas or stores, if becomes runoff and is split between surface runoff and baseflow according to a defined baseflow index which is determined from streamflow records using any established technique for portioning of flow (Boughton, 2003). The model is operated at either daily or hourly time steps. When daily timesteps are used a surface attenuation and baseflow store is also used with discharge from these stores being subject to recession constants which are also determined directly from the streamflow records (Boughton, 2004).

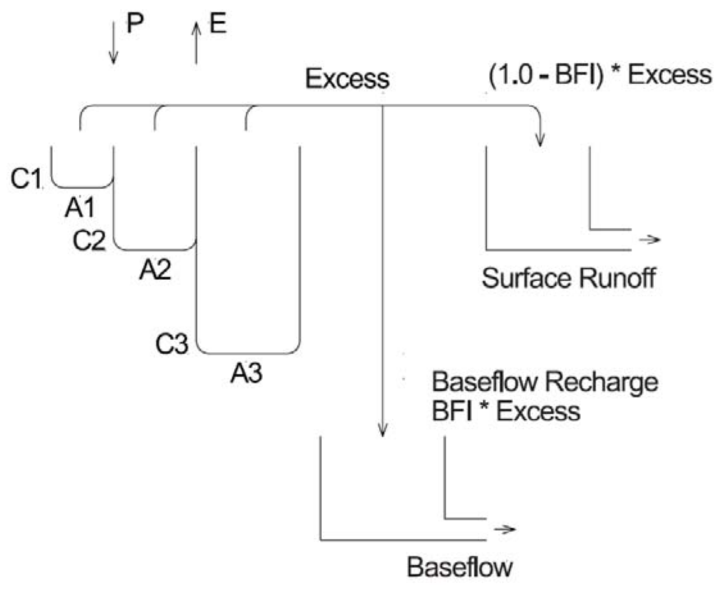

Figure 25: AWBM Model.

The parameters of the AWBM that determine amount of runoff following a rainfall event, are the three surface storage capacities and the corresponding partial areas. However in previous research, when the AWBM was calibrated against measured historical data, it was found that the total amount of runoff was mainly affected by the average surface storage capacity and much less by how that average is divided among the individual surface capacities and their corresponding partial areas (Boughton, 2003).

4.3.3 Calibration

The AWBM set up for the runoff modules within the Mokolo River Catchment was calibrated using the WRSM model and the WR2012 historical data sets available for the A42 quaternary catchment (Figure 21). The AWBM was calibrated by adjusting the three partial areas and associated storage capacities as shown in Figure 24 and Figure 25. A multiple regression analysis was run on the simulated rainfall-runoff relationship and the observed historical rainfall and subsequent runoff, to evaluate the fitness of several possible partial area and storage capacity values. Figure 26 shows a comparison of the simulated runoff and the historical runoff from the WR2012 study for RU1 for 1920 to 2000. Figure 27 also shows a comparison of the cumulative runoff for the RU module for 1920 to 2000.

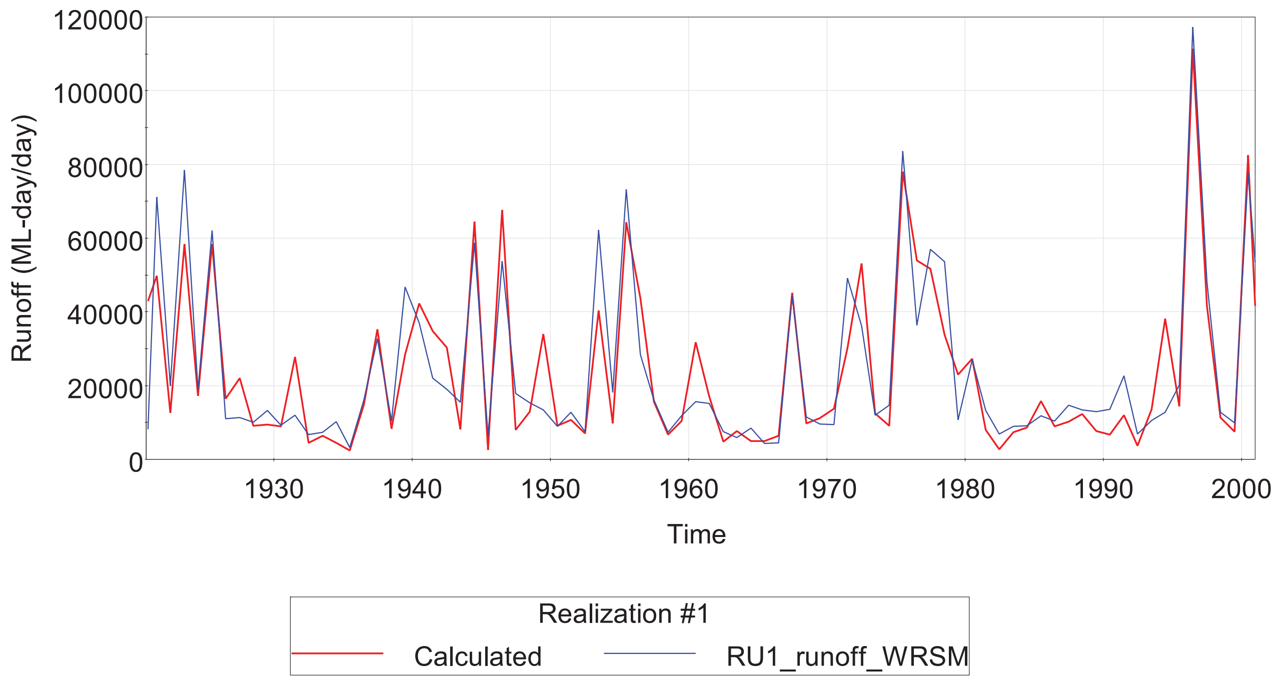

Figure 26: RU1 runoff module – Historic (WRSM) and Simulated runoff.

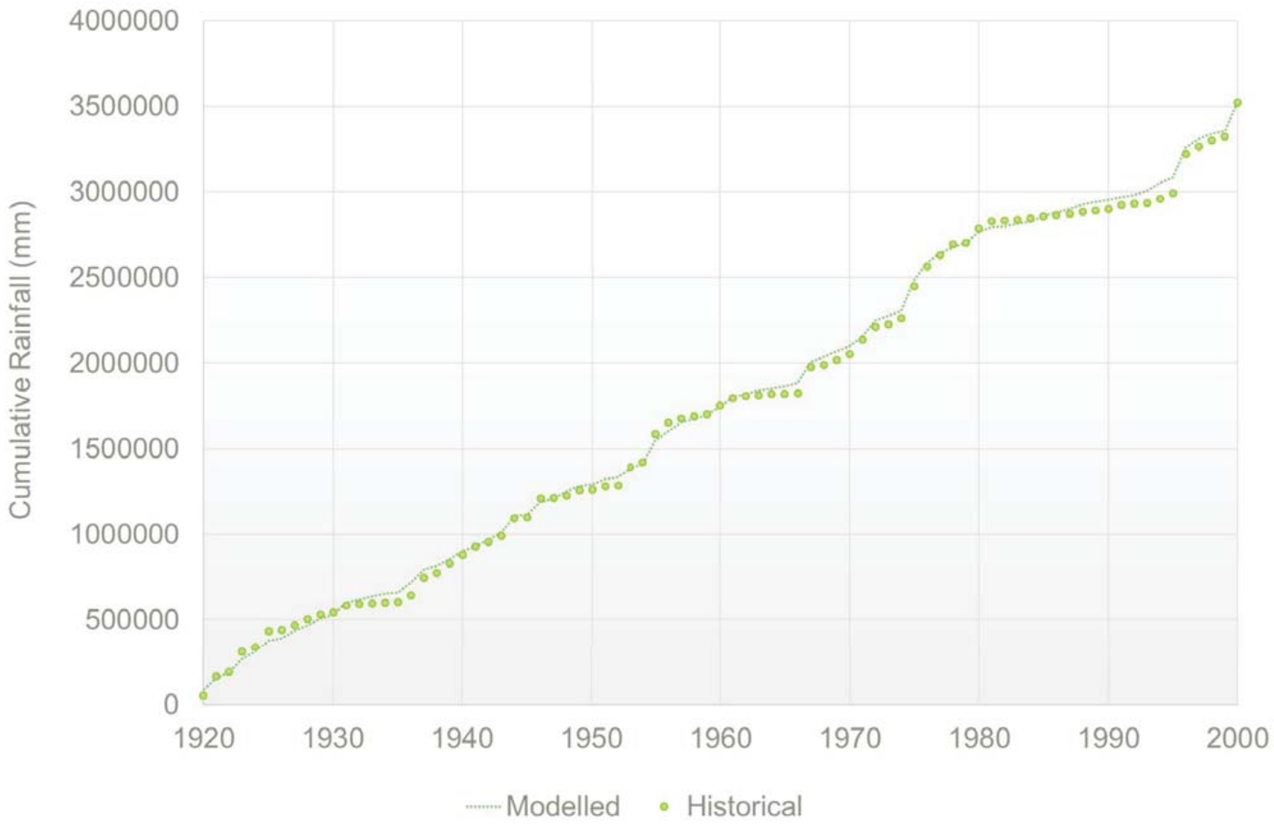

Figure 27: RU1 runoff module – Cumulative runoff comparison.

The calibrated runoff modules were ultimately included in the Mokolo River Catchment Water Balance Model focussing on the operation of the Mokolo Dam.

The water balance model was also calibrated based on the historic Mokolo Dam water levels as per the Department of Water and Sanitation's hydrology database. Historic Mokolo Dam water levels coinciding with the measured rainfall data was used to calibrate the Mokolo Dam model. Figure 28 shows a comparison of the historic dam levels and the modelled future Mokolo Dam levels for one of the 1000 iterations run by the developed model.

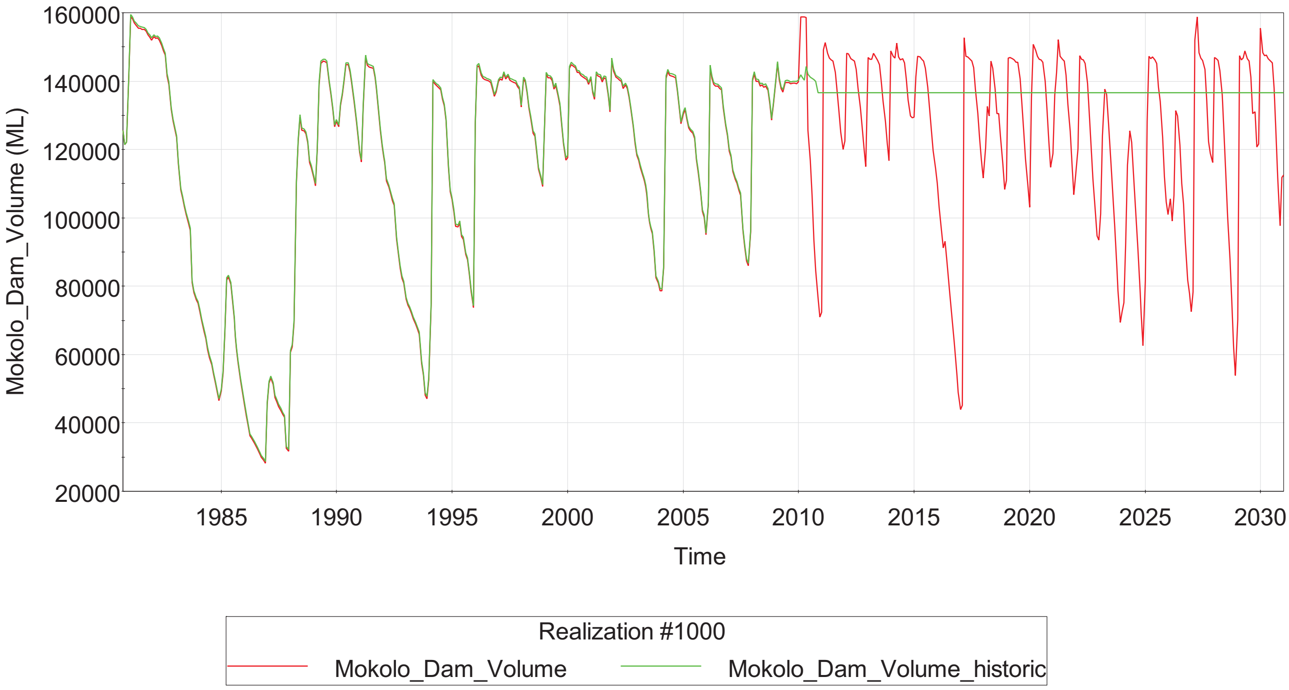

Figure 28: Mokolo Dam Level – Modelled and Historical.

4.4 CATCHMENT WATER BALANCE MODEL

The Mokolo River Catchment Water Balance Model was developed as a “modified” balance with the operation of the Mokolo Dam at its core. All upstream hydrological calculations were grouped into modelling the historical and future predicted inflow into the dam. The hydrological modelling of the inflow into the Mokolo Dam was mainly concerned with the runoff from the runoff modules (RU1 to RU6) and the irrigation demand from upstream irrigation modules (RR1 to RR6).

Since the historical WR2012 data and the WRSM modelled data is in monthly totals and the catchment water balance model was set up as a daily model there were several issues with modelling the upstream runoff module and irrigation modules as separate entities. To overcome these issues and to ensure that the model does not produce negative flows in the Mokolo River, the outflows from the upstream runoff modules were summed and modelled as contributing to a single upstream reservoir module equivalent to the capacity of the summed capacity of the five smaller upstream dams/reservoirs. The upstream irrigation demand was then modelled as a demand on this single amalgamated upstream reservoir and the outflow of this reservoir modelled as the inflow to the Mokolo Dam.

Before the upstream summation, the individual runoff modules were modelled using the AWBM and calibrated to the WR2012 data as discussed in Sections 4.1 to 4.3 of the report. The input to upstream modules of the Modified Catchment Water Balance for the Mokolo River Catchment, as well as the data used for calibration is summarised in Table 11.

Table 11: Upstream hydrological inputs

Input	Model	Calibration Data (Historical Data)	Predicted Future Values
Runoff	• AWBM	• WR2012 • Historical Rainfall Data (Kunz, 2004)	• Stochastic Rainfall Simulator • AWBM
Irrigation	• Combined upstream irrigation model	• WR2012	• LRNS* (DWS, 2015)
Reservoirs	• Amalgamated upstream reservoir model	• WR2012 • Historical Rainfall Data (Kunz, 2004)	• Stochastic Rainfall Simulator • AWBM • LRNS* (DWS, 2015)

***Limpopo Water Management Area North Reconciliation Strategy**

Outflow from the dam was categorised into four groups as follows:

- Mining Operations
- Power Station Operations
- Urban Use
- Downstream Flow Release (incl. environmental releases and overflow)

Data for the historic and estimated future outflow from the dam in terms of these four outflow groups were sourced from several different sources as outlined in Table 12.

The downstream agriculture abstracts directly from the Mokolo River downstream of the Mokolo Dam. This demand forms part of the Downstream Flow Release from the Mokolo Dam augmented by the return flows from wastewater treatment works as well as downstream urban and industrial stormwater runoff.

Table 12: Downstream hydrological inputs and water usage data

Mokolo Dam Outflow Group	Input	Model	Calibration Data (Historical Data)	Predicted Future Values
Mining Operations	Demand		• WR2012	
	Consumption			
	Runoff	• AWBM		• Stochastic Rainfall Simulator • AWBM
Power Station Operations	Demand		• WR2012	
	Consumption			
	Runoff	• AWBM		• Stochastic Rainfall Simulator • AWBM
Urban Use	Demand		• WR2012	• LRNS* (Mhlanga Robertson, 2015)

Mokolo Dam Outflow Group	Input	Model	Calibration Data (Historical Data)	Predicted Future Values
	Consumption			• WRC Report No 1536/1/06 (Van Zyl et al., 2007)
	Wastewater			• WRC Report No 1536/1/06 (Van Zyl et al., 2007)
	Runoff	• AWBM		• Stochastic Rainfall Simulator • AWBM
Downstream Flow Release	Mokolo Dam Release and Spill	• AWBM • Mokolo Dam Model	• WR2012	• Stochastic Rainfall Simulator • AWBM
	Treated Wastewater			• WRC Report No 1536/1/06 (Van Zyl et al., 2007)
	Urban Stormwater Runoff and Downstream Runoff	• AWBM		• Stochastic Rainfall Simulator • AWBM
	Downstream Agriculture Demand		• WR2012	• LRNS* (Mhlanga Robertson, 2015)
	Agriculture Return Flow		• WR2012	• LRNS* (Mhlanga Robertson, 2015)
Agriculture	Demand (surface water)		• WR2012	• LRNS* (Mhlanga Robertson, 2015)
	Demand (groundwater)		• WR2012	• LRNS* (Mhlanga Robertson, 2015)
	Consumption		•	• LRNS* (Mhlanga Robertson, 2015)
	Return Flow		• WR2012	• LRNS* (Mhlanga Robertson, 2015)

The water balance model was firstly run for 100 iterations at status quo. From Figure 29, it can be seen that on average the Mokolo Dam level reduces substantially as the mining development and water usage within the Lephalale region increases, from 85% to 41% of full supply level.

From the 100 iterations of the model run, the average demand from the Mokolo Dam, made up of the Mining, Power Station and Urban Demand, amounts to 962 882 ML from 2019 until 2030. The average shortfall on this demand and the amount of water that would need to be augmented to the Mokolo Dam Supply amounts to 57 119 ML, i.e. there is a 6% shortfall of supply over the next 10-years due to the increase in development and water usage within the Lephalale region. It is important to note that this is the average case as simulated by the rainfall-runoff relationship modelled by the calibrated AWBM. Worse case scenarios than the average, where the annual rainfall and runoff is less that than average simulated, have a much worse impact on the Mokolo Dam levels and the demand on the dam. Figure 30 shows a scenario (Realization 16) where the Dam runs completely empty 6 times and has an average level of 48% from 2019 to 2030.

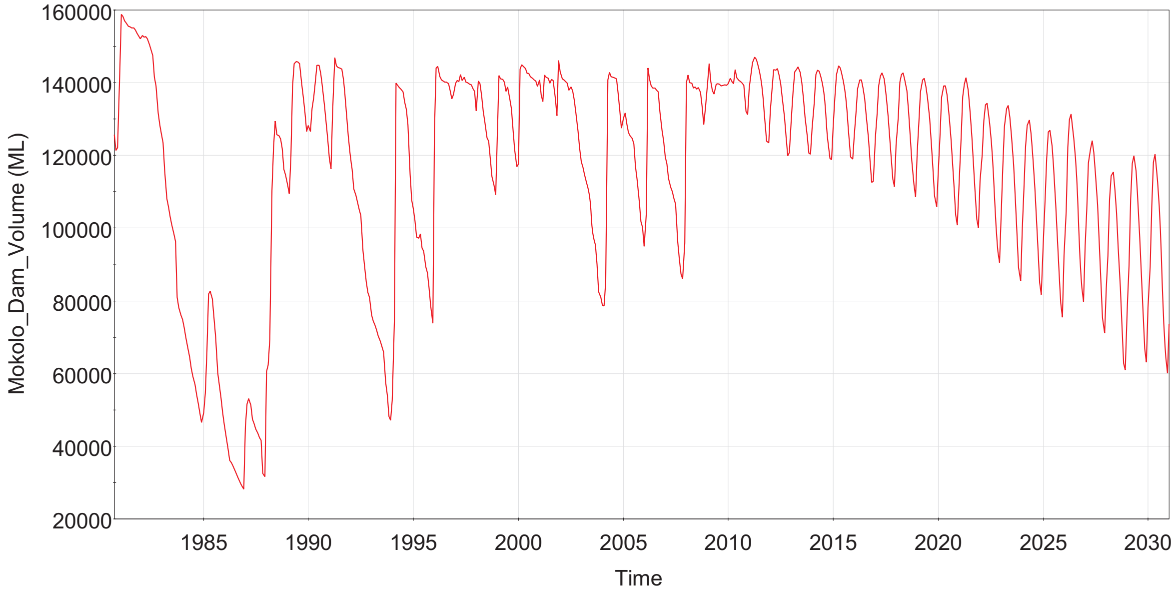

Figure 29: Average simulated Mokolo Dam levels – 1980 to 2030.

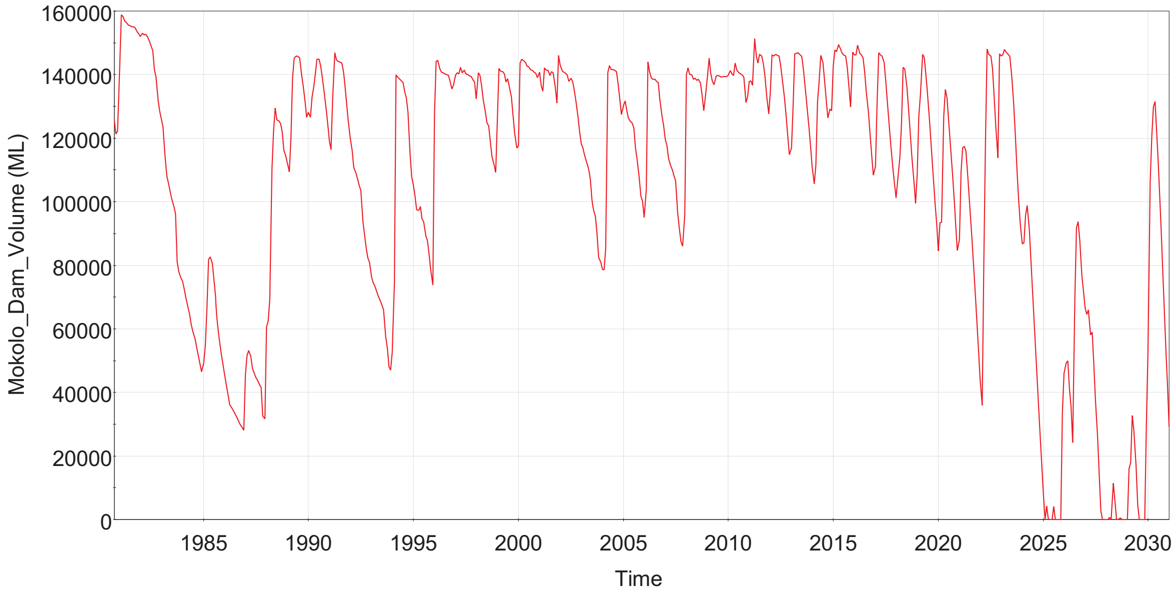

Figure 30: Simulated Mokolo Dam levels – Realization 16 – 1980 to 2030.

The developed Modified Catchment Water Balance was run for different time intervals corresponding to the reporting of the Limpopo Water Management Area North Reconciliation Strategy. Figure 31 to Figure 33 shows schematics of the results of the water balance model for the different time periods.

Results presented in these figures are average flows in Ml/day. Flows presented in the boxes are the actual flows obtained from the model. The values presented in Blue are the demands and the values presented in red is the shortfall. Results indicate that the shortfall is expected to get worse over time.

It should be noted that the model did not include the impacts of Climate Change or Increased water consumptions for upstream users. The situation is therefore expected to be worse than the values predicted here.

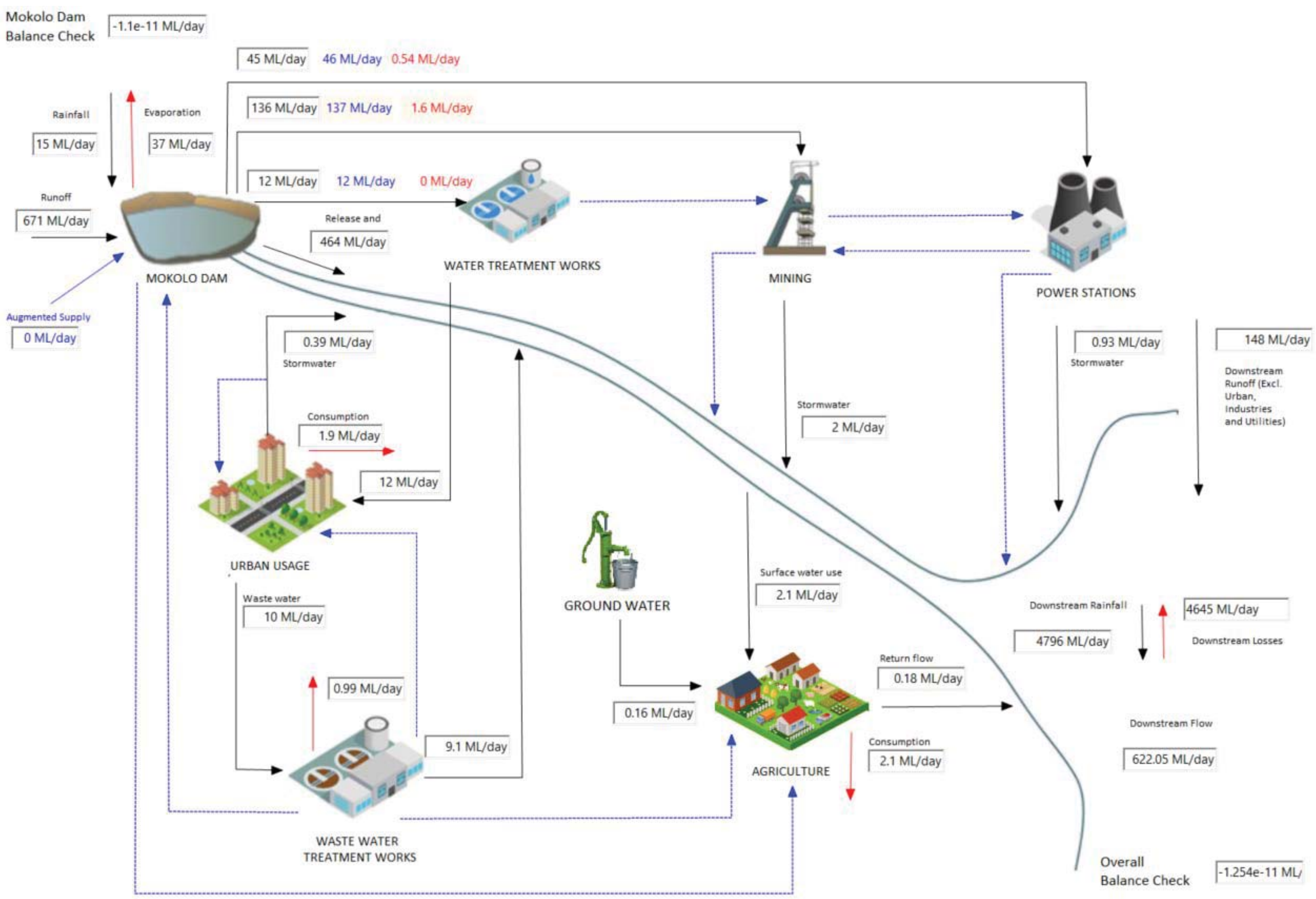

Figure 31: Predictive balance for Limpopo Water Management Area North (2020-2025)

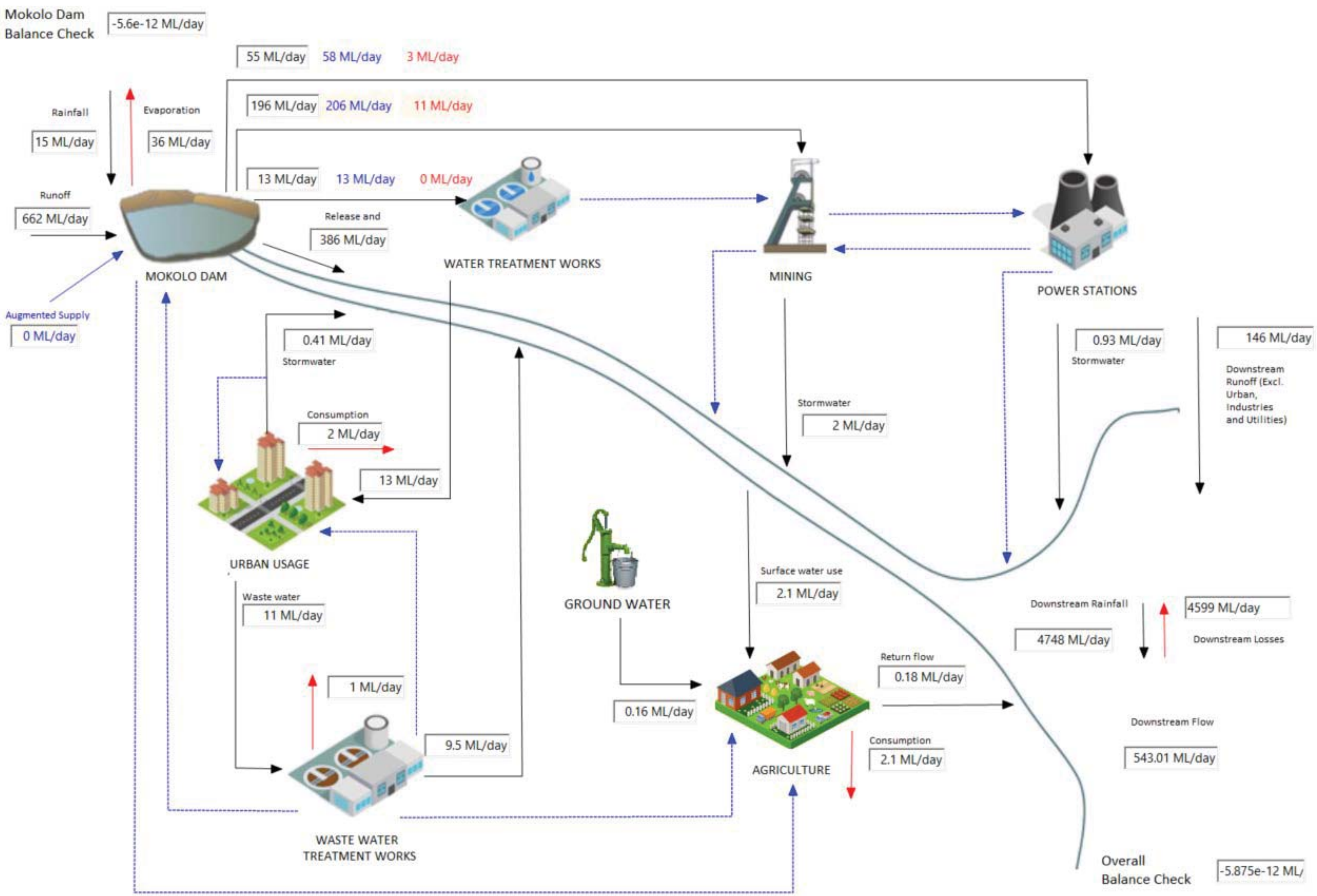

Figure 32: Predictive balance for Limpopo Water Management Area North (2025-2030)

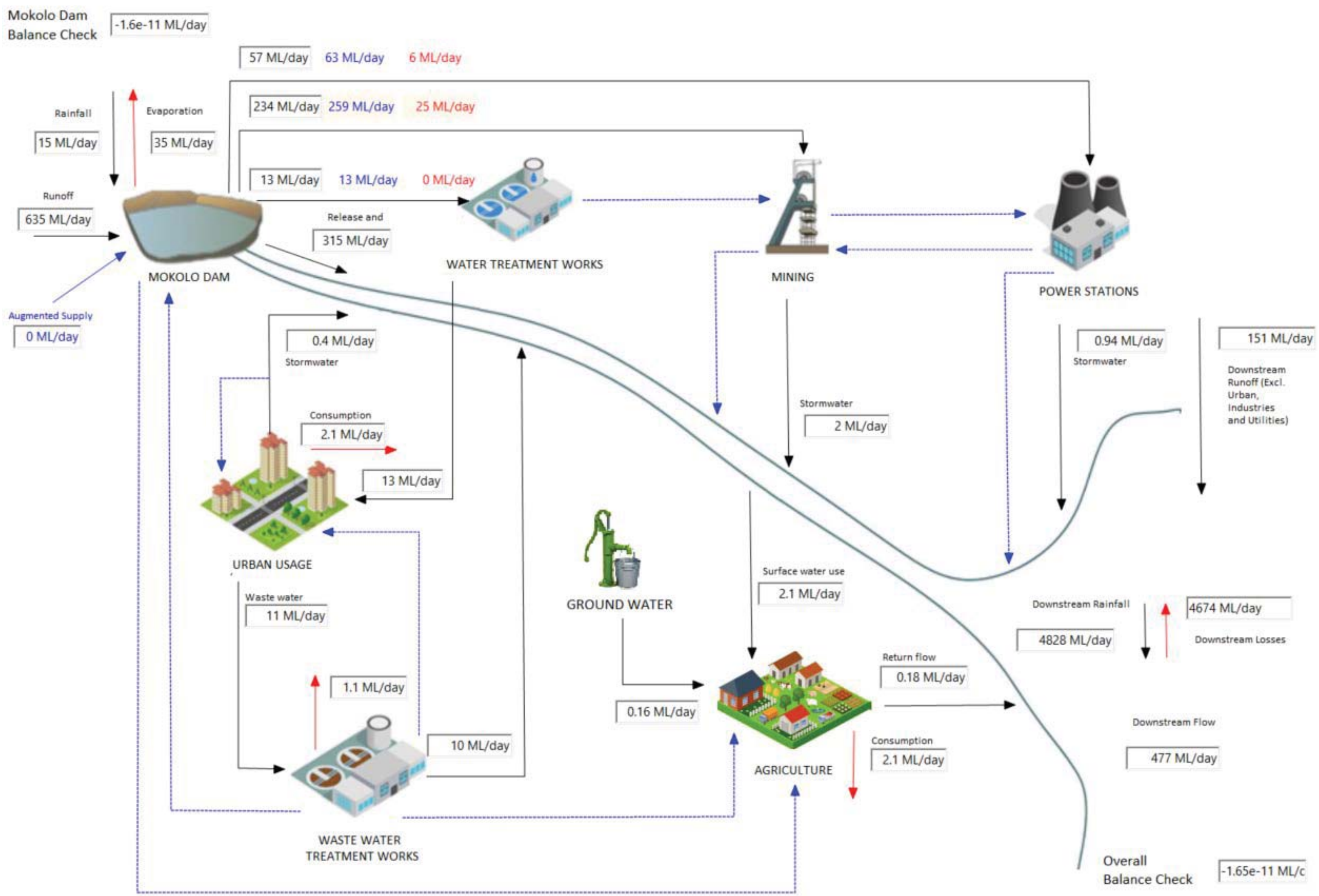

Figure 33: Predictive balance for Limpopo Water Management Area North (2030-2040)

CHAPTER 5: WATER SENSITIVE DESIGN

5.1 DEFINITIONS OF WATER SENSITIVE DESIGN

Water Sensitive Urban Design (WSUD) was conceptualized in the late 1990s driven by a recognition of the impacts urban stormwater quality has on ecological health of urban waterways (Wong, 2006). It has been recognised in recent years that not only urban areas and peri-urban areas can benefit from this approach. The integration of the water cycle into planning and design needs to include rural settlements as well. For this reason, the word Urban was removed from the term and Water Sensitive Design (WSD) will be used in this report, except in instances were previous reports and papers are referenced. (UCT – Urban Water Management, 2018). The concept draws on efforts made to improve the environmental health of the world following the awareness stemming from the Sustainable Development Principle (WCED, 1987). WSD originated from stormwater management practices which consider more holistic management of the urban water cycle. In Australia, the WSD concept was initiated to break the dependency of urban environments on large water service infrastructure (Wong, 2006). The WSD framework is hence a broad framework with various definitions.

Brown et al. (2008) defines WSD as “an approach to urban planning and design that integrates land and water planning and management into urban design and is based on the premise that urban development and redevelopment must address the sustainability of water” (Engineers Australia, 2006 as quoted in Armitage et al., 2014). Australia’s National Water Initiatives defines the WSD as “the integration of urban planning with the management, protection and conservation of the urban water cycle, that ensures that urban water management is sensitive to natural hydrological and ecological processes” (Wong, 2006, p 214). This definition incorporates a city’s potable water supply, sewage and wastewater streams and stormwater drainage but also encapsulates urban planning and design and its ability to assist in sustainable water management (Wong, 2006). The City of Melbourne builds on this by recognizing all water streams in the urban water cycle as a resource.

Despite a difficulty in accurately defining WSD, the guiding principles that it aims to achieve are well laid out in the WSUD Guidelines developed for City of Melbourne, Australia. WSD is best described through these listed goals (City of Melbourne WSUD Guidelines, n.d.):

- Reduce potable water consumption
- Maximize water reuse
- Reduce wastewater discharge
- Minimize storm water pollution before it is discharged to the aquatic environment
- Maximize groundwater protection.

SWIFT (2006) defines WSD as an interdisciplinary cooperation of water management, urban design and landscape planning and considers all parts of the urban water cycle, combining the functionality of water management with the principles of design. WSD develops integrative strategies for ecological, economic, social and cultural sustainability in an approach that:

- Manages the entire water cycle
- Contributes to sustainability, and
- Provides conditions for attractive human scale living environments.

The various definitions which present themselves in the literature fall short when applied to the South African context. This is especially the case as South Africa’s political history laid out a complex spatial and demographic landscape which brings about developmental and equity issues unaccounted for in current definitions. (Armitage et al., 2014).

5.2 THE SOUTH AFRICAN CONTEXT

The driver to the development of WSD systems worldwide is mainly anthropogenic development. Urban environments are considered the most evident form of land-use alteration and adaption to the point of modifying local and regional scale climates (Georgescu, 2014). Having a large percentage of impervious surfaces, urban areas are typically more problematic regarding water management (Teemusk & Mander, 2007). Paving, soil compaction and the development of buildings increase the impermeability of an urban region which reduces the rainwater infiltration ability of the land (Silveira, 2002 as cited in Poleto and Tassi, 2012). This leads to higher volumes of surface water runoffs to lower topographical regions generating areas of flooding (Poleto and Tassi, 2012: 56). These runoffs may also lead into streams gullies, ditches and rivers causing riverside flooding (ibid.) which increases the risk of urban flooding and the growing delineation of floodplains (Douglas, et al., 2008).

The WSD concept is fairly new to the South African context with little research on the topic. However, the challenges faced in the country's ever-expanding urban environments are much the same, as cities and towns continue to grow to support economic and social drivers for change. These include increased areas of impervious surfaces, high volumes of surface run-off, more polluted waste streams, increased wastewater discharge volumes, increased demands for bulk potable water supply and increased infrastructure. The Water Research Commission is currently driving research by exploring case studies that have been carried out and have developed water management guidelines and reports to assist urban planners, engineers and the government to incorporate WSD concepts in new and existing land settlement areas (Water Research Commission, 2013a; Water Research Commission, 2013b).

In South Africa, conventional water management focuses on avoiding the negative impacts of excess water (flooding) and the removal of wastewater and stormwater from urban centres through impervious channels. This results in large volumes of water carried to downstream sources and treatment plants. As the urban space develops in size, it is often the case that the conventional channels and downstream storages are unable to handle these large volumes, and the treatment of additional pollution loads that come with it.

The influence of poorly planned housing developments, fragmented and un-coordinated urban planning and management, inadequate infrastructure, increased demands on resources with the need to ensure a balance of social and economic imperatives with sustainable development is a challenge faced by most municipalities is South Africa. The current situation requires a paradigm shift in how urban centres are developed, integrated and managed in South Africa within the current economic, social and environmental stresses that exist. Urban environments need to move towards becoming self-sustaining, efficient ecosystems that optimally use the available resources. Innovative solutions need to be sought to create opportunities that provide a wider spectrum of options to urban water planning and management. WSD provides such an opportunity and innovative solutions for growing South African cities.

Such a shift creates an opportunity for local authorities and municipalities to generate a range of economic and social spin-offs to the benefit of their local communities thereby taking a small step towards achieving the goal of sustainable development. It however requires changes in our perception and understanding of the beneficial uses and opportunities that stormwater run-off and wastewater provide within water stressed environments.

Numerous environmental management related policies and law reform programmes have been introduced in South Africa since the dawn of democracy. This renewal process was spearheaded by the Constitution of the Republic of South Africa which laid the foundation for a democratic and open society in which government is based on the will of the people. The Constitution promotes equity, protects the rights of access to resources and also stipulates fundamental environmental rights in the "Bill Rights" which aim to improve the quality of life of all citizens, which includes recognizing the impact one's environment plays on quality of life. These

Constitutional environmental rights were enacted through a framework statute, the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA), which can be described as South Africa’s “primary” or “parent” environmental statute as it gives guidance to all environmental management related legislation.

The law reform process has been a key focus of the government for a number of years now and has seen the promulgation of a number of statutes related to environment and the management of natural resources. Amongst these are the National Water Act (Act No. 36 of 1998) (NWA), the Water Services Act (Act No. 108 of 1997) (WSA), the Minerals and Petroleum Resources Development Act (Act No. 28 of 2002) (MPRDA), the Marine Living Resources Act (Act No. 18 of 1998) (MLRA) and the National Environment Management: Air Quality Act (Act No. 39 of 2004) (NEM:AQA). However, there is also a multitude of older legislation which directly or indirectly manages the environment and impacts on it such as the Environment Conservation Act (Act No. 73 of 1989) (ECA).

Collectively a hierarchy of policies and legislation, which includes South Africa’s international commitments, the Constitution, applicable Acts of Parliament, Provincial Legislation and Local Government Bylaws, govern environmental management in South Africa. Amongst these the NEMA, NWA, WSA and ECA serve as the primary legislation that guide water management, waste management and pollution control. These statutes together with other media specific environmental legislation all reflect and pursue the common goal of sustainable development.

Being a water-stressed country, South Africa implemented the National Water Act to encourage sustainable use of water for the benefit of all users in the discourse of water resource management (National Water Act, 38 of 1998). The Act also encourages the protection of the quality of water resources and the recognition of the need to implement integrated management approaches across all sectors to ensure sustainable water practices are developed (ibid.). Further, the Waste Act (Waste Act, 59 of 2008) sets out national norms and standards for the management of waste within South Africa. It is required that the state must address waste management by planning and making provision for storage, treatment and disposal of waste.

Despite these environmental advancements in legislation, South Africa faces similar institutional issues recognized with most conventional urban planning systems. Conventional urban water management tends to be fragmented, focusing on short-term solutions with a lack of flexibility (Mukheibir, 2017). In South Africa, the responsibility of water management is fragmented with stormwater management often falling in the ambit of the roads departments while wastewater collection, treatment and disposal falls under the responsibility of water and sanitation departments. “This results in poor communication and the integration of services” (Armitage et al., 2014, p. ii). The solution to water management problems tends to be reactive, focusing on solving the current problem at hand which tend not to be cost-effective or sustainable for the long term (Mukheibir, 2017). Planning for water management further relies on long-established technologies which design structures with fixed capacities with little or no provision for exceedance. These inflexible approaches often fail to adjust to climate variability and a rapidly growing urban demand (Mukheibir, 2017).

5.3 MOTIVATION FOR IMPLEMENTING WSD IN SOUTH AFRICA

South Africa’s well-founded urban spaces consist of central industrial and economic nodes with informal settlements, low cost housing projects and suburban development along the periphery of these hubs of development. In many regions, a large industry (such as mining and power-generation) spur urban development and population growth in areas which were previously rural. The philosophy of WSD can be best applied to these new industrial areas where the urban framework is still to be planned. Since, there is little existing infrastructure, urban planning and design can be better implemented without the difficulty of retrofitting the existing layout to achieve the goals of WSD.

South Africa is recognised as a water-scarce, developing country (Armitage et al., 2014). The country’s political background led to an inequitable spatial layout and a lack of service delivery to all citizens. The current government is addressing this issue while transforming its resource-intensive economy to a more sustainable state (ibid.). Adequate access to potable water is regarded as a basic human right in the country and results from the 2011 Census indicate that over 85% of the population have access to piped water to a reconstruction and development programme (RDP) house-acceptable level. Given that the use of water is involves many stakeholders, the management of water is encouraged as a participatory approach. It should further be recognized as an economic good, stressing that the resource is finite and vulnerable which is in line with the Dublin Principles for integrated water resource management (Armitage et al., 2014).

The historical linear design approach to manage water in urban environments does not incorporate the users of the water and is largely a technical process (Armitage et al., 2014) with a strictly defined scope. Given the cyclic nature of water and the impact users have on water quantity and quality, the approach falls short of managing the resource effectively. This motivates for a more holistic, flexible approach which incorporates the key elements which can contribute positively to urban water management. The key elements are recognized for their ability to assist the transition from the conventional linear approach of stormwater management towards urban sensitive water design – being coined as the One Water Paradigm Shift (Figure 34).

Figure 34: The six key elements that can contribute positively to the One Water Approach (Mukheibir, 2017).

Water sensitive design can improve water supply security through improved water conservation in the country if implemented correctly (City of Melbourne, n.d.). It will further assist in improving the quality of water which triggers improved biodiversity by creating 'natural' treatment habitats (ibid.). WSD further addresses climate change impacts such as flooding and the urban heat island effect. (City of Melbourne, n.d.). WSD enhances the urban environments aesthetic appearance while accomplishing both biological requirements of the system and urban water management. In essence, WSD promotes the multi-functionality of water management 'infrastructure' while contributing to the aesthetic of the urban space – bridging the gap between urban and natural environments.

Through participation, the approach should develop social and intergenerational equity which assists in remediating the negative influence of the Apartheid legacy. The WSD guidelines for South Africa further recognise its contextual benefit of transforming "…the extremely divided settlements that are so typical of the country into ones where water can be used to connect disparate communities and bring about significant change" (Armitage et al., 2014, p. ii). Given the climatic and economic variability observed presently and predicted in the future, an increasingly important benefit of WSD is its ability to develop resilience within water systems in the country. Broadly, the approach strives for sustainability by protecting scarce natural resources, whilst overcoming socio-economic barriers and encouraging equitable economic growth (Armitage et al., 2014).

The WRC highlights the challenges faced with WSD implementation in South Africa which are summarized below (Armitage et al., 2014):

- Institutional structures: The current institutional structures in South Africa separate water management into different municipal departments. Stormwater, sanitation, water supply, town planning, etc. all fall under different departments, creating silos and preventing.
- Champions: To promote the use of WSDs, champions applying WSD need to be identified and supported.
- Equity: South Africa's political landscape presents socio-economic issues such as service delivery to those regarded as previously disadvantaged. Addressing these challenges with the added introduction WSD creates another layer of complexity. It is advised that government should implement basic service delivery and water sensitive projects simultaneously for an easier approach to achieve equality.
- Health aspects: Potential health risks and source-pathway-receptor models of water-borne diseases must be considered to ensure that the spread of disease and exposure to harmful contaminants is not aggravated by the implementation of WSD.
- Adaptability & uncertainty: Limitations in South Africa's technical capacity and skills make the introduction of overly complex technologies difficult, especially with regard to maintenance. The current political position and impacts of climate change create an uncertainty to water management resulting in policy-makers being risk-averse.
- Green House Gas Emissions: the CO_2 emissions due to the energy usage in South Africa requires further management and future water management approaches introduced to the country should not contribute to the CO2 output.
- Ecosystem Goods & Services (EGS): The economic spinoffs of implementing WSD may not be solely able to motivate for their use thereof. The different components of the South African government focus on different outcomes, and this may deter or promote the use of WSD accordingly.
- Water use breakdown: The lack of detailed data on water use profiling and urban area water balances within many towns and cities in South Africa creates challenges in terms of obtaining an accurate indication of the effect of water sensitive design on optimizing the water balance of the system. This is also required to understand how the catchment water balance maybe influenced by changes to the urban area water balance so that downstream users are not impacted.

5.4 WATER SENSITIVE DESIGN OPTIONS

The South African Water Sensitive Design Framework breaks up the activities to achieve WSD as illustrated in Figure 35. This study follows the structure presented in the consideration of WSD initiatives that can be implemented in Lephalale.

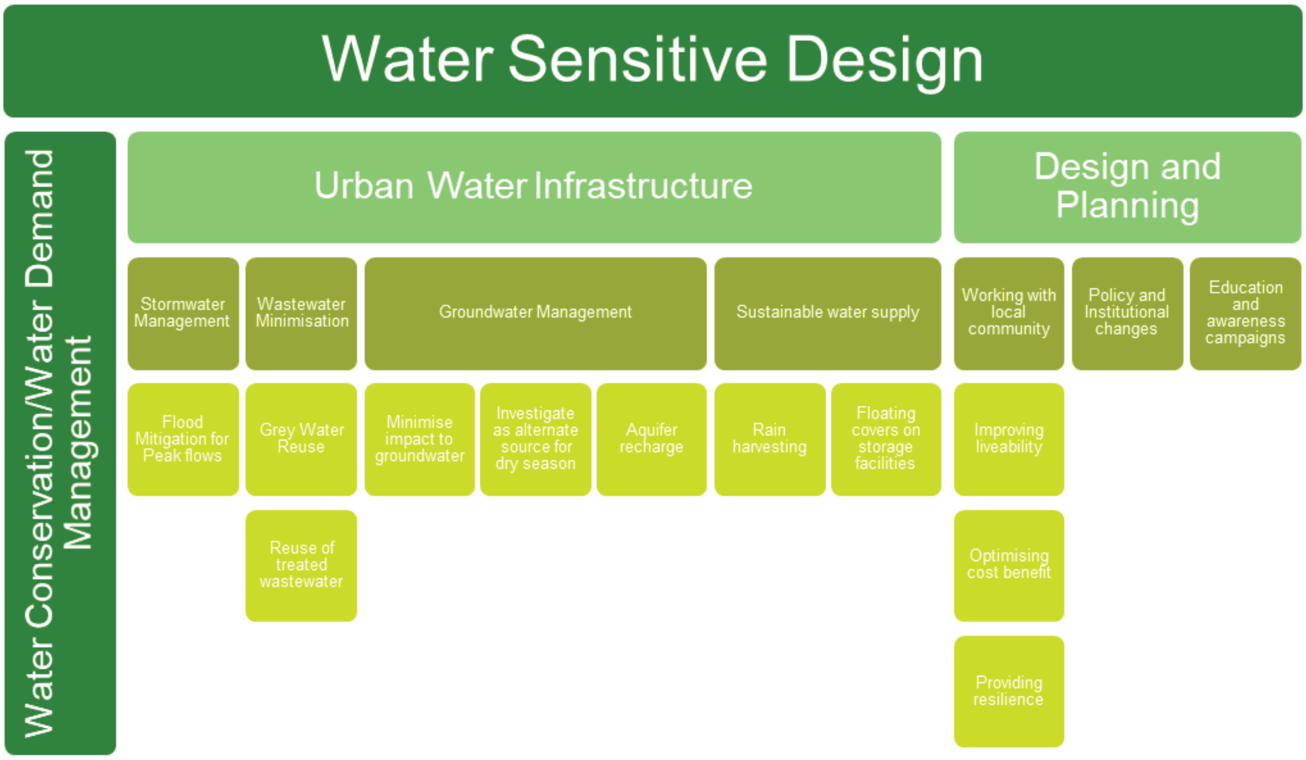

Figure 35: WSD activities (adapted from Armitage et al., 2014).

The two main categories of WSD as illustrated by Armitage et al. (2014) are Urban Water Instructure activities and activities regarding Design and Planning. The following sections of the report discusses several possible WSD activities relating to the two main categories. The guiding principles of Water Conservation, Water Demand Management (WCWDM) when applying the activities as indicated by Figure 35.

5.4.1 Urban Water Infrastructure

5.4.1.1 Stormwater management

Sustainable Drainage Systems (SuDS)

Sustainable Drainage Systems (SuDS) present an alternative approach to the management of stormwater by managing surface water drainage systems with the aim of achieving sustainable development (Armitage et al., 2014). There are various types of SuDS options that can be implemented as listed in Figure 36.

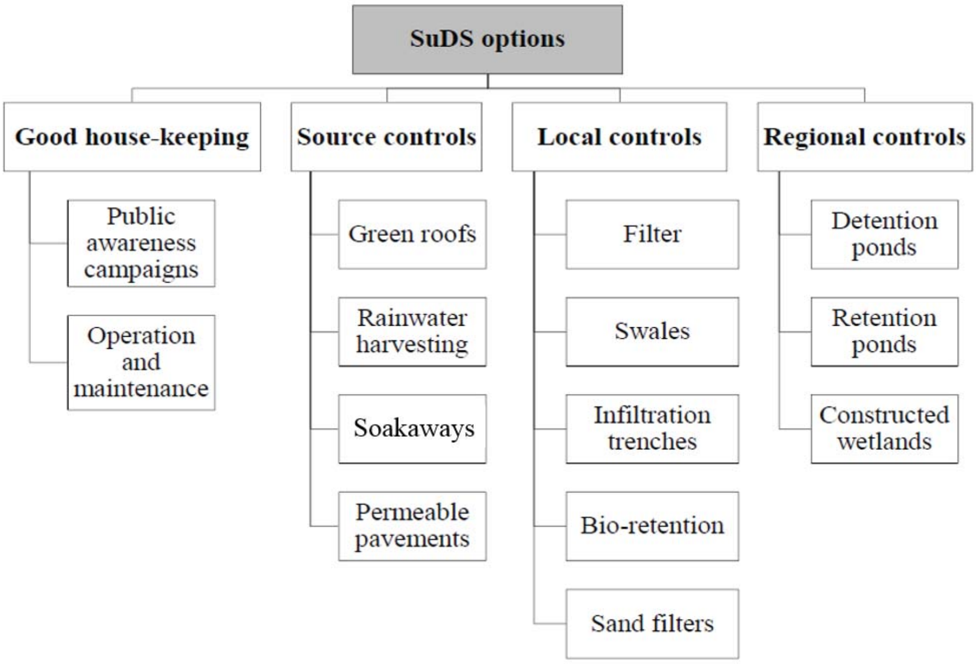

Figure 36: SuDS options at different control levels (Armitage et al., 2014).

Existing drainage in Lephalale varies depending on the land use. The current mining and power generating industries manage stormwater as per regulations set by the Department of Water and Sanitation (DWS). The philosophy in the industry is to contain and recycle contaminated water and isolate and direct clean runoff to the environment. In many instances, the industries treat contaminated water to a level that can be legally discharged to the environment. The formalized urban area of Lephalale uses conventional stormwater management to channel water away to prevent ponding and localized flooding. With the substantial urban growth predicted in the region (IDP, 2016), the existing stormwater infrastructure may not be capable to withstand the increased runoff due to large impervious areas and the predicted increased depth of storm events. The expanding urban area provides the opportunity to implement water sensitive designs at the urban planning phase making it easier to incorporate. Potential WSD initiatives to address this include:

- The introduction of swales, rain gardens, detention ponds and filtration basins in strategic areas to improve infiltration and attenuate the runoff reducing the flow to the conventional stormwater infrastructure.
- The formal urban landscape holds the potential for the use of rainwater harvesting systems. Rooftops can be designed to include rainwater harvesting tanks and/or vegetated roofs with store stormwater and attenuate the flow of excess water.
- In areas with contaminants which can potentially pollute the water, e.g. road runoff or runoff from informal settlements, constructed wetlands and filtration basins can be incorporated to filter the water and improve its quality. The improved water quality may make it permissible to re-use as greywater which reduces the water demand in the area.
- Semi-permeable paving can be introduced where imperious surfaces would typical be used. Parking areas, driveways, roads and walkways can incorporate semipermeable paving to increase the filtration of water and reduce the runoff discharge volume experienced.

The informal settlements in the area are also expected to expand and play a significant role in water management. Informal spaces are viewed as spatially fluid making it difficult to implement water infrastructure. A WSD project conducted in the Langrug Informal Settlement in Western Cape, South Africa, highlights initiatives that can be introduced to informal spaces to bring the space towards a water sensitive settlement. These initiatives are as follows:

- Greywater discharge structures which filter and direct greywater offsite preventing ponding and subsequent contamination of stagnant waterbodies which in turn reduce waterborne diseases.
- Rain gardens can be strategically placed to collect stormwater runoff from settlement roofs and impervious areas. The collected water percolates reducing the peak runoff volumes and attenuate the runoff.
- Semi-permeable paving can be introduced in areas with high traffic to prevent topsoil erosion and encourage filtration of runoff while making pathways more resilient to the high traffic.
- Working with residents in the settlement to construct and maintain these structures, creating employment, community buy-in and ensuring a sustainable solution.

Enhancement of amenity/biodiversity

The introduction of SuDS frequently enhances the biodiversity of an area due to the incorporation of natural to semi-natural elements. Many SuDS make use of vegetation, gravel, shrubs and trees which create semi-natural, small-scale ecosystems. Insects, amphibians and birds thrive in these small ecosystems. The linking of individual SuDS interventions to 'green' corridors creates migration pathways further promoting the biodiversity in the urban region (Armitage et al., 2014). As birds and insects are capable of flight, they are more prone to migrate. Their presence promotes the habitation of reptiles and small mammals which feed on them.

Amenities are also enhanced by the introduction of SuDS. Constructed wetlands may create pleasant spaces for bird watching, and other recreational activities. Vegetated infiltration ponds and attenuation ponds can serve a multi-functional purpose as parks during low rainfall periods. Rain gardens and swales along roads create organic separators between living spaces and public spaces and reduce noise pollution in urban areas. These semi-natural spaces also break the rigid urban landscape and make it more liveable and pleasant for inhabitants. In informal settlements the improved management of water reduces ponding and the transport of pollution through gullies, improving the overall appearance and liveability in the settlement.

Flood mitigation

Higher rainfall events are predicted in the area due to the impact of climate change (Schulze, 2012). Coupled with the increase in urban development, the Lephalale district may experience significant urban flooding. However, the area does have high evaporation and long dry periods where little to no water is available (Schulze, 2012). WSD initiatives to address urban flooding and the periodic aridity include the introduction of stormwater and rainwater harvesting techniques. Case studies in other countries have made use of filtered underground concrete tanks to capture stormwater runoff for later use. This prevents the high peak flows during flooding while assisting in water supply during dry periods.

5.4.1.2 Sanitation and Wastewater Minimization

Effluent quality improvement

The management of water treatment plants in the Lephalale poses the greatest opportunity to improve effluent quality. The area currently has three wastewater treatment plants namely the Paarl, Witpoort and Zongesien Treatment Plants. The optimization of these plants' operations and their compliance with the Department of Water Affairs' Green Drop certification program will improve the effluent quality of treated water (Armitage et al., 2014). The allocation of resources (human and/or financial) may be required to ensure the plants' effective operation. Source management to reduce the pollutant load of water to the treatment plants will further reduce the strain on plants. The projected urban growth must be considered and the retrofitting and upgrading of infrastructure will allow the treatment plants to operate effectively with the increased water input. The drive to improve the management of wastewater requires participatory approach where the users of water and the operators/mangers of the treatment plants are made aware of the benefits to sustainable management of the wastewater treatment systems. Further, the separation of stormwater and sewage should be conducted to reduce the volume of water to be treated. In many cases stormwater runoff requires less aggressive treatment.

Use of treated wastewater / recycled water

The management of wastewater in South Africa is challenging due to the range of socioeconomic contexts present and the technical constraints associated with the various settlement types. Cost, social acceptance and institutional accountability are recognised as the key factors to be considered for the sustainability of sanitation systems (Armitage et al., 2014).

The minimisation of wastewater in residential households will reduce the volume of water that requires treatment and reduces the potable water demand in the area. Water efficient devices such as low-flow taps, low-flow showerheads, and low volume toilets can be introduced to both formal and informal settlements. Public buildings and public water supply points can be fitted with self-timers to prevent taps running unattended and/or leaking.

In many cases, water intended for re-use does not require treatment to drinking water standards. Such examples include greywater for pour flushing of toilets, greywater for garden and crop irrigation, greywater for cleaning and dust suppression activities (Armitage et al., 2014). The partial treatment of water intended for re-use through either semi-natural system such as constructed wetlands or elementary water treatment facilities will reduce the volume of water that requires complete treatment at water treatment plants. The reduction of wet weather flows through the use of SuDS and eliminating the connections between sewage and stormwater networks (Armitage et al., 2014).

The recycling of water in different industries should be implemented at the respective level. Currently, the mining and power generating industries are regulated by the DWS to recycle process/contaminated water. Less emphasis is placed on formal and informal residential settlements. Introducing awareness programs highlighting the benefits of recycling water and addressing the cultural and contextual reservations around the recycling of water will improve its incorporation into the lifestyle of the inhabitants. Community leaders and those passionate about WSD hold a strong ability to influence their communities and will play a vital role to the adoption of WSD in their respective communities. Guidance from these leaders and infrastructure systems aimed to improve recycling should be introduced to the urban space. In-house tanks that collect greywater from drainage pipes is a possible intervention to assist recycling in both formal and informal settlements.

Biomimicry

Biomimicry is the practice of learning from and emulating natural forms, processes and systems in human designs. The purpose of biomimicry design is to generate more sustainable and resilient designs that are better adapted to local and global contexts.

It is important to acknowledge that the planned development in the area, while driving economic growth and employment is also driving demand for resources. The nature of urban areas is that they concentrate the demand for resources into a small area in relation to their surroundings, but the resources they demand do not all come from within that area. The footprint of the city expands far beyond the city limits. Dams upstream in the catchments pipe water into the urban areas, affecting the entire catchment. The urban areas compete with natural areas, while heavily relying on the services provided by the natural areas.

The Biomimicry Thinking framework integrates design principles from the natural world into all stages of the design process. For projects in the built environment, the process includes:

- In-depth Scoping phase – Research into biological information including relevant climate and rainfall data, understanding of underlying geology and related hydrology, mapping of existing water flows, as well as an assessment of the local ecosystem responses to the climate context of the area

- Discovery phase – During the Discovery phase, the biological information that is researched includes:
  - Genius of Place (how the local ecosystem and species manage water in context),
  - Ecological Performance Standards (where ecosystem services data is available – the standards for hydrology, as well as nutrient/sediment management are determined (as far as possible based on availability of data)
  - International best practise for biomimicry applied to water sensitive design would also be researched.
- Creation phase – The relevant design principles relating to water management are abstracted from the biological research findings. In addition, ideas as to how these principles can be applied in the design are brainstormed. A concept design is then developed
- Evaluation phase – The final design is Evaluated against Life's Principles as well as social/technical requirements. The design may evolve through a number of iterations, returning to the Creation phase, as a result of evaluation process.

Both ecological infrastructure and biomimicry within the built environment, can have benefits for water availability, water quality and water-related risks. The following is a summary of the benefits of nature-based solutions for these three areas, abstracted from the UN WWDR Report (2018):

- Water availability – Nature based systems mainly address water supply through managing precipitation, humidity, and water storage, infiltration and transmission, so that improvements are made in the location, timing and quantity of water available for human needs.
- Water quality: Source water protection reduces water treatment costs for urban suppliers and contributes to improved access to safe drinking water in rural communities. Where water becomes polluted, both constructed and natural ecosystems can help improve water quality. Urban green infrastructure is increasingly being used to manage and reduce pollution from urban runoff
- Water-related risks: Water-related risks and disasters, such as floods and droughts associated with an increasing temporal variability of water resources due to climate change, result in immense and growing human and economic losses globally. Nature based solutions or biomimicry for flood management can involve water retention by managing infiltration and overland flow, and thereby the hydrological connectivity between system components and the conveyance of water through it, making space for water storage through, for example, floodplains.

It is, however, also important to note the Challenges of implementing biomimicry and nature-based solutions as summarised below from the UN report. There remains a historical inertia against Nature based solutions or biomimicry due to the continuing overwhelming dominance of built (grey) infrastructure solutions in the current instruments – from public policy to building codes and regulations. This dominance can also exist in civil engineering, market-based economic instruments, the expertise of service providers, and consequentially in the minds of policy makers and the general public. These and other factors collectively result in NBS often being perceived to be less efficient, or riskier, than built (grey) systems.

Key factors to be taken into consideration when employing the biomimicry approach to designing a town from a water use/water supply perspective in the context of the Waterberg catchment are:

- Projections indicate that the water usage in the town is going to double in the next 20 years
- Population in the area is expected to increase with the new power stations and mines coming up and
- Mean annual rainfall of 450 mm/a with Mean annual evaporation of 1 800 mm/a. Dry catchment with high evaporation losses.

- Further rainfall analysis indicates that even though the MAP in the area is low, they do experience high peaks (High intensity rainfall followed by long dry periods) so we need to include management measures such as SUDs, storage with covers/underground reservoirs, groundwater recharge, etc.

5.4.1.3 Groundwater Management

Managed aquifer recharge

Groundwater recharge is a factor that is required if South Africa is to have adequate water resource potential to meet its requirements (DWA, 2012 as cited in Armitage et al., 2014). Urbanisation reduces the infiltration to groundwater which in turn increases the cost of extraction and has potential for environmental damage (Armitage et al., 2014). Groundwater management in the area should be focused on maintain the appropriate quantity and quality of the groundwater resource at the lowest cost while preventing irreversible degradation (Todd & Mays, 2005 as cited in Armitage et al., 2014, p. 92).

Given the geology of the Lephalale, artificial recharge options are possible. 5.4 Mm^3/a of storage can be created in the Waterberg aquifer. Artificial recharge options include aquifer storage recovery, aquifer storage transfer and recovery, soil aquifer treatment and infiltration ponds (VSA Leboa Consulting, 2010). Artificial options of the Moloko alluvial aquifer include bank filtration and infiltration ponds along the river. These options are viable as the water quality in the alluvium and the river are similar (ibid.). These recharge options require legislative and monitoring controls to prevent the contamination of the groundwater bodies (Armitage et al., 2014).

Groundwater use

The concept of groundwater use in WSD revolves around adaptive thinking around the protecting and developing groundwater as a resource which is linked to the urban water cycle (Armitage et al., 2014). In Lephalale, the mining industry will significantly affect the groundwater. Mines in the area are considering options to extract the groundwater to prevent the contamination of large volumes of water. Such initiatives protect the resource by considering the risks and associated costs with the contamination of groundwater. However, a recent study on the groundwater in the Turfvlakte Farm has found that the groundwater quality of the investigation area is mainly represented by poor (Class 3) to unacceptable drinking water quality (Golder, 2017). Hence, groundwater cannot be used for potable water supply. The water quality may be of sufficient standard for crop irrigation and other greywater uses.

5.4.1.4 Sustainable Water Supply

Water conservation and water demand management (WC/WDM) and Non-Revenue Water (NRW)

Water conservation and water demand management (WC/WDM) is a water management strategy to ensure the long-term effective management of water resources ultimately ensuring environmental sustainability, social equity and economic development (DWAF, 2004). The drive to implement WC/WDM strategies derives from the projected population growth, the increased percentage of formal water users and the expected improvement in the standard of living resulting in a higher water demand (ibid.) the strategies aim to achieve sustainable, efficient and affordable management of water resources and services, contribute to the protection of the environment, create a culture of water conservation amongst consumers and users and enable water management and water institutions to adopt integrated planning (ibid.). To implement WC/WDM strategies effectively awareness of the benefits of WC/WDM must be developed to obtain community and industrial buy-in. Institutional plans and strategies need to be developed for the Lephalale area addressing the long-term demand of water. Further, the allocation of appropriate resources to the plans is required to ensure that WC/WDM is carried out.

In part of the WC/WDM strategies developed for Lephalale, steps need to be implemented to reduce the unaccounted water losses in the water supply system. Leaks, unaccounted users, and spillages must be reduced to reduce water losses in the system. Initiatives aimed at reducing non-revenue water, water that does not yield any revenue due to leaks, billing/metering errors and non-payment by consumers, reducing water wastage at the point of consumption and replacing potable water supply on a ‘fitness for purpose’ basis (Armitage et al., 2014).

Strategies aimed at reducing the water use are separated into four categories. Structural methods refer to physical infrastructure aimed to reduce the quantity of water required to perform respective functions. Operational methods include pressure management systems and leak detection and repair programs aimed at improving efficiencies. Economic methods include all aspects of cost recovery for water use and lastly socio-political methods refer to education and awareness campaigns that can be implemented to move consumers towards sustainable water supply. (Armitage et al., 2014).

Rainwater/ Storm water harvesting

Due to the high evaporation present in Lephalale and the high rainfall events predicted in future, water harvesting is vital to WSD. Rainwater and storm water harvesting are possible solution to mitigate the risk of urban flooding and is a possible solution for water supply during dry periods. Formal urban buildings can introduce rainwater harvesting infrastructure on roof-space and basement space which can be used for irrigation, flushing and cleaning. Residences can also incorporate water storage tanks to collect runoff from roofs and impervious spaces to supplement their water demand requirements.

5.4.2 Design and Planning

Celebrating local character, community WSD Initiatives introduced to Lephalale must align to the local traditions and culture of the communities to be effective. WSD should aim to adopt and build upon similar philosophies and mindsets of the local community. The inclusion of cultural practices and design concepts can improve the acceptance of WSD in the community. The community’s involvement in the design, implementation and operational phases is vital and their roles must be celebrated to create the sense of ownership which will strengthen the implementation of WSD.

Concepts pertaining to design and planning and more specifically working with the local community includes improving liveability, optimizing cost-benefit and providing resilience.

5.4.2.1 Improving liveability

As seen in the Langrug WSD project, the liveability of inhabitants is improved by the implementation of WSD. Vegetation is introduced to previously barren areas and stagnant water ponds; gullies and pollution sumps are reduced. The effective management of greywater and black water prevents the risk of harbouring waterborne diseases, reducing the risk of exposure to the community. Ensuring the multi-functionality of SuDS as recreational green spaces further improves the lifestyle of the communities as many do not have access to green spaces. The improvement of water management and storage also makes it more viable for inhabitants to grow food gardens which improves their nutritional intake with little to no cost.

5.4.2.2 Optimizing cost-benefit

The costs of WSD infrastructure must be weighed against its benefits to the community. However, costs of infrastructure can be low if materials of low value are used, such as construction rubble. The maintenance costs of WSD infrastructure rarely exceed conventional storm water infrastructure maintenance. Further, the low and attenuated peak flows reduce the frequency of maintenance required on conventional storm water infrastructure. These costs are compared to the financial benefit of the residents who require less water, the benefits of lower water volumes that require treatment and the financial benefit of the reduced risk in urban flooding damages.

The social benefits of improved health and liveability and the financial savings that the community makes from recycling and subsistence farming should also be included in the costing.

5.4.2.3 Providing resilience

The incorporation of WSD increases the resilience of the Lephalale area by advancing the conventional linear water management system to a more distributed management system with alternate flow-paths, feedback loops and cyclic processes. The recycling of water reduces water demand in the area and eases the strain on water treatment plants. The recycling of process water within the mining and power generating industries creates water security and ensures the operation of the industry even during periods of drought. The harvesting of rainwater creates a reserve for the long, dry periods. The improved access and availability of water strengthens the concepts of WSD amongst the communities it is implemented within and the community buy-in increases growing the adoption of WSD.

5.4.2.4 Reducing Greenhouse Gas emissions

Energy awareness has been growing in both public and private enterprises. This is due to:

- Increased electricity and fuel prices – Prices have been escalating at rates well above the inflation rate,
- Interrupted power supply risks – Load shedding has become a regular occurrence in SA and is expected to increase in frequency for the foreseeable future,
- Growing environmental awareness – The concern with global warming and the impact of the release of Greenhouse Gasses on the environment has been identified as one of the largest risks to conducting business in the future,
- Impact of energy inefficiency – Most wastewater treatment works (WWTWs) in SA are fairly old and use older less efficient equipment which directly impacts on the operating cost of a WWTW.

At 17% of the total energy consumed by South African municipalities, WWTWs are one of the largest energy consumers within the sector. When only electricity consumption is considered, this increases to 25%, with electricity consumption representing up to 30% of the total operating cost of an activated sludge type WWTW (South African Cities Network, 2014). Optimising the energy efficiency of these facilities could therefore result in a significant carbon footprint reduction, as well as operating cost savings. New technologies and a number of optimisation opportunities are available to improve the energy efficiency of WWTWs.

The opportunity to generate electricity from biogas produced in anaerobic digesters could further reduce the carbon footprint of WWTWs. In addition, the digested sludge produced can be composted and used as fertiliser in agricultural activities resulting from an integrated solution. The biogas generated can be stored and used for power generation, thus reducing the need for imported electricity from Eskom.

Locally, energy efficiency parameters have been added as part of the latest Green Drop Assessments criteria, which list the following energy monitoring aspects:

- Energy consumption over the last financial year (kWh/day), unit cost and total cost (R/year),
- Electricity demand projections over the next > 3 years (kWh/day) and projected unit and total cost (R/year),
- Calculated electricity unit cost for current year and +1, +2 and +3 years (kWh/m^3 wastewater treated).

A guideline for the execution of energy efficiency audits in WWTWs has also been developed by the GIZ and SALGA to assist municipalities in identifying energy optimisation opportunities by conducting energy efficiency audits.

Energy efficiency improvements coupled with renewable energy exploitation (e.g. co-generation), could potentially deliver a WWTW that is self-sustainable and no longer reliant on Eskom for its power supply, depending on the technology and wastewater characteristics of the plant.

As legislation is adopted to comply with international good practices, it is anticipated that energy efficiency audits will become a legal requirement, rather than just a voluntary optimisation exercise. Energy efficiency audits may also become a required input document in Environmental Impact Assessments for any future planned expansions on WWTWs.

5.4.3 Monitoring of WSD initiatives

Monitoring of water resource quantities and qualities is key to measure the effectiveness of the WSD initiatives implemented in the area. Surface flow monitoring and water levels of water bodies should be measured, and the results considered at the planning phase. Groundwater monitoring should also be conducted in the area. Long term monitoring is encouraged as seasonal and cyclic processes should be accounted for in WSD planning. Currently, monitoring in various cities in South Africa is relatively poor and the restoration of certain programs proven to be unfeasible due to financial constraints (CoJ, 2009 as cited in Armitage, 2014). Monitoring further provides a baseline for management objectives, assists in maintaining human health standards and ensures adherence to legislation (Australian Department of Water, 2011 as cited in Armitage et al., 2014). Monitoring is also vital for the calibration and validation of models applied to WSD.

During the operation and maintenance phases of WSD initiatives, monitoring must be included to observe the impacts of the various initiatives. Monitoring initiatives will include leakage monitoring systems, peak runoff discharges, surface water and groundwater quality, flow monitoring and water quality of water bodies as well as volumes over time, vegetation and silting monitoring and water quality of effluent discharge. The effectiveness of awareness programs, management strategies and community participation also need to be monitored throughout the lifecycle of WSD initiatives in Lephalale.

5.4.4 Maintenance of WSD initiatives

The maintenance of WSD infrastructure and programs are considered vital for the successful implementation of WSD. Maintenance plans and costs must be included in the planning process carried throughout the lifecycle of the project. Adequate programmes and the appropriate allocation of resources towards maintenance is necessary (Armitage et al., 2014). Maintenance activities will include the maintenance of SuDS infrastructure, the maintenance of wastewater treatment works, the long-term execution of awareness programs, engagement with the communities and other stakeholders and the accurate management of the various systems and processes put in place to ensure WSD. There should be methods in place to ensure that consumers and service providers "… clearly understand their roles and responsibilities with regard to the operation and maintenance of the implemented systems" (Armitage et al., 2014, p. 66). The failure to maintain the WSD initiatives implemented leads to a degradation of the environment and can have negative impacts on the sustainability of the region. Examples of poor maintenance includes unsightly wet/dry ponds, algal growth, garbage build-up (Armitage et al. 2014) and a lack of interest from the stakeholders involved.

5.5 EVALUATION OF COMMERCIALISED WSD

The South African Water Sensitive Design Framework can be categorised as Stormwater Management, Sanitation and Waste minimisation, Groundwater Management and Sustainable Water Supply.

The following sections address proposed ideas of commercialised WSD that have been implemented within South Africa. Some options have already been evaluated and others will be processed and screened out accordingly.

5.5.1 Storm Water Management

The philosophy of storm water management is to contain and recycle contaminated water, isolate and direct clean runoff to the environment. In many instances, the industries treat contaminated water to a level that can be legally discharged to the environment. The formalized urban area of Lephalale uses conventional stormwater management to channel water away to prevent ponding and localized flooding. With the substantial urban growth predicted in the region (IDP, 2016), the existing stormwater infrastructure may not be capable to withstand the increased runoff due to large impervious areas and the predicted increased depth of storm events. The expanding urban area provides the opportunity to implement water sensitive designs at the urban planning phase making it easier to incorporate. Potential WSD initiatives that maybe applied are addressed in the following sections of the document.

5.5.1.1 Sustainable Urban Drainage Systems (SuDS)

Sustainable Drainage Systems (SuDS) present an alternative approach to the management of stormwater by managing surface water drainage systems with the aim of achieving sustainable development (Armitage, 2014). The various SuDS categories that can be implemented are:

- Good housekeeping – which is an initiative to create public awareness and optimise current household chores,
- Source controls – is a derivative of green roofs, rainwater harvesting soakaways and permeable pavements,
- Local controls – include filters, swales, infiltration trenches, bio-retention and sand-filters,
- Regional Controls – these controls include detention and retention ponds and constructed wetlands.

The introduction of swales, rain gardens, detention ponds and filtration basins in strategic areas is to improve infiltration and attenuate the runoff reducing the flow to the conventional stormwater infrastructure. The formal urban landscape holds the potential for the use of rainwater harvesting systems. Rooftops can be designed to include rainwater harvesting tanks and/or vegetated roofs with store stormwater and attenuate the flow of excess water. Semi-permeable paving can be introduced where imperious surfaces would typical be used. Examples of various SuDS within South Africa are shown in Figure 37 and Figure 38.

Figure 37: Pictures of Stellenbosch (left) and eThekwini (right). These are some examples of where semi-permeable pavings have been implemented (Carden, 2015).

In areas that have polluted water, e.g. road runoff, constructed wetlands and filtration basins can be incorporated to filter the water and improve its quality. The improved water quality may make it permissible to re-use as greywater which reduces the water demand in the area.

Figure 38: Example of a swale in Muizenberg, Cape Town (left) and an example of a wetland in Ridgeside, eThekwini (right) (Carden, 2015).

The informal settlements in the area are also expected to expand and play a significant role in water management. Informal spaces are viewed as spatially fluid making it difficult to implement water infrastructure. A WSD project conducted in the Langrug Informal Settlement in Western Cape, South Africa, highlights initiatives that can be introduced to informal spaces to bring the space towards a water sensitive settlement. The introduction of SuDS would enhance the biodiversity and amenities of an area as it incorporates many natural to semi-natural elements.

5.5.1.2 Rainwater Harvesting

Strategies aimed at reducing the water use are separated into four categories. Structural methods which refers to physical infrastructure aimed to reduce the quantity of water required to perform respective functions. Operational methods include pressure management systems and leak detection and repair programs aimed at improving efficiencies. Economic methods include all aspects of cost recovery for water use and lastly socio-political methods refer to education and awareness campaigns that can be implemented to move consumers towards sustainable water supply (Armitage, 2014).

The proposed study is based on the informal settlements in Marapong which are anticipated to be upgraded to low cost housing with same density as the existing township. Proposed Water Sensitive Designs (WUSD) for this development Includes, Stormwater Retention, Wastewater Reuse and Rainwater Harvesting. The stormwater retention and vegetation swales were covered in the previous study only the latter two options are covered. The options that were investigated are discussed below. The results of these options will be discussed in the next progress report.

A Stochastic Rainfall simulation model was set up using historical rainfall data sourced from Ellisras weather station. The data is resampled and forecasted in Golder Associates Water Harvesting Tool to predict future rainfall events for the modelling of the reliability of the rain harvesting and the stormwater detention / retention system. The aim of the study was to analysis the benefits of using water sensitivity design applications on the Marapong Township Development. Rainwater harvesting, and wastewater reuse options were analysis and the following results were deduced:

- The Lephalale area has a low Mean Annual Precipitation (MAP) and most of the rainfall occurs in November to March
- The Rainwater harvesting results concluded a significant amount of potable water savings
- The WWTP reuse has a significant potential saving with an achievable payback period
- By reusing WWTP effluent water the locals will have the potential of starting small scale fresh market produce and help eliminate poverty.

5.5.2 Water Reuse

5.5.2.1 Optimization of current Wastewater treatment plants

The management of water treatment plants in the Lephalale poses the greatest opportunity to improve effluent quality. The area currently has three wastewater treatment plants namely the Paarl, Witpoort and Zongesien Treatment Plants. The optimization of these plants' operations will assist in reducing the water losses as well as improve the effluent quality. Wastewater generated can also be treated to a standard that is suitable for effluent re-use opportunities (industrialised, process water or irrigation purposes).

5.5.2.2 Wastewater reclamation plants

The Waterberg District area does not have any water reclamation plants but, with the development of water treatment technology in South Africa, it has proven to be the most feasible in water-stricken areas. The Beaufort West wastewater reclamation plant treats sewage effluent to potable water standards and the eMalahleni wastewater reclamation plant treats acid mine drainage water to potable standards. Both plants have been successful in their fields and are leading examples for water reuse. The introduction of a wastewater reclamation plant into the water supply infrastructure of the Lephalale area will provide an additional source of water and alleviate stresses on the current water supply. The following sections provide a description of these plants. Unfortunately, no design criterions have been evaluated to investigate the feasibility of having the reclamation plants within South Africa.

The Beaufort West and eMalahleni Reclamation plants are described in more detail below.

Beaufort West direct wastewater reclamation plants

The first direct water reclamation plant that has been implemented within South Africa is in Beaufort West in the Western Cape. The treatment process includes the following stages:

- Phosphate removal – Addition of ferric chloride to the activated sludge for the removal of Ortho-phosphates
- Settling – This involves using a settling tank to separate the remaining suspended solids
- Pre-disinfection – The supernatant from the settling tank is disinfected with chlorine
- Filtration – This step involves the use of gravity sand filtration which removes any remaining suspended solids. This also protects the membranes downstream.
- Ultrafiltration (UF) – UF is a membrane technology that is used to remove micro-organisms such as Giardia, Cryptosporidium, bacteria and most viruses.
- Reverse Osmosis (RO) – High pressure RO membranes are used to remove most of the remaining organics, pesticides, hormones, aqueous salts and metal ions.
- Advanced Oxidation – The advanced oxidation stage involves dosing peroxide with the RO permeate and then using a UV light to absorb or breakdown any other contaminants.
- Post stabilization and Blending – The effluents pH from the advanced oxidation stage is increased and a small amount is added in the water to protect the piping network until it reaches the user.
- Blending of Water – The reclaimed water is pumped to a service reservoir and blended with other water sources. The town currently uses 20-25% of reclaimed water.

Outeniqua WWTW (George) indirect wastewater reclamation plant

A 10 ML/day indirect water reuse plant, treating effluent from the Outeniqua WWTW, using ultrafiltration technology provides an indirect potable water supply augmentation to the City of George via the Garden Route Dam. The treatment process includes the following stages:

- Settling – The feed water is obtained from the existing secondary sedimentation tanks at Outeniqua WWTW.
- Phosphate removal – Addition of ferric chloride to the activated sludge for the removal of Ortho-phosphates.
- Screening – The outflow from the clarifiers pass through a protective screen upstream of the balancing tank.
- Balancing – Balancing tanks are provided for the equalisation of the diurnal peak flows.
- Strainers – From the balancing tank the water is pumped through a strainer to the UF membranes.
- Ultrafiltration (UF) – A low-pressure UF membrane system is used to remove micro-organisms such as Giardia, Cryptosporidium, bacteria and most viruses.
- Disinfection – The UF filtrate is chlorinated to provide an additional barrier before being pumped to the Garden Route Dam.
- Blending of Water – The reclaimed water is pumped to the Garden Route dam. The header was installed to make provision for the expansion of the recovery capacity to 35 MLD. The treatment capacity represents approximately 45% of the current water demand.

eThekwini wastewater reclamation plant

The eThekwini wastewater reclamation plant treats a mixture of domestic and industrial sewage and municipal wastewater to near potable standards for reuse in industrial processes by companies such as Mondi Paper and SAPREF. The plant frees up potable water for municipal use in peri-urban communities, by reclaiming water at rate of 47,5 ML/day. It further reduces the amount of discharged municipal wastewater into the environment. The treatment process includes the following stages:

- Screening, degritting and primary sedimentation – The incoming wastewater is pre-treated as per typical activated sludge pre-treatment methods.
- Activated sludge – The supernatant from the primary sedimentation tanks serves as the feed water to the activated sludge process.
- Secondary Sedimentation – The treated water from the activated sludge process goes to secondary sedimentation tanks for the removal of the bulk of suspended solid.
- Coagulant addition – A metal salt is dosed before polymers are added to enhance flocculation.
- Lamella settling – Lamella type clarifiers are used to further clarify the water.
- Iron removal – The clarified water is dosed with polyaluminium chloride to remove residual iron and enhance the filtration process.
- Dual media filtration – For further removal of solids.
- Ozonation – To break down remaining non-biodegradable organic compounds.
- Activated carbon filtration – As a polishing step.
- Chlorination – For final disinfection.

eMalahleni Water Reclamation plant

The eMalahleni water treatment plant is one of the first water treatment plant that treats mine water to potable water standards. The plant treats acid mine drainage water from three different mines using a three-stage treatment process. The treatment stages consist of a neutralization stage that increases the pH of the acidic feed water to assist in metal precipitation. The next step consists of settling the suspended solids. The supernatant from the settlers are treated in HIPRO (High Recovering precipitation Reverse Osmosis) membranes in which low salinity water is produced. The brine reject from each stage is re-entered into the next stage to reduce the final brine volume. The final stage brine is stored in a brine pond and the water produced is blended with the municipality water where it is distributed to the eMalahleni town. This process is efficient and results in high recovery, low operational and capital costs and minimum waste.

5.5.2.3 Chemicals of Emerging Concern

CECs is a catch-all term for chemical compounds with an adverse effect on human, animal and environmental systems. CECs have a range of negative impacts, but current focus seems to be on substances that may be carcinogenic, act as endocrine disruptors, or which are toxic. A broad range of substances contribute to CECs and includes for:

- Pesticides,
- Herbicides,

- Pharmaceuticals,
- Plasticisers, and
- Flame retardants to name a few.

Typical technologies used for CEC removal, are:

- Reverse Osmosis (RO) – Achieves some removal of CECs, but at a high operating cost and carbon footprint due to the energy intensity of the technology. It further produces a problematic brine stream that needs to be disposed of,
- Nanofiltration – Less efficient in CEC removal than RO, but has lower power requirement,
- Ozonation with biological and granular activated carbon – more complex to operate and maintain. Oxidation by-products are produced that may be problematic as well.

5.5.2.4 Wastewater Reuse Quality Options

The final purpose for reuse of water determines the level of tertiary treatment that is required. Treated water from conventional WWTWs could potentially still contain contaminants such as chemicals of emerging concern and pathogens that have not been fully removed. Hence further treatment technologies, typically membrane-based, are essential. Typical levels of reuse that can be used either in conjunction or separately, can be broadly classified as:

- Recover used water for irrigation, discharge treated excess to the environment,
- Recover used water for industrial potable level use, discharge treated excess to the environment,
- Recover used water for indirect potable reuse,
- Recover used water for direct potable reuse.

Where water is treated for potable reuse, the principle of multiple barriers is used, meaning for any component that needs to be removed, at least two technologies must be installed to remove this component.

Recover used water for irrigation

This option will address environmental risk and contributes irrigation water to areas used for communal farming. When treating wastewater for use in irrigation, rather than for release to the environment as per the current model, additional disinfection and reduction of CECs is essential.

A typical configuration will as a minimum have the following infrastructure components:

- Primary treatment,
  - Pump stations and piping,
  - Screening,
  - Degritting,
  - Primary Sedimentation.
- Secondary Treatment,
  - Biological nutrient removal,
  - Secondary Sedimentation.

- Tertiary Treatment,
  - Screening and disc filters,
  - Multimedia filters,
  - Disinfection,
    - Advanced Oxidation (AO),
    - Chlorination for residual disinfection,
  - Storage capacity,
  - Distribution pumps and piping.

Recover used water for industrial potable level use

The quality of water produced in this case is near potable quality, but not classified as suitable for human consumption.

This option will address environmental risk and contributes potable water to areas used for communal farming, industrial processes and toilet flushing.

A typical configuration will as a minimum have the following infrastructure components:

- Primary treatment,
  - Pump stations and piping,
  - Screening,
  - Degritting,
  - Primary Sedimentation.
- Secondary Treatment,
  - Biological nutrient removal,
  - Secondary Sedimentation.
- Tertiary Treatment,
  - Ultrafiltration (UF),
  - Clean-in-Place (CIP) facilities,
  - Disinfection,
    - Advanced Oxidation (AO),
    - Chlorination for residual disinfection,
  - Storage capacity,
  - Distribution pumps and piping.

Recover used water for direct or indirect potable level use

This option will address environmental risk and contributes potable water human consumption.

A typical configuration will as a minimum have the following infrastructure components:

- Primary treatment,
  - Pump stations and piping,
  - Screening,
  - Degritting,
  - Primary Sedimentation.
- Secondary Treatment,
  - Biological nutrient removal,
  - Secondary Sedimentation.
- Tertiary Treatment,
  - Ultrafiltration (UF),
  - Clean-in-Place (CIP) facilities,
  - Reverse Osmosis (RO),
  - Clean-in-Place (CIP) facilities,
  - Stabilisation and pH correction,
  - Disinfection,
    - Advanced Oxidation (AO),
    - Chlorination for residual disinfection,
  - Storage capacity,
  - Distribution pumps and piping.

5.5.2.5 Wastewater Reuse Technology Options

Membrane bioreactors (MBR)

In an MBR reactor the activated sludge reactor traditionally used in wastewater treatment is followed by an integrated compartment containing ultrafiltration membranes that form a physical barrier that retains the microbial biomass within the reactor.

MBRs operate at a higher biomass concentration than typical for Conventional Activated Sludge (CAS) systems since the system is not dependent on gravity separation for the removal of the solids in large secondary sedimentation tanks. As a result of the physical barrier provided by the membranes, a higher sludge concentration can be maintained within the reactor. This also provides a separation of solids concentration and sludge age control, resulting in higher sludge age and reduced waste sludge production.

The physical barrier provided by the membranes also results in a higher, more reliable quality product water than can be provided by CAS. This makes the product water more suitable for direct re-use for industrial process water, irrigation water or for release to the environment. Further downstream processing enables the re-use of the treated water for potable purposes.

The higher sludge concentration also results in a smaller reactor volume required, resulting in reduced physical footprint and reactor construction costs. The high MLSS in the reactor however results in reduced oxygen transfer efficiency and thus significantly higher energy consumption than with CAS.

The UF membranes have a limited life of typically 5-7 years, although some reference facilities have achieved membrane lives of more than 10 years. Membrane replacement thus further increases the operating cost of an MBR facility compared to CAS.

The main benefits of MBR systems are:

- The certainty of achieving clarification regardless of the state of the sludge or its sludge index because the membrane can screen out non-flocculated bacteria and produce a suspended solids-free effluent (turbidity < 1 NTU),
- The effluent is largely disinfected (i.e. removal of pathogens such as helminth eggs, bacteria and even viruses when using an ultrafiltration membrane),
- Having overcome the need for a clarifier, the biomass concentration in the reactor can be increased to between 6 and 10 g/ℓ. For the equivalent F/M loading, this leads to the possibility of reducing the aeration reactor by a factor of 2 to 4 compared with a conventional activated sludge reactor,
- The absence of a clarifier and use of a smaller capacity membrane tank means that civil engineering costs and ground area covered will be markedly lower,
- The membrane ensures that certain macromolecular metabolites are screened out and gradually degraded, generating a final COD that is lower than that achieved with CAS.

The typical performance obtained by an MBR system is summarised in Table 13

Table 13: Typical MBR Product Water Performance

Parameter	Concentration
Suspended Solids (mg/ℓ)	< 2
Turbidity (NTU)	< 1
COD* (mg/ℓ)	< 30
BOD (mg/ℓ)	< 3
NH_4-N (mg N/ℓ)	< 1
Total N (mg-N/ℓ)	< 10
Faecal Coliforms (CFU count in 100 mℓ)	< 100

* Dependent on the non-biodegradable COD entering the facility

Tertiary Ultrafiltration

Ultrafiltration (UF) is utilised in MBR systems to obtain sludge/product water separation. In an MBR reactor, the activated sludge reactor is followed by an integrated compartment containing ultrafiltration membranes, which form a physical barrier that retains the biomass within the reactor. This results in certain benefits and disadvantages.

The option however also exists to utilise tertiary UF downstream of CAS systems or other similar biological treatment technologies. Installing the membranes in a membrane tank forming part of the MBR configuration is not required; they can be installed independently downstream of the sludge/water separation step. This results in the following benefits for the WWTW owner:

- Improved oxygen transfer efficiency when compared to MBR due to the lower biomass concentration in the reactor and thus reduced power consumption,

- Reduced suspended solids concentration to which the UF membranes are exposed results in higher flux rates and thus a smaller membrane surface area required, resulting in smaller areas of membrane required and thus reduced capital cost,
- In MBR membrane area must be provided for the total flow being treated. For tertiary treatment the membranes are not integrated in the AS reactor and hence membranes need to be installed only for the fraction of the treated water intended for re-use, resulting in the option to modularly expand the UF section as demand increases
- Depending on the level of upstream suspended solids reduction (use of intermediate disc filters), the need for air scouring to keep the membranes clean can be reduced or eliminated, resulting in reduced power consumption and operating costs,
- Depending on the level of suspended solids reduction, cheaper membrane options can be considered, resulting in reduced capital cost,
- Reduced suspended solids also results in less membrane fouling, thus reducing the frequency with which membrane CIP needs to be performed,
- Reduced membrane fouling results in longer membrane life and thus less frequent replacement of membrane cassettes, resulting in reduced operating costs compared to MBR.

Reverse Osmosis

Due to their smaller pore size when compared to UF, reverse osmosis (RO) membranes are one of the most reliable processes for the final removal of undesirable dissolved components not yet removed by filtration and UF.

In RO systems, semi-permeable membranes that retain dissolved components but permit water to pass through the membrane are used – based on the principles of osmosis. In osmosis, water would typically move through a membrane to a solution containing higher dissolved solids. In RO, pressure is utilised to force the water through a similar membrane, thus obtaining high-quality water as a product, as well as a high salt residual stream called brine being produced.

In inland areas, disposal of the brine is problematic, since it cannot be released to rivers. However, in coastal areas, the brine can be released at points of high turbulence in the ocean, resulting in almost instantaneous dilution of the brine stream.

The RO membranes will also retain some organic pollutants as well as CECs, thus providing a safer source of water for potable re-use.

5.5.2.6 Wastewater Reuse

About 500 litre out of 600 litre potable water used by lower income households ends up in the sewer collection system (Johannesburg Water, 2017) which is then treated at a Wastewater Treatment Plant (WWTP) and finally realised back into the water cycle via rivers and canals in accordance with the National Water Act of South Africa.

Figure 39 shows a schematic layout of the proposed WWTP effluent reuse. The proposed design includes reusing all the effluent from the Marapong WWTP which currently has a capacity of 1.5 ML/d (16 Ml/d in the future according to Lephalale Municipality 2018/19 IDP). This water can be used to augment the water demand for sanitation, gardening, laundry, car wash, and irrigation for subsistence or commercial use by community members on communal land. This water will be pumped using a solar pump from the WWTW sump to the 500 Kl water tower to be located 3.5 km south west of WWTP. This water will be redistributed to the community through a secondary green water reticulation system.

Due to the risk of exposing the community to E-coli and other pathogenic bacteria, the distribution will be implemented in such a way the it will connect directly to toilet cisterns, washing machine connection points, car wash systems for commercial SMME's, separate garden taps clearly marked no for drinking and to irrigation areas.

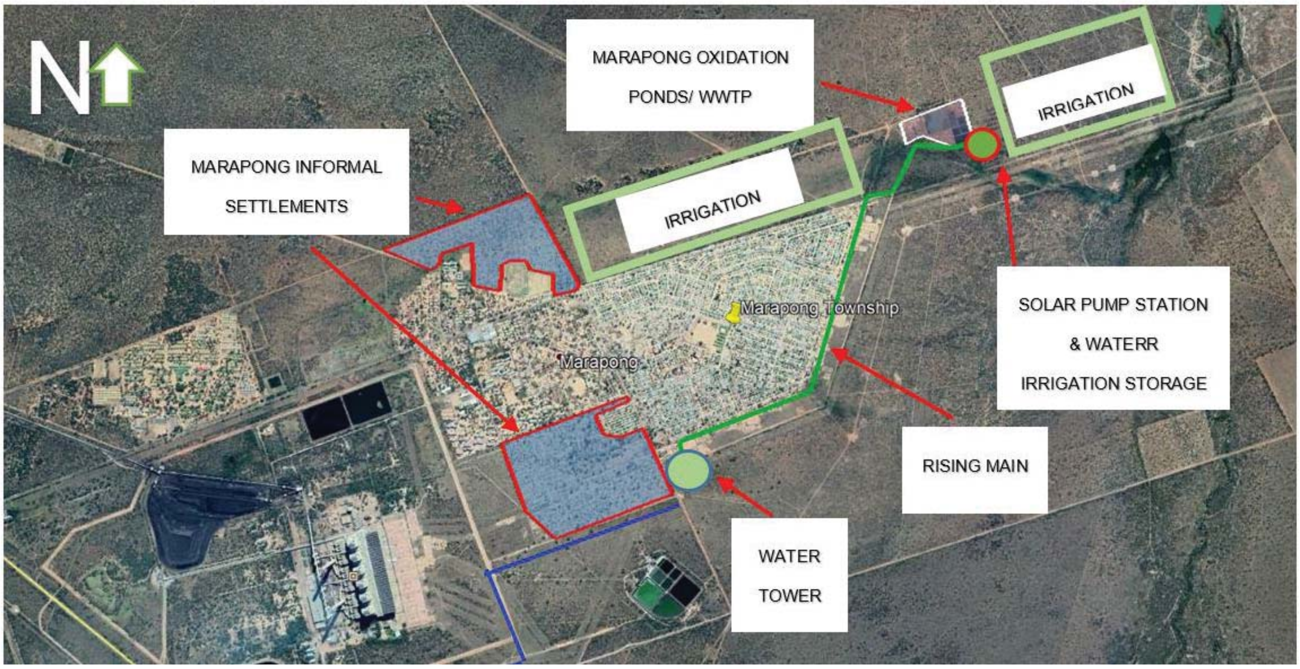

Figure 39: WWTW effluent reuse schematic.

5.5.2.7 Potable Water Savings

Water savings are generated from the amount of potable water substituted by the reuse system. The study area is estimated to have 5 persons per household which excludes backyard dwellers. The report includes an estimated amount potable water savings that can be achieved within each household.

5.5.2.8 Community Crop Irrigation Schemes

Based on the Department of Water and Sanitation a Wastewater Treatment Plant is required to meet the Green Drop effluent water quality limits. The assumption taken is that Marapong WWTP meets the green drop limits, but should it fail these limits, the barrier proposed is that the allowed irrigation crops be such that they cannot be eaten raw or those that produce fruit and not watered by sprinkling. According to South African Water Quality Guidelines Volume 4: Agricultural Use, effluent water from the WWTP will be acceptable if passed the Green Drop System. Should the WWTP fail, the Green Drop System is a threat to humans who consume the crop raw or touch this water is, Faecal Coliforms and its related pathogens. The possible prevention to infection includes, using garden gloves, avoid using surface drip irrigation systems for watering, not eating raw crop like carrots, lettuce, pepper, etc. directly from the garden but cooking it or allowing enough time to pass between last irrigation and harvest for pathogens to die out (DWAF, 1996). WWTP effluent also contains nutrients like nitrates and phosphates that are beneficial to the crop because they act like fertilizers.

Water from the WWTP can then be reuse in the environment for plant production already in being produced in and around Lephalale. These crops include vegetables, cotton, tobacco, citrus, paprika, pepper, Lucerne, groundnuts, table grapes, dry beans, wheat, maize, flowers, watermelons and oranges. The irrigation scheme will provide locals with empowerment and help to reduce poverty.

5.5.2.9 Ecological Wastewater Treatment

This system is used to treat wastewater with minimal energy uses, chemicals or mechanical parts. Ecological systems also require minimal maintenance which makes it ideal for rural areas. Lephalale is an area that consists of many farming areas. By implementing ecological systems for treatment of wastewater within the farming areas these farms could reduce the increased demand of water required

The treated water may be used as flushing water within the toilets and other activities on the farm. An operational example of this wastewater treatment by Isidima was done for the Botmansdrift Farm (Isidima, 2018). Other ecological designs that have been commercialized have treated highly polluted water that flows into the Plankenbrug River in Stellenbosch. The aim of this project was to demonstrate the effectiveness of ecological treatment systems to treat river water that is polluted from greywater run-off and sewer flooding (Isidima, 2018).

Implementing the ecological wastewater treatment to the Lephalale area is seen as a low-cost initiative to reduce the load of potable water that is supplied to the farms.

5.5.2.10 Re-use and Recycling

In many cases, water intended for re-use does not require treatment to drinking water standards. Such examples include greywater for flushing of toilets, grey water for washing cars, greywater for garden and crop irrigation, greywater for cleaning and dust suppression activities (Armitage et al., 2014). Investing in greywater treatment within the Lephalale region would be beneficial from a water demand management perspective as this would reduce the potable water that is required to each household. A common way of collecting and treating greywater is to have an in-house grey water tank that collects greywater from drainage pipes. This intervention would assist in recycling water to both formal and informal settlements. Reusing greywater would also result in reducing overall energy costs. The treated greywater can be used to water lawns, food crops/trees for flushing toilets and washing motor vehicles.

The partial treatment of water intended for re-use through either semi-natural system such as constructed wetlands or elementary water treatment facilities will reduce the volume of water that requires complete treatment at water treatment plants.

The recycling and re-use of water in different industries should be implemented at the respective level. Currently, the mining and power generating industries are regulated by the DWS to recycle process/contaminated water through the promotion of onsite water conservation and water demand management practices. Introducing awareness programs highlighting the benefits of the re-use of water and addressing the cultural and contextual reservations around the re-use of water will improve its incorporation into the suite of options available for meeting water supply.

5.5.3 Water Conservation and Water Demand Management (WC/WDM)

5.5.3.1 Minimization of waste within Households

The minimisation of potable water demand in residential households, within the Lephalale region will reduce the volume of wastewater that requires treatment. The introduction of water efficient devices such as low-flow taps, low-flow showerheads, and low volume toilets can be introduced to both formal and informal settlements. Public buildings and public water supply points can be fitted with self-timers to prevent taps running unattended and/or leaking.

CHAPTER 6: KNOWLEDGE AND SCIENCE BASED SUPPORT TOOLS

This study aims to adopt the Watershare® tools and assess its applicability in urban water management in in the South African context. The Watershare® Tools were developed by KWR Watercycle Research Institute. The tools are designed by an international collaboration of various institutes with the aim of creating an effective knowledge base available internationally. For the investigation of the feasibility of WSD, four tools were identified as potential tools to assist in water management. These are namely the City Blue Print, Wastewater Treatment Selection System (WASS), Water Use Info and Urban Water Optioneering Tool (UWOT). Each tool's functionality is evaluated and its applicability for the implementation of WSD is discussed in the forthcoming sections.

Several other tools in addition to the Watershare® tools are typically used for water balance assessments and stormwater design. Options identified and tested using the WaterShare tools was also evaluated using these tools in parallel.

6.1 WATERSHARE TOOLS

Watershare is a worldwide network of water research organisations and utilities dedicated to applying global expertise to master local water challenges. Watershare is an international collaboration in which water sector-proven methods, techniques and experiences are shared and applied. Watershare's objective is to make the most appealing and effective knowledge and expertise internationally available to water practice.

The Watershare members develop models and methods based on scientific knowledge and successful practical applications. The resulting tools are incorporated into the online Watershare Tool Suite which secures the knowledge and makes it available to be applied by other Watershare members to a wide range of situations. The tools cover current, urgent and relevant water themes: Subsurface Water Solutions, Future-Proof Water Infrastructures, Resource Recovery & Upcycling, Emerging Substances and Resilient Urban Water Management. They can consist of databases, smart data handling tools or modelling tools. Most tools are web-based and are optimally designed to support water-practice managers in responding to both tactical as well as more strategic questions.

The following available Watershare® tools applicable to WSD are discussed in detail in the subsequent sections of the document:

- City Blueprint
- Wastewater Treatment Selection (WASS)
- Water-Use Info
- Urban Water Optioneering Tool (UWOT)

6.1.1 City Blueprint

Urbanization creates a greater strain on water management. As cities aim to improve the sustainability of their water management, the identification of their water-related strengths and weaknesses is required. The city blueprint is a practical communication tool to assess a given city's sustainable water cycle strengths and weaknesses regarding other cities. The tool makes use of questionnaires to gain information on a city. This information is used to calculate indicator scores on a scale from 0, where attention is needed, to 10, where no attention is needed. The results are given context by further information gathered by literature references obtained from the tool itself, other cities' assessments and explanations. The results serve as a basis to identify a city's sustainable water conservation and management status. The comparison between other cities assist in identifying possible strategies and policies which can be adopted by a city. It is considered a vital first step to the use of Watershare® tools. University of Cape Town Student, Boipelo Madonsela used the City Blue Print Tool to assess the City of Cape Town (Figure 39)

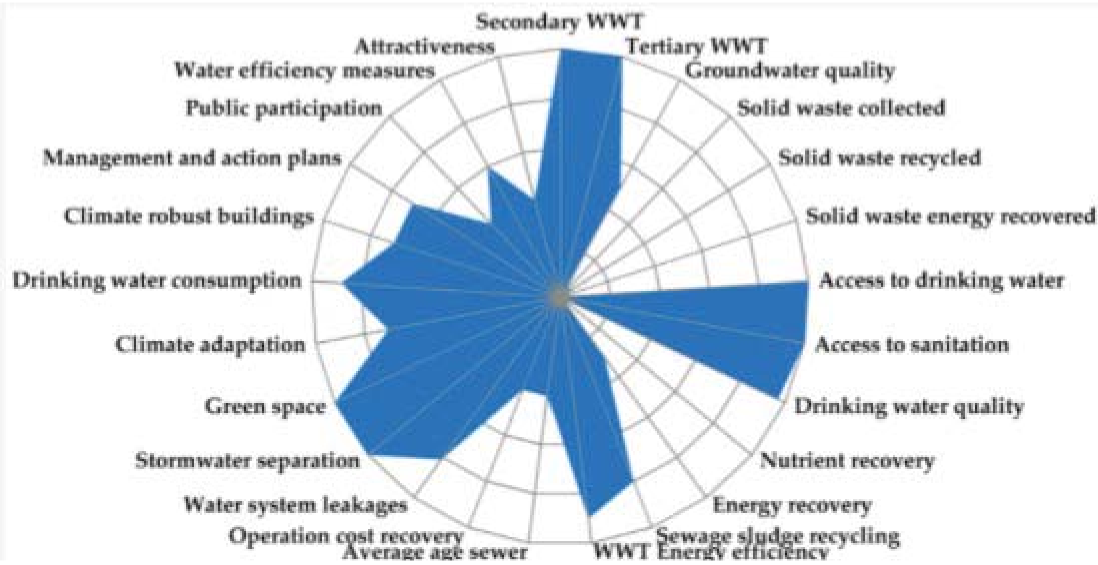

Figure 40: City Blueprint generated for City of Cape Town (Madonsela B, Koop S, van Leeuwen, Carden K, 2019)

The tool is data intensive requiring detailed and current information on a city to accurately assess its water sustainability ranking. This becomes a challenge when applied to areas that are not well managed where little information about a city is readily available. From research done in Cape Town, South Africa, it is seen that even for the developed city, it is difficult to obtain all the information required. The area of Lephalale is predicted to be an area with even less readily available information and many assumptions would be made, skewing the results of the City Blueprint analysis.

Further, the urban growth in Lephalale is predicted based on the economic drivers in the region. Hence, much of the information in the area would be based on predictive models and assumptions which may not represent the actual future situation. It is however recommended that the town implements a monitoring and data management program in order to track current trend for use in planning going forward.

6.1.2 Wastewater Treatment Selection (WASS)

The WASS tool was developed by the BAT knowledge centre of VITO, a leading European independent research and technology organization in the area of sustainable development. The tool analyses potential sustainable treatment methods for wastewater based on the he influent water properties, such as the inorganic components present and the pH. The influent properties are inputted by the user. The user further indicates the desired degree of removal. The tool then outputs the treatment options that would be effective in treating the water.

The usefulness of this module is in its evaluation of treatment and recycling options in urban areas. The treatment options are well described with its advantages and disadvantages which assist the user in choosing the most appropriate treatment and/or recycling option.

The WASS tool assists in providing possible combinations of treatment techniques to solve wastewater problems. The tool was used to analyse the effectiveness of implementing a Sewage treatment plant within the Lephalale area. The reliability of the test was confirmed by using two sewage feed water qualities. The influent was characterised by the sewage feed water quality from the Johannesburg Water (JW) and the eThekwini municipality. The tool provides a treatment solution for wastewater treatment based on the water quality inputted by the user. The tool assesses the following categories of the influent wastewater quality.

- Wastewater Characteristics (Flow composition, pH, suspended solids, separability, settleability, etc.);
- Organic Compounds;
- Nutrients; and
- Metals;

WASS requires a significant amount of inputs by the user based on the feed water quality data. Figure 41 shows an example of the objectives and outputs of the WASS tool.

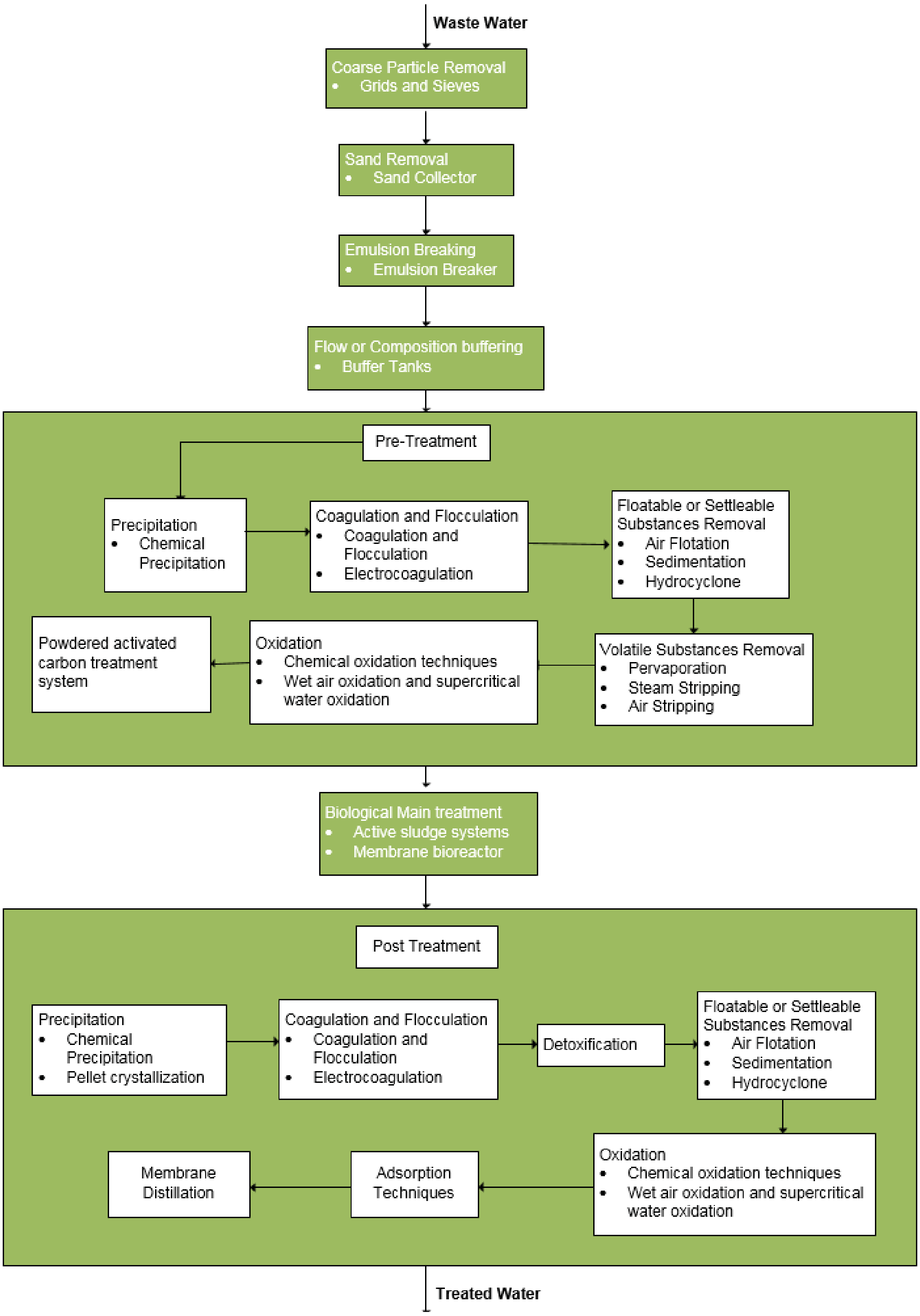

Figure 41: Flow diagram displaying the outputs of the WASS tool.

Figure 41 shows that there are four treatment sections that the water quality needs to go through. The Upstream Process, these are categorised as the mandatory stages require to remove the interfering substances. The Pre-Treatment, this involves a series of precipitation, coagulation and flocculation, removal of floatable and volatile substances, oxidation and an activated carbon system. The main aim of this stage is to remove harmful substances that will cause harm to the main biological treatment. The next stage is the biological treatment stage which is used to remove and purify the wastewater stream entering the system. The effluent from this stage enters the post treatment stage which has numerous polishing techniques that assist in removing the remaining organics and pollutants. This stage also assists in producing water quality to potable standards.

The WASS tool incorporates the inputs specified by the user and provides a series of outputs that can be beneficial to the application. For each impurity specified the tool comes up with a strategic solution to remove it.

The following Conclusions were drawn based on the analysis of the WASS Tool for the use in the study on the Lephalale region:

- The tool is user friendly
- Requires several inputs that require laboratory testing. Some of these parameters are not provided in typical water quality in South Africa.
- Some of the application solutions provided by the tool are still in piloting stages and do not have an industrial application in wastewater treatment especially within South Africa.
- The costs for these preferred solutions are mostly dependent on the water treatment quality and the estimates may not be correct
- The tool does not account for influent flowrates which will have an impact on the size of the treatment and recycling options applicable
- Tool does not account for other types of water qualities such as Mine water.

6.1.3 Water-Use Info

The Water-Use Info tool assists in designing and operating water installations and networks without monitoring the water flow in residential and non-residential areas. The tool considers both quantity and quality aspects of the water demand. The module considers each individual in a household and their presence in it. Their water uses are then inputted. Appliances characteristics, such as the flow rate, duration of use, frequency and temperature is also incorporated into the tool. The tool is developed in the SIMulation of water Demand, and End-Use Model (SIMDEUM) software. The aspects can be examined for various design and operational scenarios. The tool generates graphic results on household demand as illustrated in Figure 42.

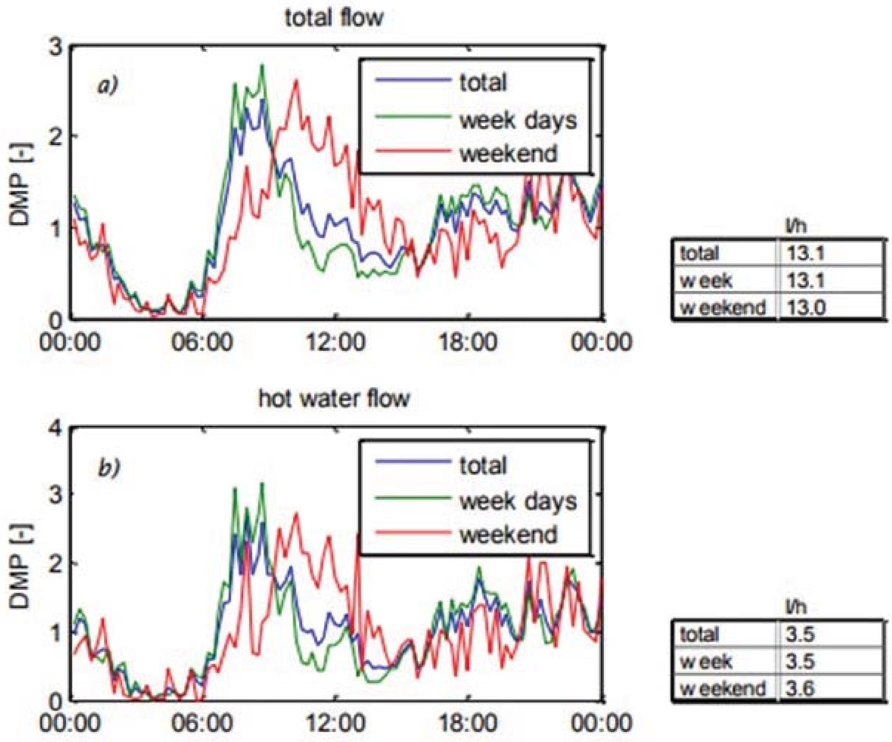

Figure 42: Averaged normalised demand patterns for total number of houses, for all days (blue), during weekdays (green) and during weekend days (red); a) for total water flow and b) for hot water flow.

When applied to the Lephalale area, the software may be limited in its application as formal residential and non-residential areas become difficult to define. Informal settlements are common and water use and management in these areas becomes a complex and fluid concept.

6.1.4 Urban Water Optioneering Tool (UWOT)

UWOT (Figure 43) is a model that simulates the generation and routing of water demand at an urban scale. The tool facilitates the planning and assessment of the urban water cycle. Alternative interventions to reduce the demand on potable water are assessed in the model. Beneficial uses of runoff and wastewater is also evaluated. Energy is also considered in the model with regard to the benefits of green areas on the urban heat island effect and the energy requirements for water appliances.

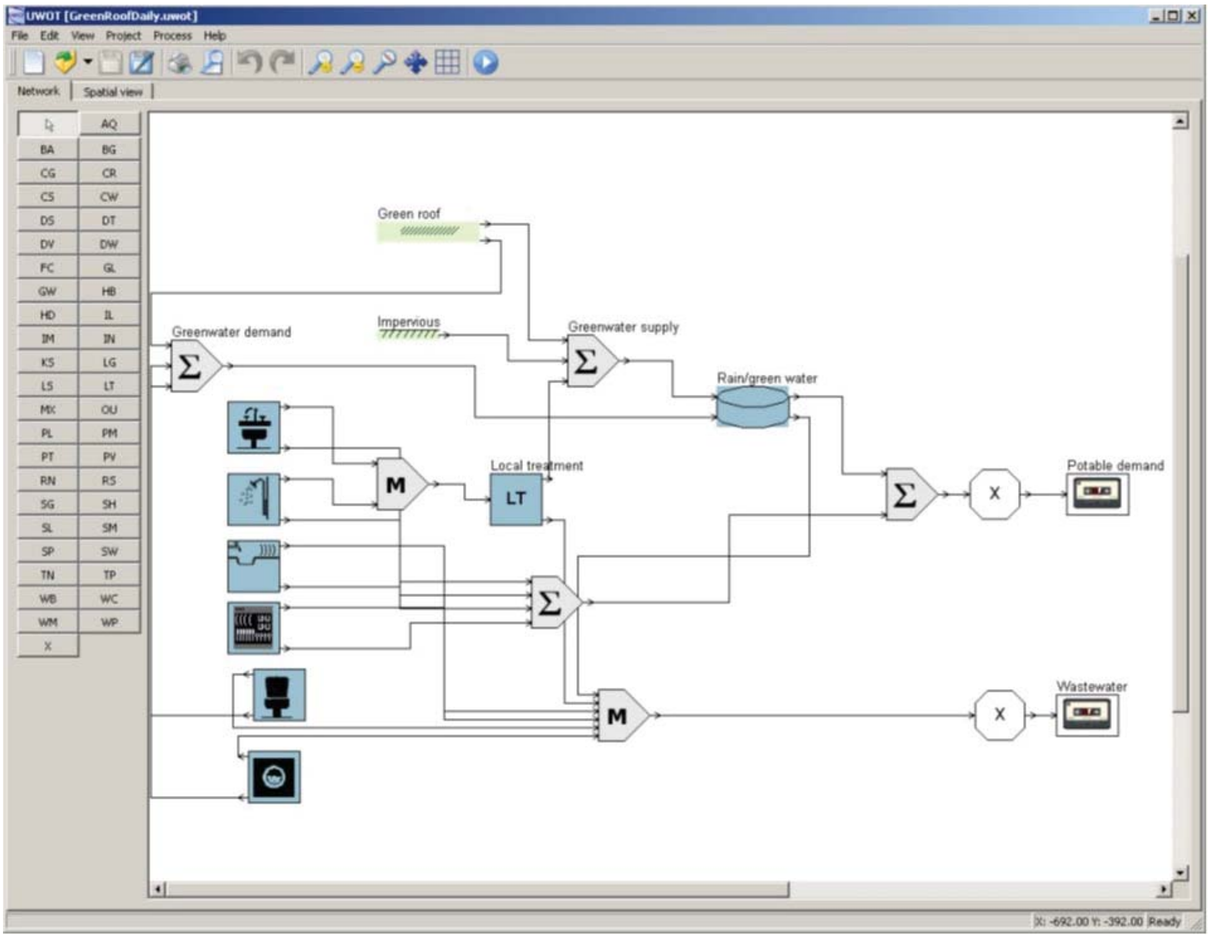

Figure 43: Screenshot of the UWOT Watershare® tool. Various water uses are linked to up and downstream water uses in a graphical format for an urban scaled development.

The tool showed great potential for its applicability to the feasibility study in Lephalale because it allows the user to evaluate different options to manage the area's water and would indicate which options would be most effective. The tool is also at an appropriate scale to observe the impacts of future urban growth and flexible enough to be adapted to various scenarios. This tool however required to be customised by the developer for each site. The tool was also in construction the duration of the evaluation phase of this project.

From the assessment of the tools, the City-Use Info and the UWOT tools prove to be most valuable to model water systems in a growing peri-urban environment such as Lephalale. The Water Use info software will be used to estimate domestic demands and serve as input to the UWOT software. The UWOT software will be used to model the initiatives identified and assess the workable initiatives

6.1.5 GAP Analysis

After an evaluation of the water share tools, it was found that the some of these tools were constrained and other evaluation tools will be required to adapt the water resilient designs to the Lephalale region.

The WASS tool was used to analyse the feasibility of implementing a Sewage reclamation treatment plant in the Lephalale area. The tool is user friendly and has descriptive explanations of each input parameter. The limitations of the tool are as follows:

- Requires several inputs that require laboratory testing. Some of these parameters are not provided in typical water quality reports for wastewater treatment works in South Africa.

- Some of the application solutions provided by the tool are still in piloting stages and do not have an industrial component in wastewater treatment especially within South Africa.
- The costs for these preferred solutions are mostly dependent on the water treatment quality and the estimates
- The tool does not account for influent flowrates which will have an impact on the size of the treatment and recycling options applicable
- The tool does not account for other types of water qualities such as Mine water.

6.2 PARALLEL TOOLS

6.2.1 PCSWMM

Personal Computer Storm Water Management Model (PCSWMM) is a spatial decision support tool for water management modelling. A comparison of available stormwater modelling software and its ability to model WSD initiatives was conducted by Armitage et al. (2014). “A list of all the software models identified was compiled, and an internet-based search was undertaken to determine whether the software was still available and compatible with current operating systems. Mitchell et al. (2007), Elliott & Trowsdale (2007), Zoppou (2001) and Last (2010) all provided extensive background information on what models were available…” (Armitage et al., 2014, P. 112) and formed the basis of the investigation. Eight models were compared on design criteria computations, SUDS component capabilities and costs of purchasing software licenses. They are namely;

- MOUSE: MOdel for Urban SEwers
- MUSIC: Model for Urban Stormwater Improvement Conceptualisation • P8: Model for the generation and transport of stormwater runoff pollutants in urban watersheds
- SLAMM: Source Loading and Management Model
- StormTrac: Stormwater quantity and quality
- SWMM: Storm Water Management Model
- PCSWMM: Personal Computer Storm Water Management Model
- UVQ: A tool for assessing the water and contaminant balance impacts of urban development scenarios
- WinDes: A drainage design software

The results are tabulated in Table 14 and Table 15.

Table 14: Potential models for design criteria computation (Elliot and Trowsdale, 2005, as cited in Armitage et al., 2014).

	Public education	Research	Developing sizing rules for devices	Planning of land use in catchments/cities	Preliminary design of regional controls	Preliminary design of a subdivision or site	Detailed design of regional drainage system	Detailed design of subdivision or site	Site layout and material selection
MOUSE									
MUSIC									
P8									
SLAMM									
StormTrac									
SWMM									
PCSWMM									
UVQ									
WinDes (Quant. Only)									
Key		Model explicitly addresses the use of the device or approach			Model may be used for the approach			Cannot be used for device or approach	

Table 15: SuDS component capabilities for selected design models (Elliot and Trowsdale, 2005, as cited in Armitage et al., 2014).

	Imperviousness reduction	Ponds and wetlands	Soil protection	Reduction of contaminant generation	Infiltration trenches/bores	On site detention tanks	Swales	Run on	Rain tanks	Bioretention, rain gardens, filtration devices	Permeable paving	Green roofs
MOUSE	green	green	orange	orange	orange	green	green		orange	orange	orange	
MUSIC	green	green	orange	orange	green	green	green	orange	green	green	orange	orange
P8	green	green	orange	orange	green	green	green		orange			
WinSLAMM	green	green	orange	orange	green		green			green		
StormTrac	green	green	orange	orange			green					
SWMM	green	green	orange	orange	orange	green	green	green	green	green	green	green
UVQ	green	green	orange	orange	green	orange		green	green	orange		
WinDes (Quant. Only)	green	orange			orange	orange	orange		orange	orange	orange	orange
Key	green	Model explicitly addresses the use of the device or approach			orange	Model may be used for the approach			(blank)	Cannot be used for device or approach		

The SWMM modelling software has the greatest ability to model SuDS components and is appropriate to use for design sizing, planning for land use and from preliminary design. From these findings, SWMM is recommended for the modelling of various WSD initiatives in the Lephalale region.

The following case studies have been included to demonstrate how PCSSWMM will be used in the study. These modules will be further refined as the study progresses.

PCSWWM Runoff Evaluation – Lephalale

Runoff from the urban areas, viz. the Marapong and Onverwacht settlements and the Lephalale town, currently contribute to the Moloko River. Applying WSD principles which involve containment and reuse of water within the catchment would impact on the overall catchment yield. PCSWWM will be used as one of the tools to determine the extent of this impact.

PCSWMM is useful in analysing catchment runoff provided contours are available. At this stage of the project, 5 m contours of the Lephalale area were obtained and catchments delineated for the areas. The urban areas of Marapong, Onverwacht and the Lephalale Town were delineated as well to observe the impacts of water sensitive design initiatives to various degrees on the different types of urban forms.

PCSWMM is capable of simulating climatic conditions based on user input and site specificity. The rainfall for the area is obtained from historic weather station records and inputted into the model. From hydrological studies in the area, Lephalale experiences a South African SCS Type III design storm pattern. The 1:50 year and the 1:100-year storm depths are inputted into the model and the SCS type III storm pattern distributes the rainfall intensity accordingly. The areas delineated are linked to assumed stormwater channels and outlets around the catchment of interest. The positions and sizes of the catchments, channels and outlets can be altered to investigate specific areas of concern and other parameters. The catchment areas are displayed in Figure 44.

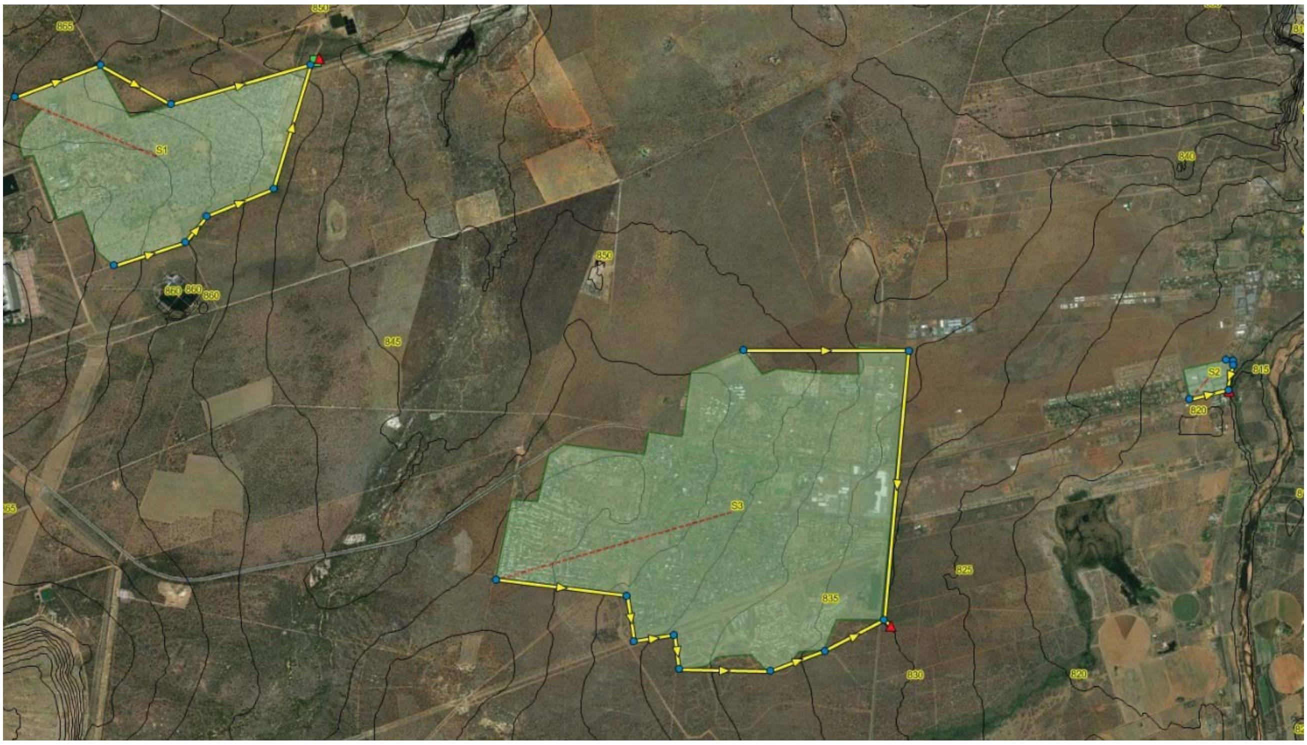

Figure 44: PCSWMM Catchment Area Delineation, channels and outlets modelled for the Marapong (left), Onverwacht (centre) and Lephalale Town (right) areas.

The current climate scenario is run as a baseline scenario. No water sensitive design measures are modelled. Key results include the peak runoff flows experienced in the channels, the volume of water infiltrated and the runoff hydrographs from the 1:50 and 1:100-year flood events.

PCSWMM is capable of evaluating the effectiveness of Low Impact Development (LID), green infrastructure and other best management practices. LID follows the same concepts as WSD. LID details are inputted by the user to develop site-specific LID components which are linked to the catchments previously delineated. For example, green roof details include the surface, soil and geo-synthetic characteristics

The various LID components are linked to respective catchments. The model is then run taking into consideration the impact of the components on the hydrology of the catchment. Dependent on the parameter details defining the LID component, a variation to the hydrograph, peak runoff and volume of water stored in the catchment is expected. These results are recorded and compared to the baseline results to observe the impact of the components on the catchment. For example, the green roof LID component retains a larger volume of water over the urban catchment reducing the peak runoff entering the stormwater infrastructure. Various forms of green roofs and different inputs may alter the findings.

LID components to be considered in this project include:

- Bio-retention cells
- Infiltration trenches
- Permeable paving

- Rainwater harvesting
- Vegetative swales
- Rain gardens
- Green roofs

Similar modelling investigations will be conducted for the above listed components. The combination of various LID components will also be investigated. These combinations will be informed from literature and the findings from the Water Share tools.

Preliminary findings on the catchment runoff models have found that over the Marapong settlement, rain gardens are more effective at reducing the runoff than green roofs for both the 1:50-year and 1:100-year storm events (Table 16).

Table 16: Preliminary peak runoffs from various LID initiatives implemented in PCSWMM.

Runoff Volume of different LID components	1:50-year 24 hr storm event (114 mm)	1:100-year 24 hr storm event (125 mm)	Average percentage reduction in runoff to environment (%)
Current Scenario peak runoff	5.23 ML	5.77 ML	-
Rain Gardens over 30% of catchment peak runoff	4.73 ML	5.24 ML	9.37
Green Roof over 25% of catchment peak runoff	5,21 ML	5.76 ML	2.77

The results from the PCWMM model are to be compared to the Water Share's Urban Water Optioneering Tool (UWOT) to evaluate the effectiveness of the tool.

6.3 TOOLS DEVELOPED FOR THE PROJECT

6.3.1 Rainwater Harvesting Tool

WRC CSAG Water Harvesting Tool (Figure 45) was developed and funded by WRC in collaboration with Climate System Analysis Group and Climate Information Platform (CIP). This water harvesting design tool applies an iterative design model which allows the user to input various options as shown in the design process diagram below where by the Location of the study area /house/ development, roof type and size, tank volume, water usage demand pattern are inputted to evaluate resulting water harvested. The user can evaluate and adjust inputs for the desired outcome.

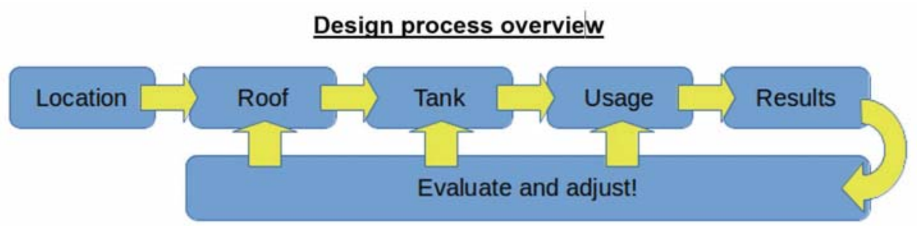

Figure 45: WRC CSAG Water Harvesting Tool Design Process Overview (WRC).

This tool will be applied to Lephalale Municipality to determine the probable amount of household water saved on average per year. There cost-benefit analysis of the system will be determine based of the current and future cost of potable water from the municipal. The impact on the water supply risk at a catchment level will also be evaluated based on the output of the analysis for existing and future development based on the Lephalale Municipality 2018/19 IDP. Building on the work done by the WRC CSAG Water Harvesting Tool, the project team at Golder Associates developed a Water Harvesting Tool for the project.

Available rainfall data from weather stations near Lephalale was used to generate the mean annual precipitation (MAP) (Table 17) and monthly rainfall patterns for the case study catchment area (Figure 46). From the Ellisras weather station data, the MAP was calculated as 463 mm (Figure 47).

Table 17: Weather stations in the Lephalale area (2017).

Station Name	Station Nr.	Years of data	Altitude (mamsl)	Longitude	Latitude	MAP (mm)
Grootgeluk	0674100W	95	908	27.34	23.40	483
Ellisras	0674400W	96	837	27.44	23.41	460
Grootfontein	0674429W	96	853	27.45	23.39	437

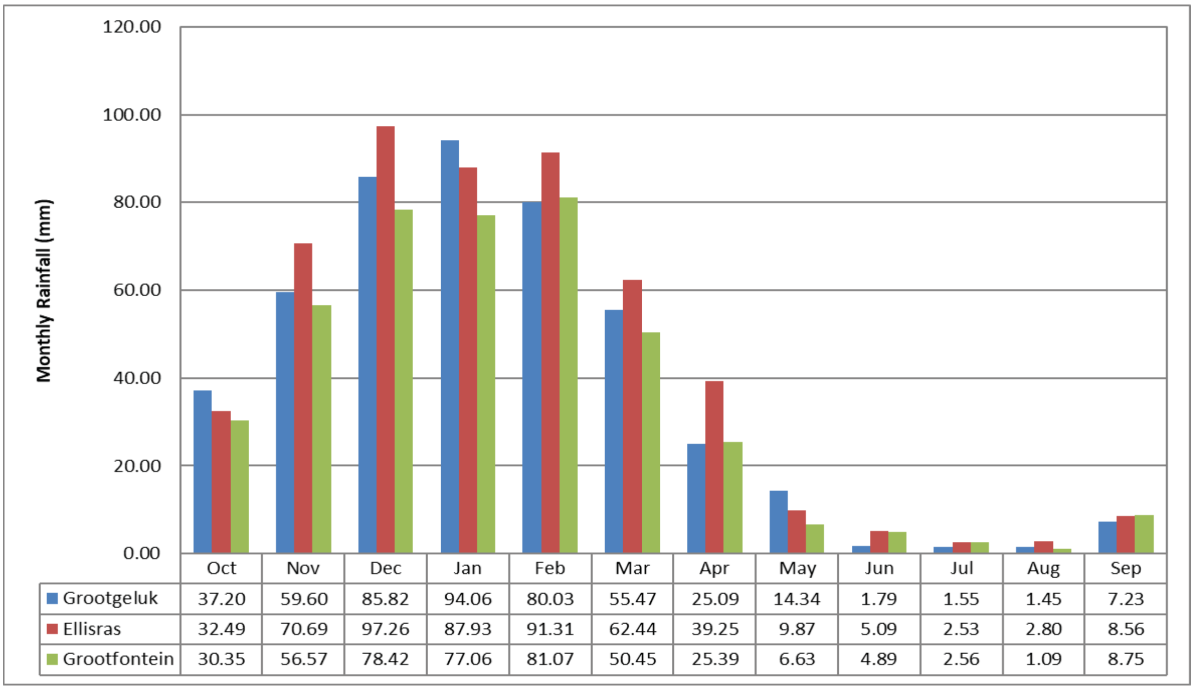

Figure 46: Monthly average rainfall for weather stations in Lephalale (2017).

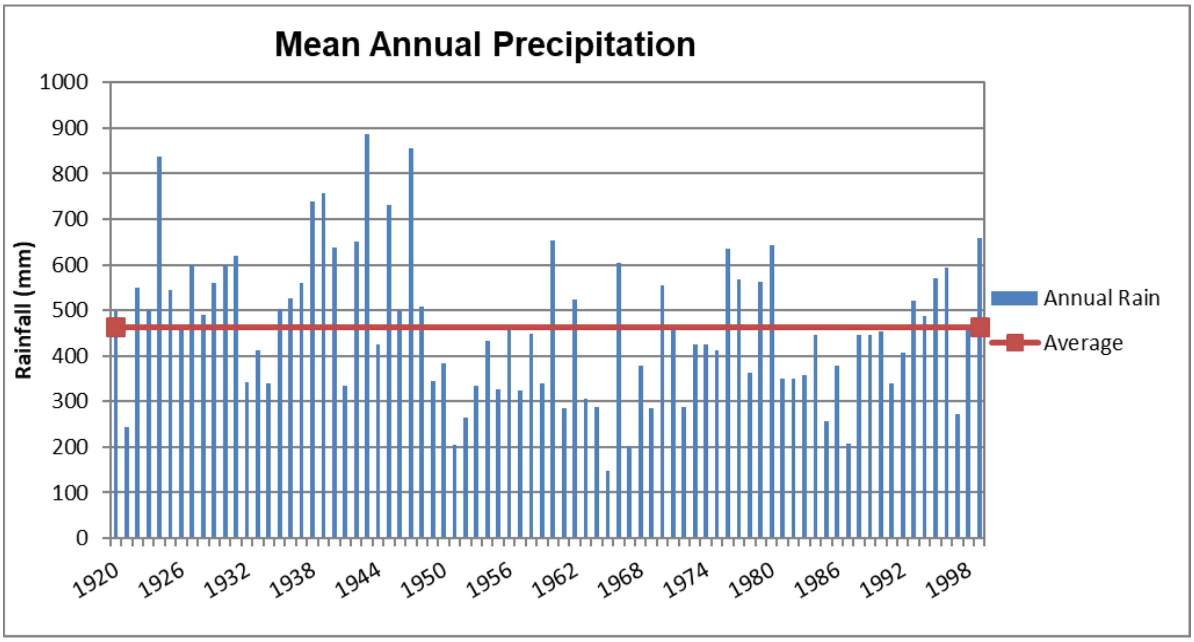

Figure 47: Mean Annual Precipitation for Ellisras weather station. (2017).

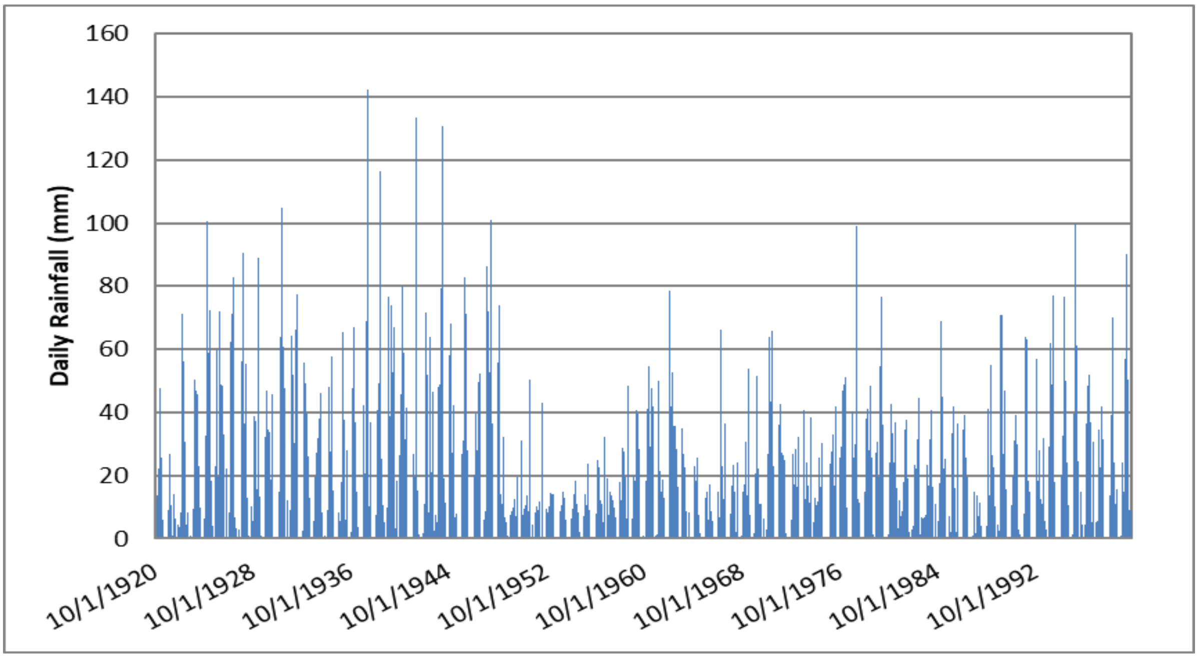

Figure 48: Ellisras weather station historical rainfall data.

Historical rainfall data for the area was used to develop a simulation module on Golder Associates Water rainfall simulation tool to predict a series of rainfall patterns. Historical rainfall records are used to generate synthetic sequences of daily rainfall patterns, using the transition probability matrix model. The historical rainfall data is separated into “states”. For each month, the probability of rainfall in one state of being followed by rainfall in the same state or another state on the next day is recorded in a matrix. The historical rainfall and simulated rainfall for the catchment is presented in Figure 48.

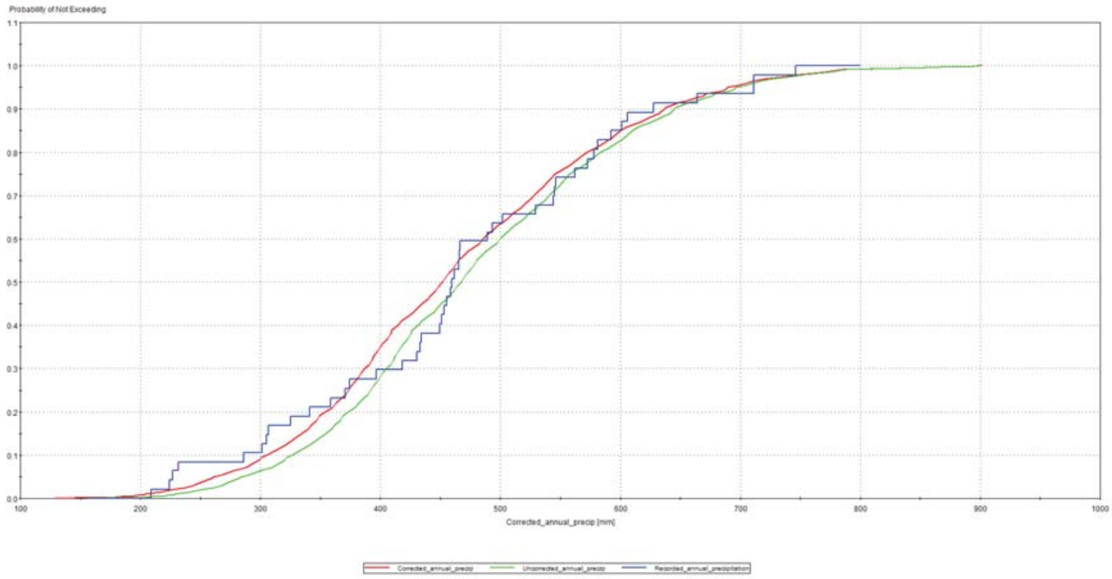

Figure 49: Rainfall Distribution curve.

A Stochastic Rainfall simulation model was set up using historical rainfall data sourced from Ellisras weather station. Golder Associates Water Harvesting Tool was used to predict future rainfall events.

Rain Harvesting Results

The rain harvesting study was based on the assumption of one tank per house, and that water will be reused for domestic purposes like cleaning, flushing toilets car washing and watering home vegetable gardens or lawns. This will require a dual supply system whereby isolation valves are installed to allow for municipal supply when the rainwater system is dry. The average size of the low incomes house roof of approximately 60 m^2 was assumed based on the average size of roofs in Marapong Township. Figure 50 shows the estimated average annual rainwater that can be harvested and average spillage per year for each tank size. The amount of water that can be captured on average per year is approximately 31 kl for the 3 kl to 6 kl storage per 60 m^2 roof.

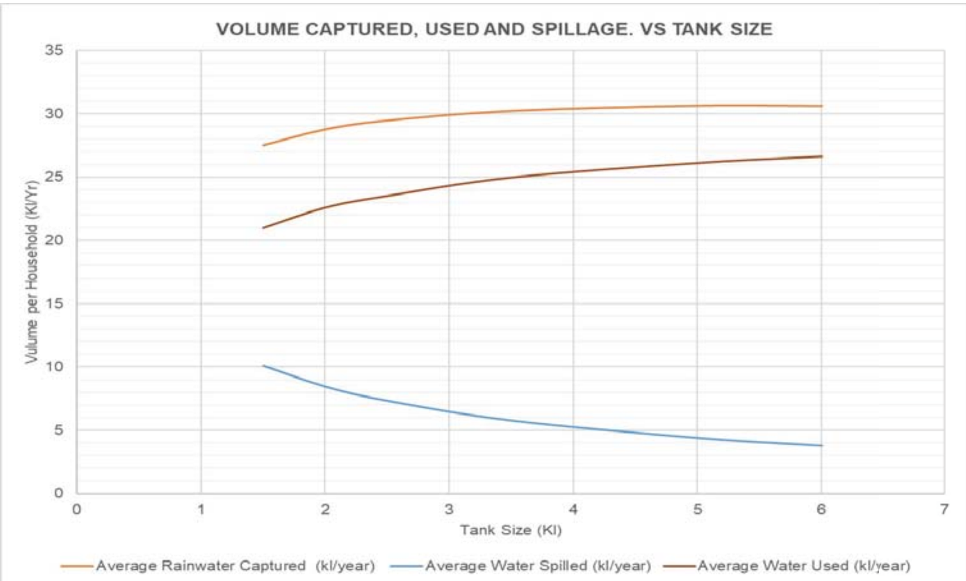

Figure 50: Tank size determination.

Cost Benefit Analysis

The estimated cost associated with implementing the system was defined as the capital cost which includes the cost of the tank and the gutter system and the benefit realised were defined as the savings from potable. The cost of water was assumed to be R20 /litre with an annual increase of 6% over the design life of 30 years. The amount of water saved on average per year ranges from 20.96 kl to 26.64 kl for tanks of size 1.5 kl to 6 kl. The savings achieved by rain harvesting system were approximately 9.6% to 12.2% of the normal potable water supply. The number of days in which rainwater was available to meet the household demand ranged between 109 to 138 days per year. Results indicate that rainfall harvesting is not a financially rewarding option for a household in the Waterberg area due to the infrequent rainfall.

Table 18: Rain harvesting results per household @ 9 litres per flush.

Tank Size (Kl)	Cost of Installation	Pay Back Period (Yr.)	Savings per Year @ R20 /L	Water Saved (Kl/Yr.)	Potable Water saved per year (%)	No of days Rainwater used (days/year)
1.5	R 4,500.00	16	R 419.00	20.96	9.6%	109
2	R 5,000.00	17	R 451.68	22.58	10.3%	117
2.5	R 5,200.00	17	R 470.14	23.51	10.7%	122
3.5	R 6,500.00	22	R 499.36	24.97	11.4%	129
5	R 7,500.00	34	R 522.53	26.13	11.9%	135
6	R9,000.00	54	R532.73	26.64	12.2%	138

An assessment was carried out for the town, considering schools, businesses and shopping centres. The payback period is presented in Figure 51. Here, a payback period was found to be 8 years.

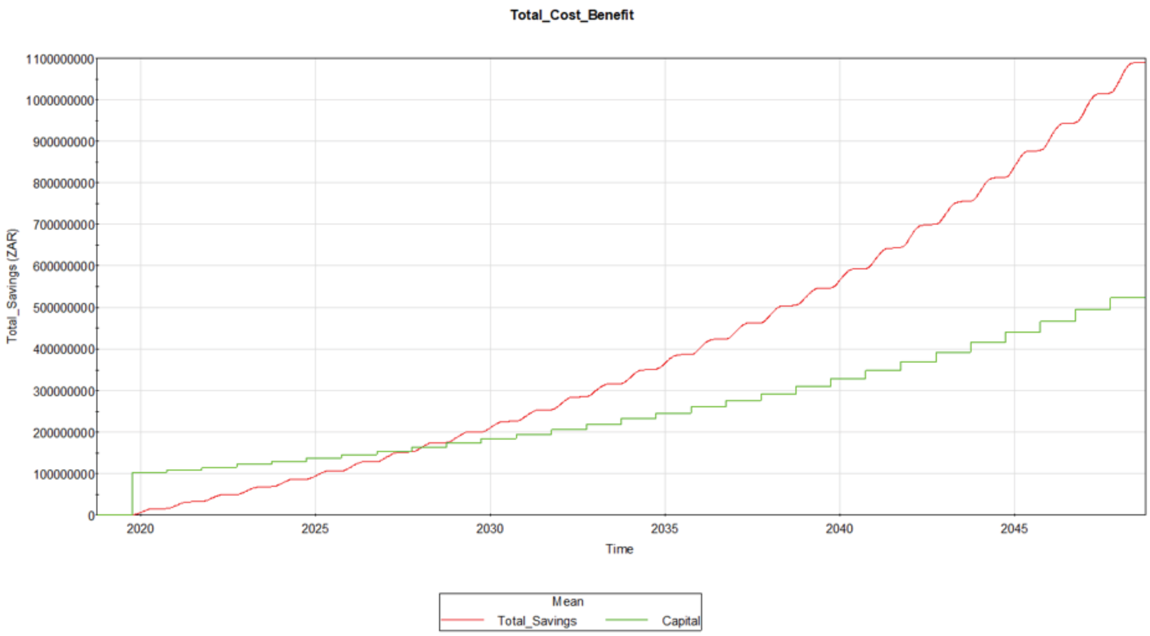

Figure 51: Capital cost and savings for the town, implementing rainfall harvesting for businesses and schools

A similar exercise was carried out for a town with a much high rainfall and rain throughout the year. In this scenario, the payback period was within 1 year.

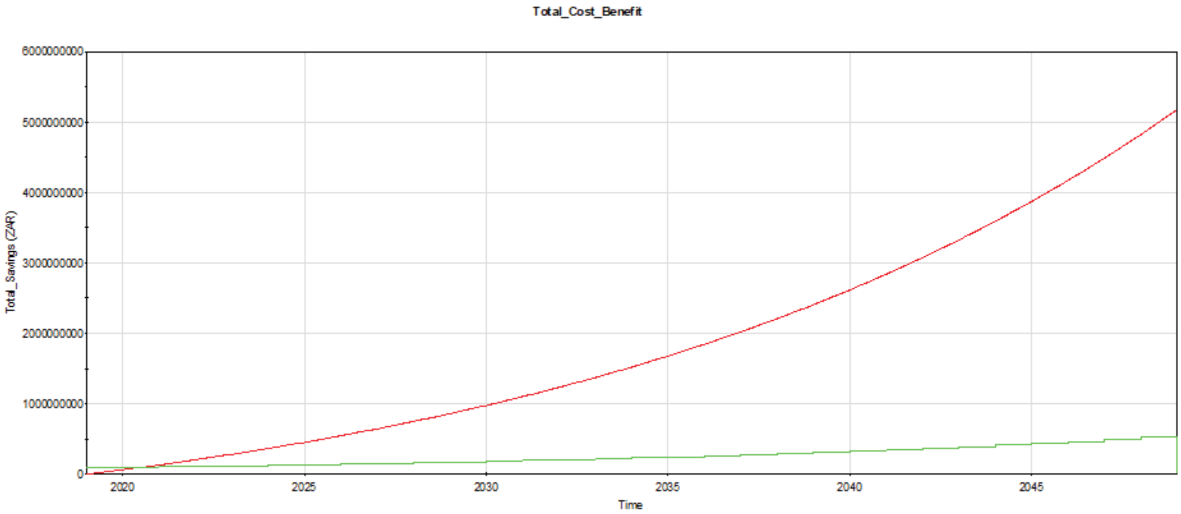

Figure 52: Cost benefit of applying Rainfall Harvesting in a high rainfall catchment

6.3.2 Water Savings Tools

6.3.2.1 Water saving devices

A module was developed on Golder Associates Water Harvesting Tool to investigate the potential savings when using water efficient devices within a household or in an eco-estate. The user is able to select the number of households, frequency of use, and water consumption rates for various household items consuming water.

6.3.2.2 Wastewater (Green) Treatment Effluent Reuse

Water savings are generated from the amount of potable water saved by the reusing green drop status water effluent. The study estimated to have 5 persons per household which excludes backyard dwellers. The water savings realised by reusing effluent water from WWTW was approximately 24.8% for the normal potable supply as shown in Figure 53. This means for every 1 litre of potable water supplied 250 ml (glass) would be saved. Approximately 62% of the potable water was reused given that about 75% of the sewage water is recovered (flushing toilets, car wash, cleaning, home garden, and laundry). Since toilet flush is the major domestic water usage that can be replace by WWTP effluent, the difference between 6 litre and 9 litre toilet cisterns were compared.

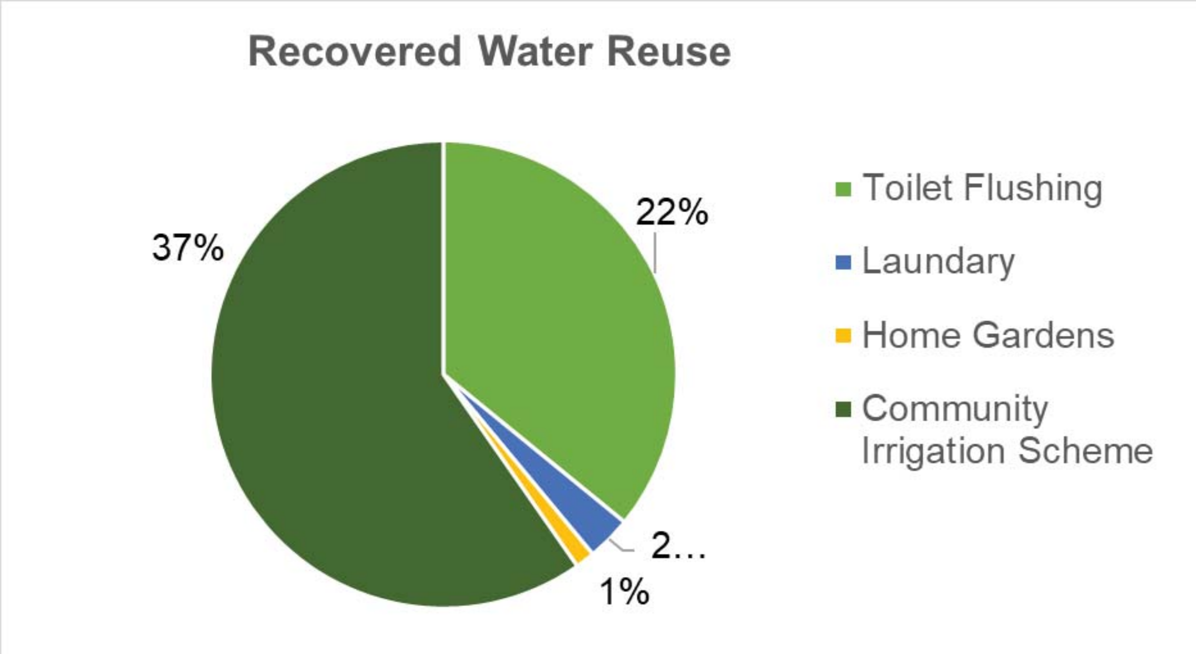

Figure 53: Recovered Water Reuse distribution @ 6 litre per flush.

The water savings realised by reusing effluent water from WWTW was approximately 36% for the normal potable supply as shown in Figure 54 for 9 litre cistern. Approximately 59% of the potable water was reused given that about 75% of the sewage water is recovered.

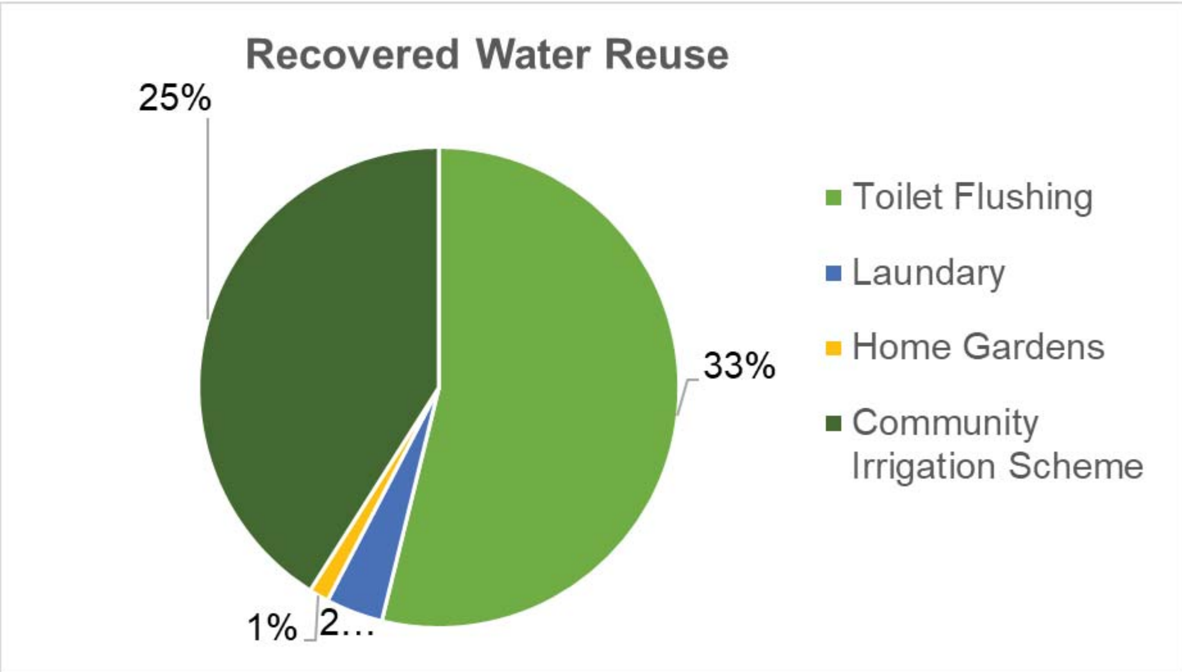

Figure 54: Recovered Water Reuse distribution @ 9 litre per flush.

6.3.3 Cost – Benefits Analysis

The cost of implementation vs the payback period for a 6 litre cistern option is shown in Figure 41. The design period for the system was assumed to be 30 years with water tariff at R20 per kilolitre. The water being reused from the WWTP effluent was subdivided into two categories: billable (used for domestic uses) and non-billable (donated to community for vegetable/crop irrigations scheme). The water used for irrigation was not considered as monetary savings even though it will result in social benefit and revenue for people who will be working at this irrigation scheme. The project payback time is estimated to be 19 years.

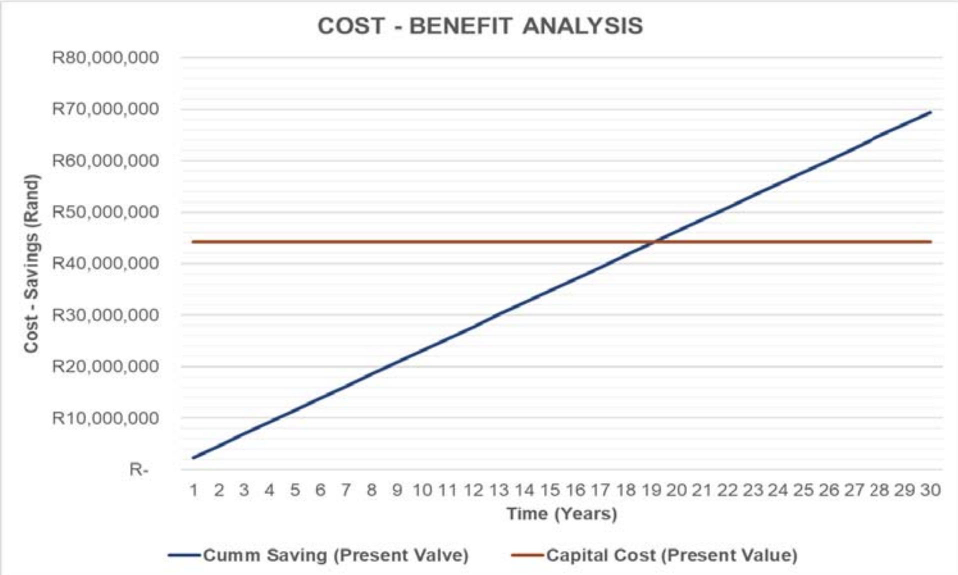

Figure 55: Cost Benefits Analysis (Project payback) @ 6 litre per flush.

The cost of implementation vs the payback period for a 9 litre cistern option is shown in Figure 42. The design period for the system was also assumed to be 30 years, with water tariff at R20 per kilolitre. The project payback time was estimated to be approximately 12 years.

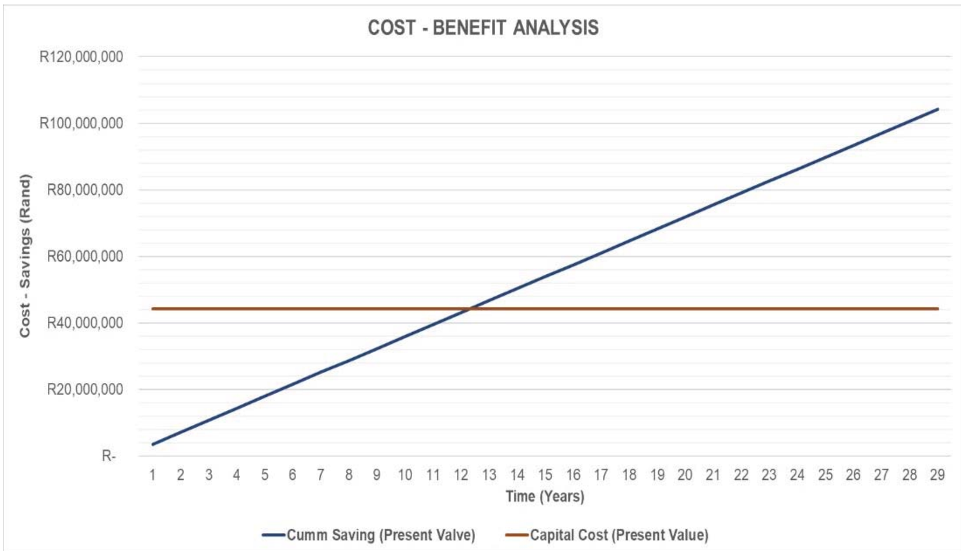

Figure 56: Cost Benefits Analysis (Project payback) @ 9 litre per flush.

CHAPTER 7: CONCLUSIONS

The baseline assessment undertaken for the area confirmed that the Waterberg catchment is a water stressed area currently and future growth plan will lead to water shortages. Lephalale was selected as the case study due to the projected growth in the area.

The Biomimicry principles highlight the importance of context. In this study, the following key aspects were considered in the context:

- The climatic conditions;
- Current water requirements;
- Future water requirements;
- New developments verses existing developments;
- Demographics of the town.

An important outcome from the project is WSD requires a good understanding of a baseline environment and cannot be a generic solution that can be replicated in different towns.

Applying WSD measures can bring some relief for the area, but the greatest challenge in the long dry season and high evaporation rates experienced. Analysis carried out on rainfall harvesting indicated that whilst this is not very effective on a household level, Industries, shopping centres and schools can benefit from rainfall harvesting. The area receives high rainfall followed by long periods of no rainfall. Smaller tanks overflow when it rains and empty within a day or two and are therefore not as effective.

The town is currently in a high development and growth phase and this brings a unique opportunity for the municipality to include WSD in the planning and development of new areas. This would be more cost-effective than trying to retrofit WSD design measures at a later stage.

New developments and households should be incentivised to use water savings devices. Bulk purchases will be more cost-effective and the benefits for the town will be long term.

Initial investigations also indicated that the town has a high water consumption rate per capita. Running awareness campaigns and driving water saving projects through schools will be beneficial.

One of the concerns raised in initial discussions was whether applying WSD in the town would have a negative impact on downstream water users. The Mean Annual Runoff (MAR) for the Lephalale catchment is 141.0 million m^3/ annum. Reducing the demand from the Mokolo Dam will make this water available to downstream users.

An assessment on roof gardens was carried out as an option to manage peak events. Results indicated that the gardens would require additional water for maintenance and measures such as permeable paving will be more effect for managing peaks.

Analysis using a rainfall harvesting tool developed for the area indicated that whilst the payback period improved with shopping centres, large developments and rainfall harvesting was not as attractive a solution in Lephalale as it would be in an area with more frequent rainfall.

Water saving devices proved to be effective and should be encouraged. Bulk purchases will result in reduced Capital costs. Developers can be encouraged to use the installation of water saving devices as a marketing tool for new property developments.

Industry and mining should consider floating covers for pollution control facilities. This will reduce the evaporative losses from return water systems thus reducing the top-up water requirements. Recent developments on floating covers include solar cells that provide a dual benefit of reduced evaporation and energy production

Greywater reuse was found to be feasible for new developments but not in established suburbs. The risk of cross-connections is high and changes to bylaws in terms of signing off on plumbing connections and training is essential in order to reduce the risk of contamination of drinking water sources.

Local wastewater treatment plants will need to be upgraded to meet the increased flow anticipated. The option if reusing treated wastewater in the mines and industry should be considered. This will offset potable consumption being used as makeup water in the dry season.

A change in mindset is required in South Africa as a whole. Under drought conditions, the population is able to use water wisely and responsibly. A compendium of successful water saving initiatives applied in Cape Town over the 2017/2018 water shortage can be a useful document for South Africans.

The team experienced various challenges when assessing the Watershare® tools. Whilst the Watershare team was very helping and willing to assist, the tools were not designed for small rural applications where information was limited. The UWOT tool requires user intervention and customisation in order to address the catchment specific needs.

Results obtained from the use of tools developed by the project team were very generic. The risk here is that results can be manipulated based on user inputs. Finding the balance between flexibility and ensuring reliable outputs is key to a good water management tool.

In conclusion, whilst applying WSD in the area will results in a water saving, this cannot guarantee surety of supply for the town. The area would still be dependent on an external water source to meet its growing demand. WSD will however reduce the volume required from external suppliers.

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