Sep 23, 2020

Stormwater harvesting in eThekwini

Pre- feasibility study for the stormwater harvesting and water re-use public-private partnership in eThekwini metropolitan area - track 2

Final report

ETHEKWINI MUNICIPALITY

ACACIAWATER

Executive summary

Context

eThekwini Municipal Municipality is facing an increasing challenge to meet a growing demand for water on an already existing water gap of 120 Mm^3/y, with projections of population growth estimating an increase to 700 Mm^3/y without additional measures. Meanwhile the area has is reaching its maximum potential for traditional water provision systems (i.e. dams). Moreover, the area has been hit by heavy flooding events in recent years, with climate change expected to exacerbate these challenges. Investing in alternative ways in water service delivery which use the water surplus of flooding events and make it available for provision.

For these reasons, eThekwini Water and Sanitation (EWS) has expressed interest in assessing alternative means of water provision; options which are more focused on using excess runoff water (contributing to flooding issues) and making it available for provision.

This pre-feasibility assessment is the second track of a two-track pre-feasibility study, in which the other track focuses on institutional, organisational, financial and technical elements of the stormwater harvesting and water reuse, focused specifically on the EWS preferred area of the Umbilo and Northdene waterworks which is done by RHDHV.

Goal

The goal of this pre-feasibility study is to identify possible alternatives for securing future water provision and give a preliminary assessment of the feasibility of three different options, providing a go/no go for a full-fledged feasibility study, with focus on technical/hydrological and economic feasibility.

Assessment of a number of frameworks has yielded the following options as having the most preliminary potential for eThekwini and therefor the most interesting for assessment of pre-feasibility:

- Managed Aquifer Recharge (MAR) through Sustainable Urban Drainage Systems (SUDS): artificial infiltration of runoff water to recharge groundwater and reuse for water supply after underground storage.
- Rainwater harvesting: capturing water from rooftops in tanks.

Approach

MAR through SUDS is examined in two steps. Firstly, pre-feasibility is approached in terms of water availability and provision:

- The quantity of water that is potentially available for infiltration;
- The capacity of the aquifer to store water;
- The potential of the aquifer for abstraction.

Subsequently, pre-feasibility is assessed for other key factors for feasibility:

- Potential quality concerns;
- The degree to which floods are mitigated;
- Potential major social or institutional challenges.

For rainwater harvesting, first an estimation of water capture is given for different urban landcover types. Second, an elaboration on quality considerations is given and the social and practical feasibility are assessed.

MAR through SUDS

For the first option, the following considerations are addressed in this study, based on literature, local data, discussions with EWS officials and local professionals, and expert judgment:

- The applicability of MAR applicable for eThekwini;
- The feasibility of MAR through SuDS in terms of potential water provision (infiltration, storage, abstraction); and
- The degree to which cost-effectiveness, quality and social/institutional concerns potentially inhibit feasibility of MAR through SUDS.

For this study four different potential areas (hydrogeological formations) where MAR is applicable are selected:

- The Berea formation
- The Umgeni alluvial deposit
- The Harbor beds
- The Natal Group Sandstones (NGS)

An overview of feasibility and potential for different parameters is shown in the table below. The Berea formation, Harbor beds and the NGS show good promise for MAR through SUDS, with total potential water provision potential of 45, 20 and 135 Mm3/y respectively; jointly enough to close the current water gap (130 Mm^3/y). Quality concerns in the Umgeni alluvial deposits make MAR currently inadvisable here.

Table 1. Overview of feasibility for MAR through SUDS across four formations for both total potential water provision and assessment of multiple key factors

		Berea formation	Umgeni alluvial deposits	Harbor beds	NGS
Potential water provision (Mm^3/y)		45	40	20	135
Key factors	Quality	+	-	o	+
	Flood mitigation	+	o	+	+
	Social/institutional	o	o	o	+

For MAR in the Berea formation, aquifer characteristics are well suited, with potential volumes of 45 Mm3/y when fully exploited or 5 Mm3/y when focusing on the Berea ridge aquifer. Most potential for SUDS is through infiltration trenches, with opportunities to augment infiltration by re-purposing old existing stormwater infrastructure. To reach full potential, implementation is quite infrastructure intensive (5 km of trench within every square kilometer), options for which should be explored with the relevant institutions. Management and protection of the aquifer unit should be adapted to the current environment and land use; sensitization, monitoring and emergency planning are pivotal in aquifer management when MAR is applied here.

While the Umgeni alluvial beds have a potentially have a high infiltration capacity, water quality and pollution of the aquifer are a possible constraint to development of MAR-schemes, due to active leaching from industries, landfill sites and more. Quality and pollution should be thoroughly investigated before any meaningful considerations for MAR through SUDS can be made here.

The Harbor beds similarly show a high potential for MAR in terms of infiltration potential and aquifer characteristics. Potential for flood mitigation is very high here as well; while runoff reduction percentage is in the mid-range, the specific SUDS infrastructure and its location is better equipped to mitigate high flows. Specifically at the Isipingo area and Mlazi river, opportunities have been identified, with provision potential up to 10 Mm3/y. Aquifer management and protection challenges promote focus on a local level, where a balance needs to be found with storage and infiltration potential. Finding the required space is pivotal for the feasibility of this option; if an appropriate area can be found, this option shows high potential for MAR through SUDS.

The NGS covers by far the largest area and as such has a very high potential for infiltration and abstraction, with potential of providing 135 Mm3/y. The relatively complex hydrogeology requires careful planning of MAR through SUDS, but by adopting a regional approach many opportunities exist. Moreover, the large extent and flexibility in implementation mean potential challenges with key factors can be minimized by thorough location selection.

Cost comparison of MAR through SUDS options

Provided that space can be found, the Harbor beds provide the most cost-effective opportunity for water provision through MAR through SUDS in the eThekwini area. While infiltration infrastructure is relatively high cost, abstraction is favorable in the Berea formation and with opportunities outweighing challenges this area is the second most cost-effective. The hydrological characteristics of the NGS make MAR through SUDS generally less cost-effective than MAR in the Berea formation or the harbor beds. However, the flexibility of application of MAR in the NGS is much higher and potential schemes are still cost-effective.

MAR through SUDS in the NGS is worked out for a specific case in collaboration with a study by RHDHV in a preferred area as indicated by EWS. Aiming at a provision of 10 Ml/d, it is expected that MAR through SUDS can work with a capital investment of 66 million rand and an operational/maintenance cost of 0.9 million rand/y, for an average yearly costs of 6.8 million rand/y.

Rainwater harvesting

With rainwater harvesting, quite a viable business case can be made, with an expected 11 years of return on investment when implemented for industrial use specifically. There is much potential for implementation at household level as well, but concerns with cost-effectiveness and social implications make it especially interesting when focused on sustainability and water security with less regard to finance.

Feasibility study

A feasibility study is required before implementation of MAR-schemes and SUDS. The primary focus should be on the Harbor beds and Berea formation, as they are potentially most cost-effective. If these areas are feasible, MAR systems with SUDS can be investigated to the full extent. If constraints are identified, or the potential cannot meet the targeted water gap, the NGS is the most interesting for MAR through SUDS. The following steps are recommended:

- Determine the technical feasibility for preferred formations:
    - Quality, management and infrastructural constraints of the Harbor beds;
    - Infrastructural constraints for the Berea ridge and other Berea formation areas

- Determine highest potential formation

After these steps, the highest potential formation can be identified and a full feasibility can be made, in which an exact design is drawn up and institutional requirements are identified.

When the implications of these specific challenges are assessed and full designs are drawn up, full business cases can be made.

Colophon

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Abbreviations

3R	Recharge, Retention and Re-use of water
DWA	Department of Water and Sanitation
EMM	eThekwini Municipal Municipality
EUL	Expected Useful Life
EWS	eThekwini Water and Sanitation
GIS	Geo-Information Systems
IFC	International Finance Corporation
IFI	International Finance Institution
MAR	Managed Aquifer Recharge
MODIS	Moderate Resolution Imaging Spectroradiometer
NGA	National Groundwater Archive
NGS	Natal Group Sandstones
PPP	Public-Private Partnership
SABS	South African Bureau of Standards
SRTM	Shuttle Radar Topography Mission
SUDS	Sustainable Urban Drainage Systems
UKZN	University of KwaZulu-Natal
WHO	World Health Organization
WSUD	Water Sensitive Urban Design
WTP	Water Treatment Plant
WWTP	Waste Water Treatment Plant

Units

˚C	Degree Celsius
km	Kilometer
km^2	Square kilometer
l	Liters
l/s	Liters per second
m	Meters
m^3	Cubic meters
m/d	Meters per day
m^2/d	Square meters per day
mm	Millimeters
mm/d	Millimeters per day
mm/h	Millimeters per hour
mm/y	Millimeters per year
Mm^3	Million cubic meters
Mm^3/y	Million cubic meters per year
Ml/d	Million liters per day
µg/l	Micrograms per liter
mg/l	Milligrams per liter
R	(South African) Rand
R/m^2	Rand per square meter
R/m^3	Rand per cubic meter
R/y	Rand per year

1 Introduction

1.1 Project background

The International Water Ambition of the Netherlands is to contribute to solving water challenges in different countries, among which South Africa. The water cooperation between the Netherlands and South Africa is formalized in a Memorandum of understanding (MoU) with the Department of Water & Sanitation. For several years, the Netherlands and eThekwini Water & Sanitation (EWS) collaborated on new ways to solve water challenges.

Due to climate change, South Africa faces increasing drought and extreme water events, putting more pressure on water management and critical water infrastructure. eThekwini suffers from flash floods due to increasing heavy and unpredictable rainfall. To ensure future water security, either for agriculture, industrial use or human consumption, EWS needs to invest in alternative water resources as well as making better use of existing infrastructure. EWS is therefore looking into new 'public-private partnership' (PPP) for the water sector. eThekwini municipality has positive experience with PPP's in the field of energy production and has already established two water re-use PPPs together with the IFC.

As a third PPP, approved by National Treasury of South Africa, EWS wants to scope how to make better use of periodic abundant rainfall and match this with the demand for water in drier periods of the year. Possible technical solutions are artificial aquifer recharge or controlled drainage to (existing) (waste) water treatment plants (WWTP/WTP).

Royal HaskoningDHV (RHDHV) and Acacia Water have expertise in the field of stormwater harvesting and water re-use, as well as creating PPPs in the water sector. The two companies were commissioned by Rijksdienst voor Ondernemend Nederland (RVO) to undertake the prefeasibility studies for stormwater harvesting and water-reuse PPP to assist eThekwini Municipality to find solutions to the water supply challenges.

In this report, Acacia Water presents practical and robust solutions to improve the access to clean and safe water for the city. Various interventions are needed at different scales for increased water resilience for eThekwini. Adopting nature-based solutions could assist with the ambition to become a Water Sensitive City that aims to integrate the urban water cycle (including stormwater, groundwater and wastewater management and water supply) into urban design. This helps minimize environmental degradation and improves aesthetic and recreational appeal (as illustrated in Figure 1).

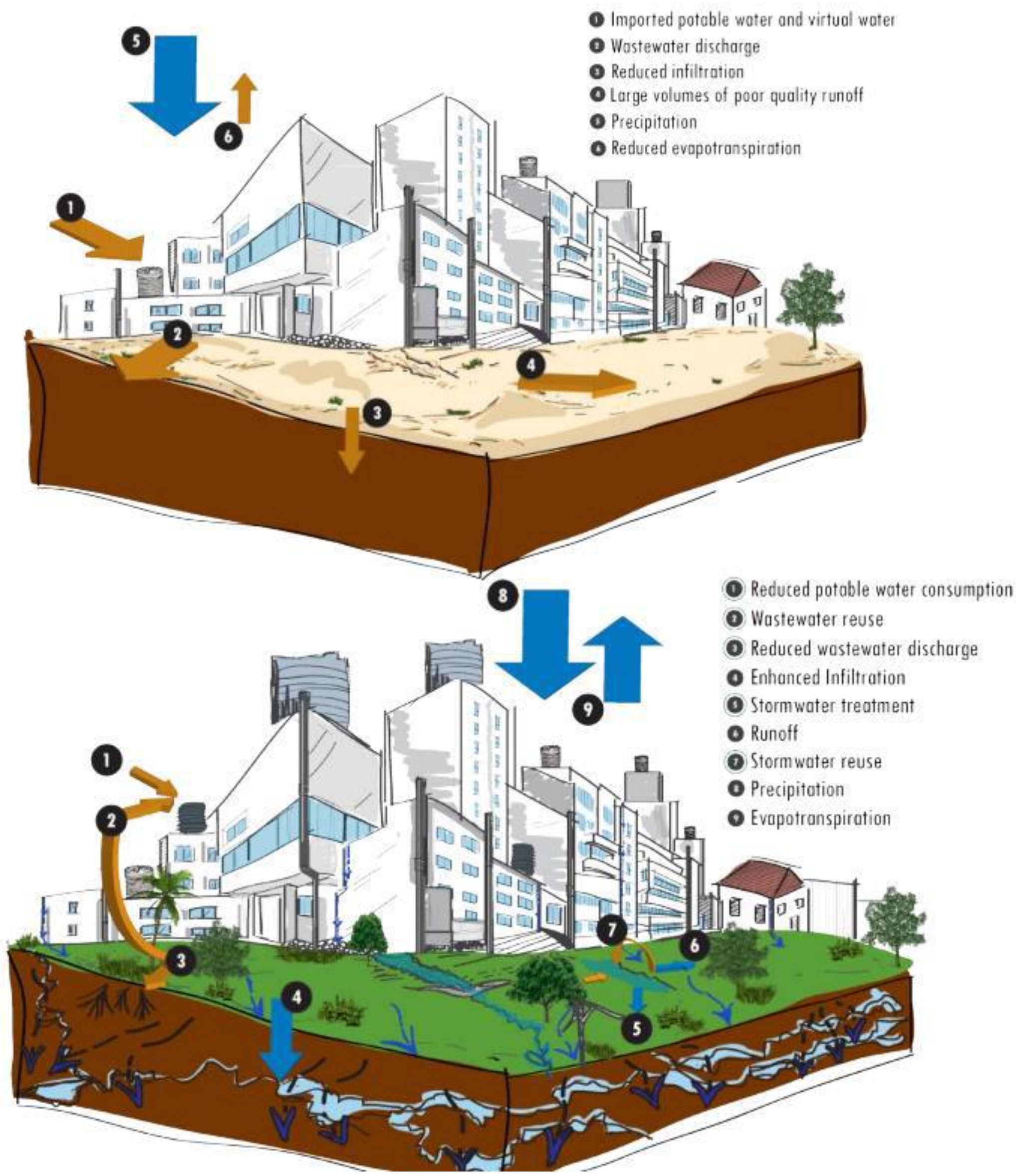

Figure 1. Urban solutions can restore natural processes and produce Water Sensitive Cities

1.2 Organisations and Stakeholders

The pre-feasibility study has been split into two tracks identified as Tracks I & II.

As initially described, Track I focuses on the institutional, organisational, financial and technical elements of the stormwater harvesting and water reuse, focused specifically on the EWS preferred area of the Umbilo and Northdene waterworks. Track II focuses on the availability, quantity & quality of the stormwater, technical elements of stormwater harvesting and underground storage (aquifer recharge); primarily on a regional scale but secondly worked out in more detail for the EWS preferred area as focused on in the first track.

RHDHV was tasked with undertaking the activities under Track I while Acacia Water was tasked with Track II activities.

Separate but aligned reports covering both tracks have been submitted by the Consultants, RHDHV and Acacia Water, as the final deliverable of the project.

The beneficiary of the final deliverables of the Project is eThekwini Water and Sanitation (EWS). EWS is a department of eThekwini Municipality responsible for ensuring access to water services within the eThekwini metropolitan area. In order to fulfil its function as a Water Services Authority (WSA), EWS purchases bulk potable water from Umgeni Water. Umgeni Water is a Water Board whose primary purpose is to provide water services to EWS and other water services providers in its area of jurisdiction. The water demand and supply projections within the eThekwini metropolitan area, and more specifically on this project area, take into consideration and has to align with the development plans that Umgeni Water has already put in place to avoid duplication of effort.

1.3 Scope of study

In this pre-feasibility study, the preliminary potential of alternative ways of stormwater harvesting is investigated. This pre-feasibility is to determine the conditions how to proceed in investing and building the required facilities and infrastructure.

The outcome of this pre-feasibility will be two separate but aligned reports on the outcomes of Track One and Track Two, building towards a 'business case' on stormwater harvesting in eThekwini that should help potential private partners, investors and (International) Financial Institutions (IFI's) to decide to participate in the feasibility.

1.4 Water harvesting

The project calls for 'stormwater harvesting'. Stormwater harvesting is a rather broad term, with many different methods of application and nuances in definitions. This chapter is focused on defining clear terminology and exploring frameworks for application of 'stormwater harvesting'.

Stormwater harvesting is the collection, accumulation, treatment or purification, and storing of stormwater for its eventual reuse. Note that stormwater refers to water that originates from rain in any form or intensity, and thus is not limited to water from heavy rainfall events (i.e. storms). Generally, it differs in its definition from rainwater harvesting in that the runoff is collected from drains or creeks rather than roofs.

For exploring these options, the following themes and frameworks will be explored:

- Water buffering through Retention, Recharge and Re-use (3R) and Sponge Town concepts
- Stormwater management through Sustainable Urban Drainage Systems (SUDS).

1.4.1 Water buffering through Retention, Recharge and Re-use (3R) and Sponge Town concepts

The 3R approach, as developed by the 3R consortium including Acacia Water, Aqua for All, aims to increase the water buffer through **R**etention, **R**echarge and **R**e-use of water.

Most rain falls during the wet season, with high intensity showers. Such showers trigger runoff and limit infiltration, which is further aggravated by hard/compacted surfaces such as buildings and roads. Such surfaces don't allow water to easily infiltrate. A high proportion of the water instead flows downhill as runoff. The amount of water flowing away from urban areas is commonly more than 80% of the total amount of water received by it. Where is all this water flowing to? This is exactly the essence of water buffering, integrating these measures in built environment to manage natural recharge and to retain water for longer periods so that it becomes usable during periods of water scarcity; and this is exactly what the 3R concept is focused on.

The central focus of 3R is the most efficient use of water. Especially the recharge and retention components aim to buffer water from wet periods into dry periods.

Recharge

Recharge buffers water in the ground and as such it adds water to the circulation, to be accessed by pumps or boreholes. Recharge can be natural – the infiltration of rain and runoff water in the landscape – or it can be managed (artificial recharge) through special structures or by considerate planning of roads and paved surfaces. Recharge can also be a by-product of, for instance, inefficient irrigation or leakage in existing water systems.

Retention

Retention is aimed at slowing down or stopping of water flow. This can either be surface water or groundwater. Water is stored at a specific location for later use, creating large 'wet' buffers. Hence, retention makes it possible to extend the chain of water uses. Moreover, such retention also raises the groundwater table. Slowing down or even controlling lateral outflow of the water table affects soil moisture and soil chemistry: this can have a large impact on agricultural productivity.

Reuse

Reuse is the third element in buffer management. The large challenge of 3R is to make water revolve in the water cycle as much as possible. Scarcity is resolved not only by managing demand through reduction in use but also by keeping water in active circulation. In managing reuse, two processes are important. The first is to manage non-beneficial evaporation to the atmosphere. Water that evaporates 'leaves' the system and can no longer circulate in it. Rather than that, one should try the opposite and capture air moisture, such as dew, wherever possible.

Four main categories of water harvesting, storage and conservation can be distinguished based on their functioning, location in the landscape and main purpose:

1. Protection and restoration
2. Soil and water conservation
3. Off-stream water storage
4. Instream water storage

Each category of interventions has its own purposes, strengths and weaknesses (illustrated in Figure 2). Whether interventions aim at improving vegetation cover and biodiversity, promoting soil formation, storing water or any other purposes, and the rate at which this happens differs per category, and even per specific intervention. In general, however, the first two categories ('Protection and restoration' and 'Soil and water conservation') are more focused on landscape health while the latter two categories (Off-stream and instream water storage) are focused on increasing water provision.

Figure 2. Different types of 3R water harvesting categories and examples

Literature on 3R is available for more information (also listed in Annex A):

- *Managing the Water Buffer for Development and Climate Change Adaptation; Groundwater Recharge, Retention, Reuse and Rainwater Storage,* http://www.bebuffered.com/downloads/3R_managing_the_water_buffer_2010.pdf
- *Profit from Storage The costs and benefits of water buffering,* http://www.bebuffered.com/downloads/profit-from-storage-reprint-2013_digitalvs.pdf
- Deal Book: Reaching the Millions, http://metameta.nl/wp-content/uploads/2018/04/Deal-Book_Reaching-the-Millions_digitalversion.pdf

3R in urban areas

In general, the 3R concept has been mostly applied to rural areas. It is however very much suited for urban areas as well, explored in another concept: the Sponge Town approach. Developed by another consortium of partners, including Acacia Water, VIA Water and more, the Sponge Town approach integrates 3R into a set of guidelines to increase the water buffer in urban areas.

3R interventions which can be suited (dependent on purpose and local landscape characteristics) in urban areas include:

- Surface water storage interventions:
  - Water pans or small ponds
  - Green areas for infiltration and recharge
  - Rainwater harvesting (rooftops)
  - Road water harvesting
  - Rock catchments
- Groundwater storage
  - Sand dams
  - Subsurface dams

    - MAR (Managed Aquifer Recharge)
- Runoff reduction measures
    - Check-dams and gully plugs
    - Swales and bunds
    - Permeable paving

More information can be found in the Sponge Town guidelines developed within a pilot project for two towns in Kenya (listed in Annex A):
How to create a Sponge Town? Sponge Town Guideline,
https://www.viawater.nl/files/sponge_town_guideline.pdf

1.4.2 Stormwater management through SUDS

Stormwater management in the urban areas of South Africa has been predominantly focused on collecting runoff and diverting it to the nearest watercourse. Stormwater drainage currently prioritises quantity (flow) management with little or no emphasis on preservation of water with little regard for the environment. The result has been a significant impact on the environment through erosion, siltation and pollution. An alternative approach is to consider stormwater as part of the urban water cycle, a strategy which is being increasingly known as Water Sensitive Urban Design (WSUD) with the stormwater management component being known as Sustainable Urban Drainage Systems (SUDS). SUDS attempt to manage drainage of stormwater holistically and sustainably. In so doing many of the negative environmental impacts of stormwater are mitigated and some benefits may in fact be realised.

SUDS are a collection of water management practices that aim to align modern drainage systems with natural water processes. SUDS efforts make urban drainage systems more compatible with components of the natural water cycle such as storm surge overflows, soil percolation, and bio-filtration. SUDS refer to stormwater harvesting techniques specifically suited for urban environments.

SUDS have been applied all over the world, but the approach has gained quite some traction in South Africa over the last few years. Through the University of Cape Town, Future Water has developed a number of papers on SUDS in South Africa, including 'The South African Guidelines for Sustainable Drainage Systems' (Armitage et al, 2013). This paper will form the basis of much of what will be discussed on SUDS in this study, and is included in Annex A, including a series on application of SUDS in the Gauteng region.

1.4.3 Options for eThekwini

From the 3R and SUDS frameworks, options need to be selected which are specifically suited for eThekwini. Many 3R interventions are well adapted for increasing water provision, but the focus is generally more on rural areas than on urban areas like eThekwini. Within SUDS on the other hand, while being specifically suited for urban environments, the focus is generally more on reducing flooding than on increasing water provision. However, there are two types of interventions where these two frameworks come together and have been identified as the options with the most preliminary potential:

- Managed Aquifer Recharge (MAR) through SUDS; and
- Rainwater harvesting

Managed Aquifer Recharge (MAR) through Sustainable Drainage Systems (SUDS)
One of the main mechanisms for flood reduction in SUDS is through promotion of infiltration. Connecting these interventions to an aquifer system form which water is

subsequently abstracted will both reduce flooding and increase water provision, in what is called a MAR system.

A MAR system consists of an infiltration component (SUDS), a storage component (aquifer) and an abstraction component (boreholes/wells).

MAR starts from the storage component, and is fully hydrogeology dependent: locate a suitable formation for storage of groundwater (an aquifer).

Subsequently, the abstraction component is relatively straightforward: place infrastructure to abstract stored water from the ground (boreholes/wells).

The infiltration component is generally more complex and can be done in a multitude of ways. In this study, infiltration is explored through the SUDS framework.

For SUDS, there is an array of sub-options which can implemented. Stormwater can be infiltrated through:

- Permeable pavements
- Buffer and filter strips
- Swales
- Infiltration trenches and soakaways
- Bio-retention
- Dry stormwater ponds
- Wetlands and retention ponds

These options are briefly explained below, using Armitage et al. (2013) as a main source of information.

Permeable pavements

Permeable pavements refer to pavements that are constructed in such a manner that they promote the infiltration of stormwater runoff through the surface into the sub-layers and/or underlying strata. There are many alternatives for the load-bearing surface material including: permeable concrete block pavers, brick pavers, stone chip, gravel, porous concrete and porous asphalt. They can be installed as driveways, parking bays, private roads, public service roads, industrial storage and loading areas, bike pathways, walkways, terraces, etc.

Buffer and filter strips

Buffer and filter strips are maintained grassed areas of land that are used to manage shallow overland stormwater runoff through several filtration processes in a similar manner to buffer strips. They can be as simple as uniformly graded strips of lawn alongside a drain. They are effective as stormwater runoff mitigation options in low-density developments. They intercept and spread out stormwater runoff thus helping to attenuate flood peaks. Filter strips are commonly used along stream banks as vegetated buffer systems, but are also used downstream of agricultural land to intercept and infiltrate stormwater runoff. They are particularly useful for providing a first line of defense against sheet flows from large paved areas such as parking lots and arterial roadways.

Swales

Swales are shallow grass-lined channels with flat and sloped sides. Although they are normally lined with grass, alternative linings can be used to suit the characteristics of the specified site. They serve as an alternative option to roadside kerbs and gutters in low density residential areas but because they generally have a larger stormwater storage capacity, they help to reduce runoff volumes and peak stormwater flows. They require relatively large surface areas to function effectively.

Infiltration trenches and soakaways
Soakaways usually comprise an underground storage area packed with coarse aggregate or other porous media that gradually discharges stormwater to the surrounding soil. Infiltration trenches are excavated trenches that are filled with rock, or other relatively large granular material, or commercial void forming products. They are both similar in operation, but soakaways usually have a smaller plan. Stormwater permeates through the voids in the trench or soakaway and is temporarily stored. Over a period of time this water infiltrates into the underlying soil and replenishes the groundwater.

Bio-retention
Bio-retention areas, also referred to as 'rain gardens' or 'bio-retention filters', are landscaped depressions typically employed to manage the runoff from the first 25 mm of rainfall by passing the runoff through several natural processes. These processes include, inter alia, filtration, adsorption, biological uptake, sedimentation, infiltration and detention. Bioretention areas normally incorporate a series of small stormwater management interventions such as grassed strips for infiltration, temporary ponding areas, sand beds, mulch layers and a wide variety of plant species (Endicott & Walker, 2003). They are particularly effective in managing stormwater runoff from minor and more frequent rainfall events. Excess stormwater runoff generated during major rainfall events is routed to other structural stormwater controls. Bio-retention areas are applicable for managing stormwater runoff on many sites, such as: between residential plots, parking lots, adjoining roadways, and within large landscaped impervious areas. The concept of 'bioretention' can be incorporated into most other SUDS options and/or technologies, such as swales and detention ponds to improve pollutant removal potential and enhance the amenity and biodiversity of the immediate environment.

Dry stormwater ponds
Detention ponds or detention basins are temporary storage facilities that are ordinarily dry but are designed in such a manner that they are able to store stormwater runoff for short periods of time. The captured stormwater runoff either infiltrates into the underlying soil layers or, more usually, is drained into the downstream watercourse at a predetermined rate. This means that detention ponds are particularly effective at regulating the flow in the downstream watercourses and/or supplementary treatment systems. The use of detention ponds depends on the availability of adequate space.

Wetlands and retention ponds
Wetlands generally refer to marshy areas of shallow water partially or completely covered in aquatic vegetation. They may be categorised into natural-, modified natural- or constructed wetlands. They are most often to be found serving catchments larger than 10 hectares and are particularly useful in attenuating stormwater flood peaks and 'polishing' the runoff from residential areas. Retention ponds, also referred to as 'retention basins', have a permanent pool of water in them. They are generally formed through the construction of a dam wall (or walls) equipped with a weir outlet structure. Stormwater coming into the pond is mixed with the permanent pond water and released over the weir at a reduced rate. Retention ponds are usually capable of handling relatively large

quantities of stormwater runoff. Both wetlands and retention ponds can be designed to increase infiltration.

Which of these options are specifically suited depends on local factors: what space is available, what infrastructure is present, where and how much stormwater is collected, etc. What is most important however is the local hydrogeology: the infiltration measures need to be connected to an aquifer. So first, suited locations for MAR need to be identified based on the hydrogeology; only then can the suited infiltration measures be determined.

For more information on MAR or SUDS, see the list of reports included in Annex A.

Rainwater harvesting
Rainwater harvesting (the practice direct rainwater collection from roofs in storage tanks) is one of the few SUDS which can directly increase water provision. As such, this option is investigated separately in this study for its preliminary feasibility in eThekwini.

1.4.4 Scoping study objectives

In this study, the pre-feasibility is examined of two stormwater harvesting options for eThekwini:

1. Managed Aquifer Recharge (MAR) through Sustainable Urban Drainage Systems (SUDS); and
2. Rainwater harvesting.

For MAR, first the hydrogeology of the area is examined to identify suited potential aquifers. Second, both MAR and rainwater harvesting are examined in terms of water quantity, quality, cost-effectiveness and flood mitigation.

2 Approach

2.1 Data Collection

An important aspect of the collection of data and information, both from local organizations and open sources. This includes physical/digital data such as reports and GIS files, but also information passed on in discussions. Normally, data collection would also include a field visit, where visual observations and physical data would be collected as well. The outbreak of the COVID-19 pandemic has made this impossible. With a revised approach however, with an increased focus on literature and data analysis, focused discussions and close collaboration with a dedicated local technical specialist provides a solid foundation for this pre-feasibility study.

The results of the data collection on the general area are presented in chapter 3 and inform the analyses of the subsequent chapters.

2.2 Managed Aquifer Recharge (MAR) through SUDS

To study the applicability and feasibility of Sustainable Urban Drainage options for eThekwini, first the hydrogeology of the area is studied to identify the formations with the apparent highest potential for MAR.

Important input for hydrogeological analysis includes:
Reports:

- Maud & Bell, 2000
- Ndlovu, 2018
- Ndlovu, 2019

Topical discussions with local experts on (hydro)geology:

- Debbie Abel of EWS
- Taryn Swales of Geomeasure Group
- Hlengiwe Msweli of UKZN

Borehole GIS data from EWS, DWA, Geomeasure, GRIP, Aquabase and NGA

Firstly, pre-feasibility is approached in terms of water availability and provision

- The quantity of water that is potentially available for infiltration;
- The capacity of the aquifer to store water;
- The potential of the aquifer for abstraction.

Through exploring these considerations, total potential for provision with MAR though SUDS options is assessed.

Subsequently, pre-feasibility is assessed for other key factors for feasibility:

- Potential quality concerns;
- The degree to which floods are mitigated;
- Potential major social or institutional challenges.

Lastly, the cost-effectiveness is discussed for all areas in a separate chapter.

The methods used to answer of these questions is laid out in the following paragraphs. Please note that, which considerations are the most important or which factors would be the most limiting, will differ per aquifer. As such, the detail of the answers of these questions will differ widely between formations.

2.2.1 Water availability and provision

Potential for infiltration

To estimate the total potential for infiltration, first total local water availability is calculated. This includes the amount of rainfall as well as water which is drained to the area through rivers; estimates are made of total quantities for both these processes.

Second, the most suited SUDS infrastructure is identified. Specific SUDS can capture a certain percentage of rainfall or river/flood flows. This will inform how much of the total available water could be captured.

These two factors together determine the total potential for infiltration.

Aquifer storage capacity

Water cannot be infiltrated and abstracted infinitely; the rate of abstraction and infiltration is also dependent on capacity of the aquifer for storage.

To assess aquifer storage capacity, potential aquifer extent is calculated. This is compared to potential for infiltration to estimate whether aquifer capacity can potentially limit infiltration.

For sedimentary aquifers, estimation of aquifer size is quite straightforward: obtain an understanding of depth, extent and porosity and multiply these factors.

- Examine depth profile with borehole logs and literature;
- Delineate effective aquifer extent from geology GIS files;
- Examine grainsize from borehole logs and associated effective porosity from literature.

Abstraction

After abstraction and storage, it needs to be assessed whether the same amounts can be abstracted as well and what kind of infrastructure/strategy is needed.

First, the general area for abstraction is identified. Second, the necessary infrastructure is specified based on average yields in the formation.

2.2.2 Key factors

Quality

MAR has the advantage of an innate ability to improve quality; storage in the underground can be very effective in removal of especially organic materials and microbes. Still, abstracted groundwater always needs to be treated to some degree to comply with South African health and safety standards. The quality of the infiltrated groundwater is important as major quality issues can make needed levels of treatment very expensive or difficult otherwise.

Quality is considered in this study in terms of:

- Known quality concerns in the targeted aquifer;
- Potential quality concerns in the infiltration water.

Flood mitigation

To assess the potential mitigation of floods, the following methods are used.

First, an estimation of flooding intensity was made. If the system is targeted at infiltrating water from rivers at high flows, flooding figures from these rivers are used. If the system is higher in the catchment and targeted at reducing runoff to rivers, a simple rainfall-runoff model was made using precipitation, catchment size and Curve Numbers.

After an estimation of the flooding intensity is made, this is compared to the potential water provision as estimated before. To what degree the targeted intervention will reduce flooding at a specific location determines its potential for flood mitigation.

Social & institutional challenges

To determine pre-feasibility of MAR through SUDS, specific social and institutional challenges are identified which needs to be overcome or addressed in the feasibility phase. A common challenge for MAR systems is (land) ownership: where can the suggested infrastructure be built? Who has control and right of use of the area? What space is available to build infrastructure? Is space potentially costly to acquire?

Other common challenges for MAR are management and protection: how can potential aquifers be managed properly? Can access be restricted? How can pollution be avoided?

For each formation the social and institutional challenges will be considered.

2.2.3 Cost-effectiveness

To get an understanding of the cost-effectiveness, there needs to be some understanding of the system design and the costs of each component of this system.

As discussed in chapter 1.3.2, a number of papers on SUDS in South Africa have been published (Armitage et al. 2013), which provide good information for the design and costing of infiltration infrastructure. The infiltration technologies as seen in chapter 1.3.3 will be considered while opportunities for using local infrastructure will also be checked.

Cost range widely over the different SUDS. While costs differ for each location, depending on local land use, contractors, infrastructure and much more, a few basic principles are valid for most situations, specifically scale and infrastructure-intensity. Large structural interventions and infrastructurally low-intensity interventions are almost always the most cost-effective, while local interventions and intensive infrastructure are generally more expensive. In the table below, relative costs are indicated for the SUDS technologies.

Table 2. Cost indications for SUDS, derived from figures of Armitage et al. (2013)

High cost
Permeable pavements
Infiltration trenches and soakaways
Buffer and filter strips
Swales
Bio-retention
Dry stormwater ponds
Wetlands and wet ponds
Low cost

On the other hand, large structural interventions like wetlands and ponds often require a very specific location, which can be very expensive dependent on the local owners. Permeable pavements and infiltration trenches can meanwhile mostly be implemented on land already owned by the government. This subject is discussed within the key factor paragraphs of social/institutional challenges as well, but is good to keep in mind during this assessment as well.

Cost of abstraction is mainly dependent on borehole cost. Latest estimate of local cost of siting, drilling and installing a borehole is around 150,000 rand for a borehole of 30m depth. Cost is linked to depth, so costs will be lower for shallower boreholes and more expensive for deeper boreholes, for both installation costs as well as operating costs.

Secondly, in this paragraph a specific case for MAR through SUDS is worked out in more detail. Specifically, a case which would work with a complementary study by RHDHV focused on rehabilitating and expanding on old and existing EWS infrastructure. Here, the focus are the EWS preferred areas of Northdene and Umbilo treatment works. The addition of MAR through SUDS within plans for these facilities is examined and a complete cost-indication picture is worked out; this will give a more tangible understanding of cost-effectiveness of MAR through SUDS in general while providing input for this other case as part of a larger study.

2.3 Rainwater harvesting

Assessment of preliminary feasibility of rainwater harvesting is more straightforward. Similarly, as for SUDS, first an estimation of water capture is given. This is based on available roof surface for different urban landcover types, combined with an analysis of precipitation and subsequent roof surface runoff and potential capture. Second, an elaboration on quality considerations is given. More important for rainwater harvesting specifically, however, is the social and practical feasibility, for which major challenges have been pre-identified. The rainwater harvesting chapter is mainly based on discussions with local organizations and literature.

3 Study area

3.1 Project area

The eThekwini Metropolitan Municipality (EMM district), commonly referred to as eThekwini, is one of the eleven districts of the KwaZulu-Natal province in South Africa. The district is located on the East Coast of South Africa where it is bordered by the Indian Ocean. eThekwini is surrounded on land from north to south by iLembe district, Umgungundlovu district and Ugu district. The district has a total area of approximately 2,500 km^2 (Figure 3), with a hilly topography with many gorges, ravines and steep escarpments in the west to a relatively flat coastal plain in the east.

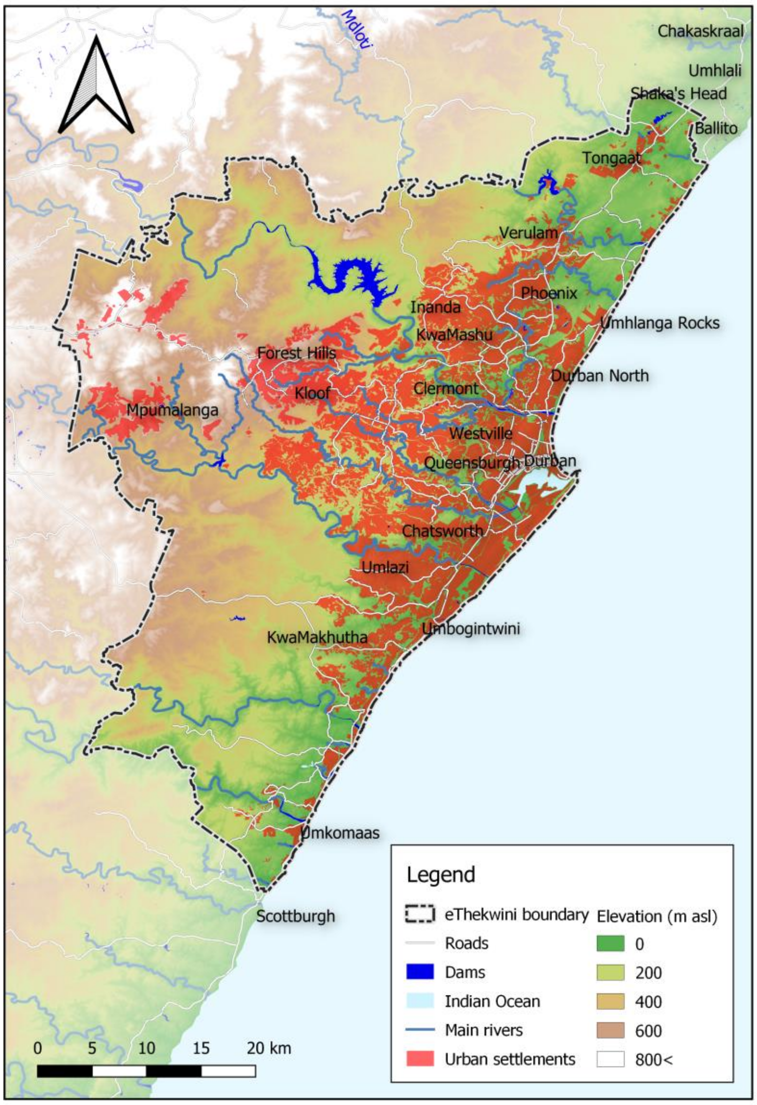

Figure 3. Map of eThekwini Metropolitan Municipality, with the main urban area highlighted

eThekwini is the third largest city in South Africa and the largest city in the province of Kwazulu. The metropolitan district has a population of over 3 million people and is considered a sophisticated cosmopolitan city. Population has grown much in eThekwini over the last few decades. Between 1970 and 2000, a major boom occurred where the urban population grew from less than one million to almost three million. Growth has declined since, but continued nonetheless, with current population estimated to increase to 3.9 million by 2020 (eThekwini Municipality, 2017).

Table 3. Population Forecast: eThekwini (eThekwini Municipality, 2017)

	2016	2017	2018	2019	2020	2030
Population Total	3.677.575	3.723.435	3.767.939	3.811.167	3.853.278	~4.400.000

The city of Durban is located within eThekwini district, and together with its neighboring towns it makes up a large urban area where most of the population is located. It is known as Africa's busiest port and a major center of tourism because of the subtropical climate and extensive beaches.

3.2 Water demand and provision

The Mgeni and Mdloti rivers are the main water resources for the eThekwini district with support from the Mooi river through a transfer scheme. The Mgeni river has several dams, Midmar, Albert Falls, Nagle and Inanda, regulating the flow in the river and the Hazelmere dam on the Mdloti river. Figure 4 shows the current water supply strategy within the Mooi/Mgeni system, where it illustrates which dams support which urban regions (EWS, 2020).

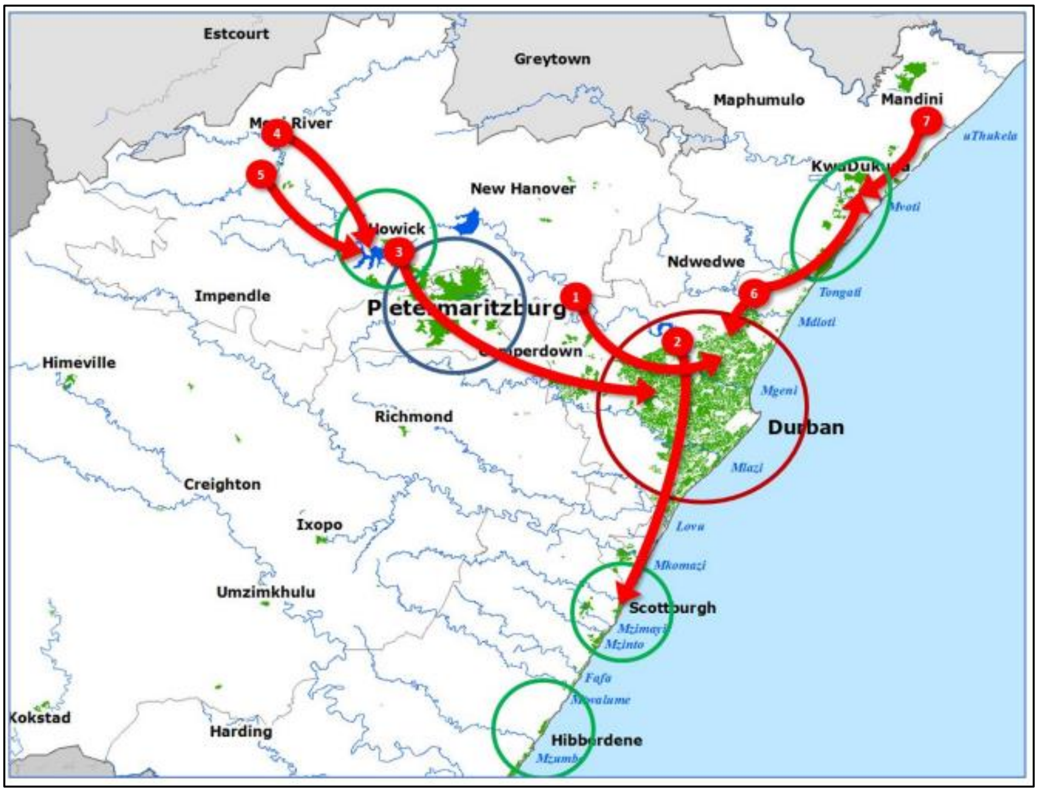

Figure 4. Mooi/Mgeni system current bulk water supply strategy (EWS, 2020)

Water from the Mgeni and Mdloti rivers is purchased from Umgeni Water, a state-owned entity water services provider, by eThekwini Water and Sanitation Unit (EWS) - the water services provider for the eThekwini metropolitan municipality. Through their large network EWS distributes the water to the customers. Effectively, there is a water delivery point within 200 meters of each resident.

Both the Mooi and Mgeni catchments are no longer open to stream flow reduction activities such as afforestation, expansion of irrigated agriculture or the construction of storage dams, i.e. they are 'closed' catchments (fully exploited) (Umgeni Water, 2013)..

Figure 5 shows the overall water balance in the Mgeni river system including water demand projections. With the newly constructed spring grove dam, total supply is just over 1,100 Ml/d, while demand is estimated to be around 1230 Ml/d, implying a current water gap of around 120 Ml/d. Moreover, demand is projected to increase to around 1,750 - 1,900 Ml/d in 2050, implying a potential future water gap of 700 Ml/d without new infrastructure.

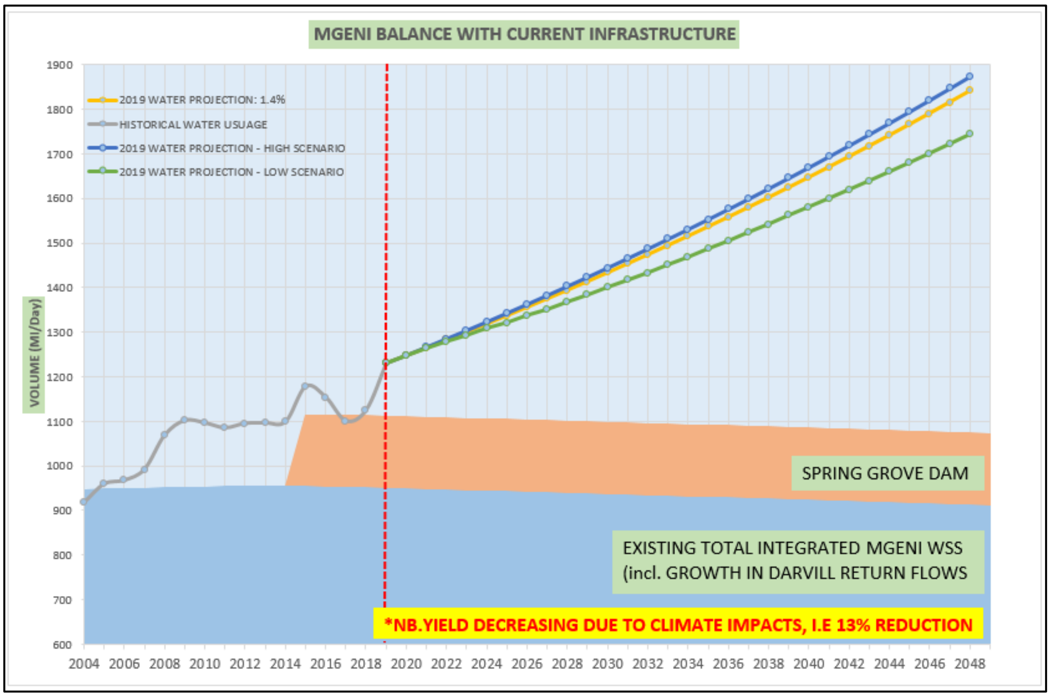

Figure 5. Water balance in the Mgeni river system (EWS, 2020)

3.3 Hydrology

Precipitation

The climate of the eThekwini district is classified as a subtropical climate with dry and cold winters and humid, hot and wet summers. Average temperatures range from 26˚C to 17˚C between summer and winter. The region has an average annual rainfall of around 1,000 mm/y, with a wet season from October to March and a dry period from May to August (Figure 6).

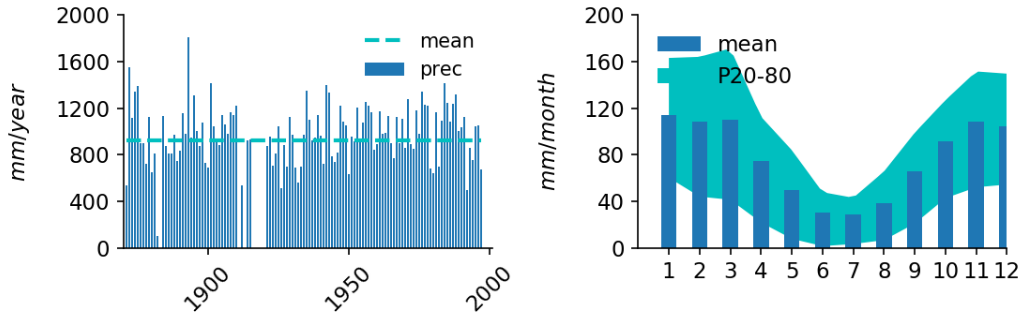

Figure 6. Annual precipitation (left) and average monthly precipitation (right) with 20th and 80th percentile as indication of variability (data from Botanical gardens meteorological station).

Evaporation

Data for the evaporation has been obtained from MODIS remote sensing data for the period of 2000 until 2014. The mean annual evaporation is approximately 800 mm with a very low interannual variation and seasonal patterns are very similar to precipitation.

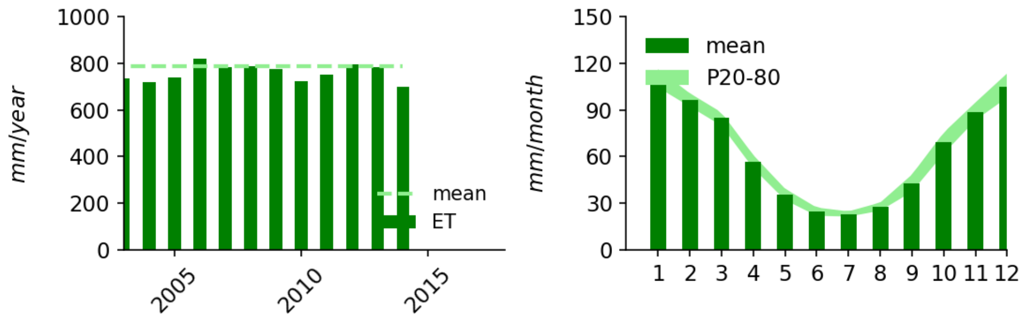

Figure 7. Annual evapotranspiration (left) and average monthly evapotranspiration (right) with 20th and 80th percentile as indication of variability (using MODIS data)

Rivers and catchments areas

The main rivers that drain the district from north to south are Mdloti, Umhlanga, Umgeni, Umbilo, Mhlatuzana, Mlazi, Amanzimtoti and the Lovu rivers (Figure 8). The Umgeni river is by far the largest river of the area, supporting a catchment of 4500 km^2 and experiences catchment runoff of over 650 Mm^3/y. The Mlazi, Lovu and Mdoti rivers support catchments of intermediate size (1400, 1000 and 600 km^2 resp.), while the rest of the catchments are smaller than 250 km^2.

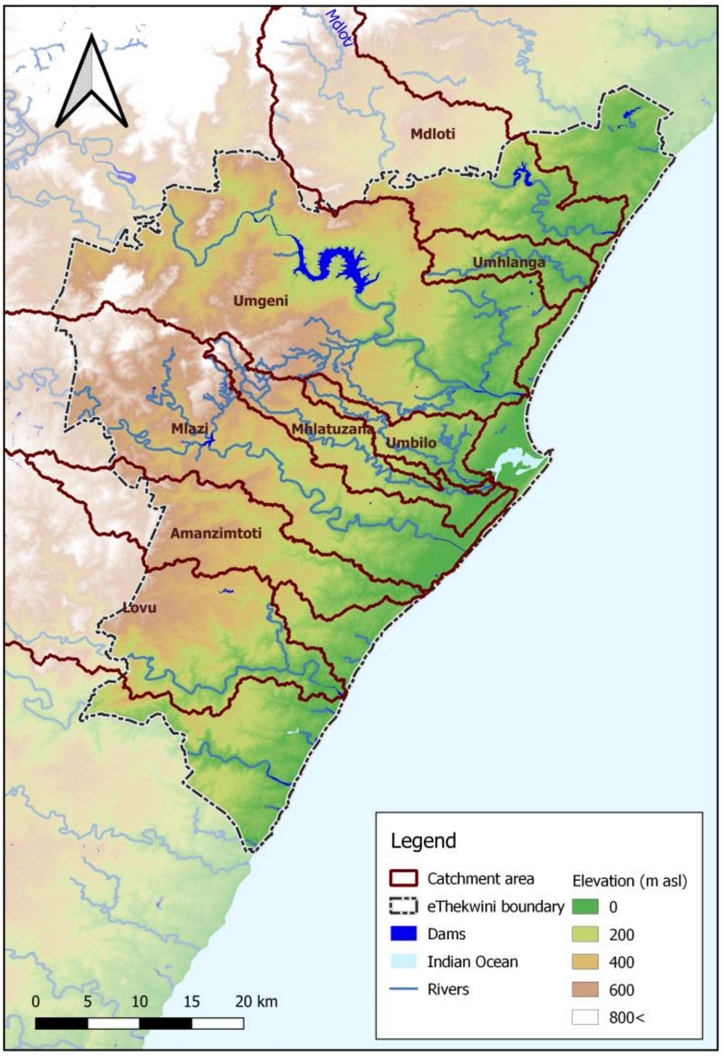

Figure 8. Major rivers and catchments of the eThekwini area (derived from SRTM)

In Figure 9, flood risk areas are mapped for eThekwini area, developed by an analysis of the topography combined with data from local partners. The most flooding takes place around the end of the major rivers, especially along the lower Mlazi and Isipingo areas.

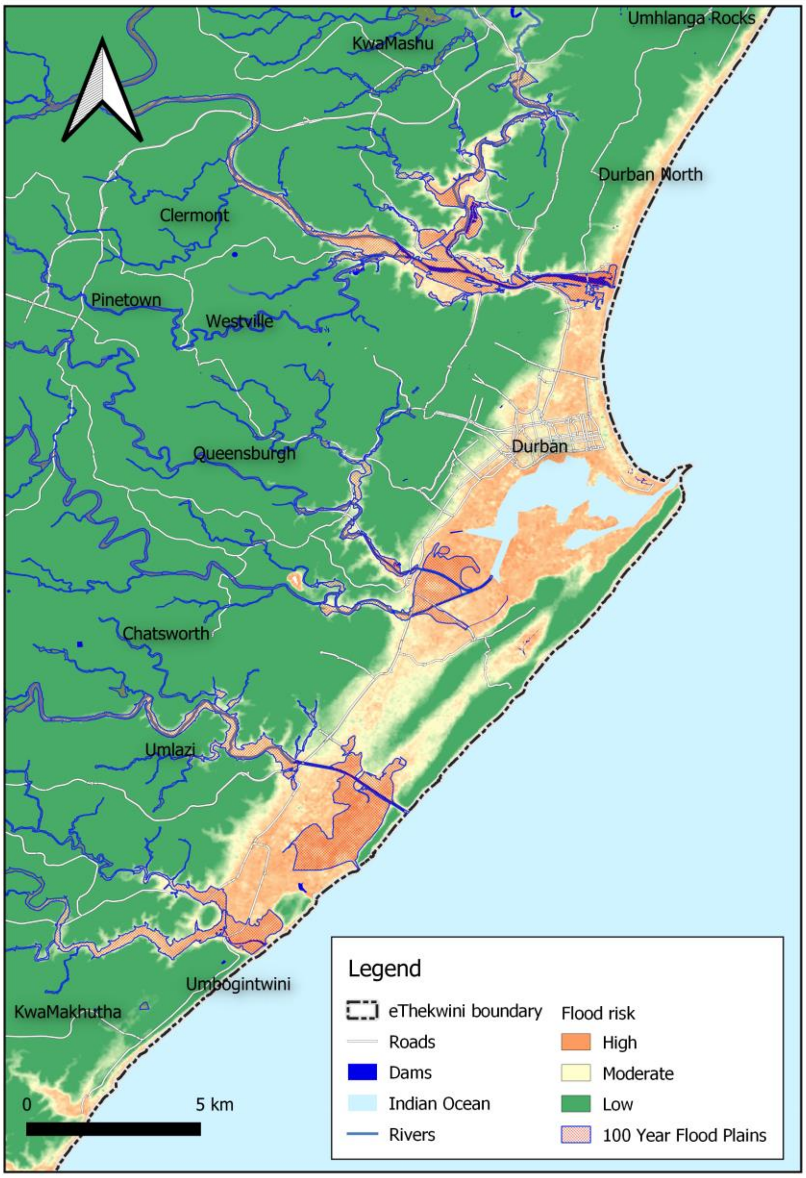

Figure 9. Major flooding areas

Groundwater

The groundwater in eThekwini district flows from the west to the east towards the Indian Ocean. Locally flow directions change under the influence of the geology and topography where a steep flow gradient occurs in the granitic basement and gentle sediments. As shown in Figure 10, the groundwater discharges into major streams and surface water bodies.

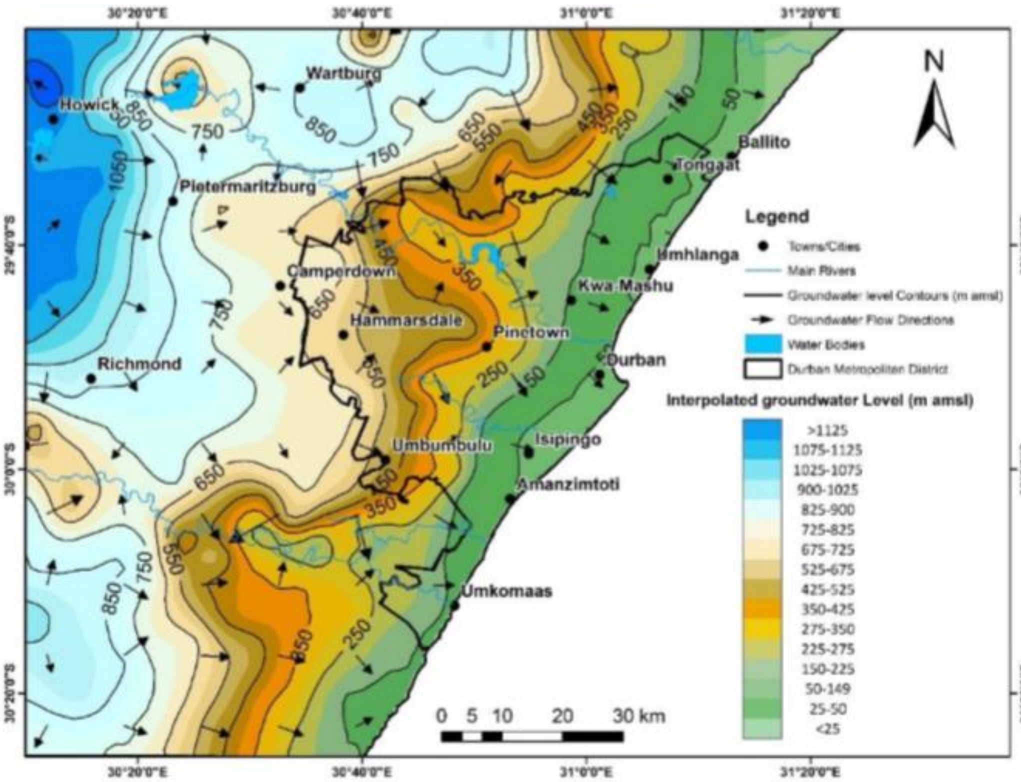

Figure 10. Groundwater levels in the eThekwini area (Ndlovu, 2018)

Groundwater recharges were estimated by Ndlovu, 2018 using the chloride mass balance and water budget method. Results took several locations in the district into account from which resulted that about 9.2 % of the annual precipitation infiltrates and recharges the various aquifers (Ndlovu, 2018) in the eThekwini district. Generally regional groundwater recharge occurs in the west and discharges into the Indian Ocean along the east coast. A total registered amount of 9.24 Mm^3/y is abstracted from the district's groundwater, which is mainly used for irrigation of golf courses and for industrial uses.

Groundwater depth in the district is also controlled by the local geology and topography and therefore vary spatially. The depth increases from east to west with the shallow depths of 6 m below ground level along the eastern coastal area and valley bottoms to 45 m below ground level. The overall trend of the groundwater quality is that the Electrical Conductivity (EC – a measure for the mineralization) decreases inland and is of good quality. Exception to this are the high concentrations of EC around Camperdown, Durban and Ballito, which are due to industries, landfills and sea water intrusions.

3.4 Landscape

Landcover and land use

Figure 11 illustrates landcover of the eThekwini area. The eThekwini district has a landcover of 32% urban area and 68% rural. The urban area is concentrated near the center east coast and is dominated by residential, commercial and industrial land uses (eThekwini Municipality, 2017). Industrial and commercial activities are mainly concentrated in Pinetown, Isipingo and Mobeni. In the rural area there are pockets of dense settlements where 10% is commercial farming. The main agricultural land use is sugar cane farming. The remainder of the rural area is characterized by rugged, hilly terrain, grasslands, savannas, forests thickets, wetlands and dispersed traditional dwelling settlements.

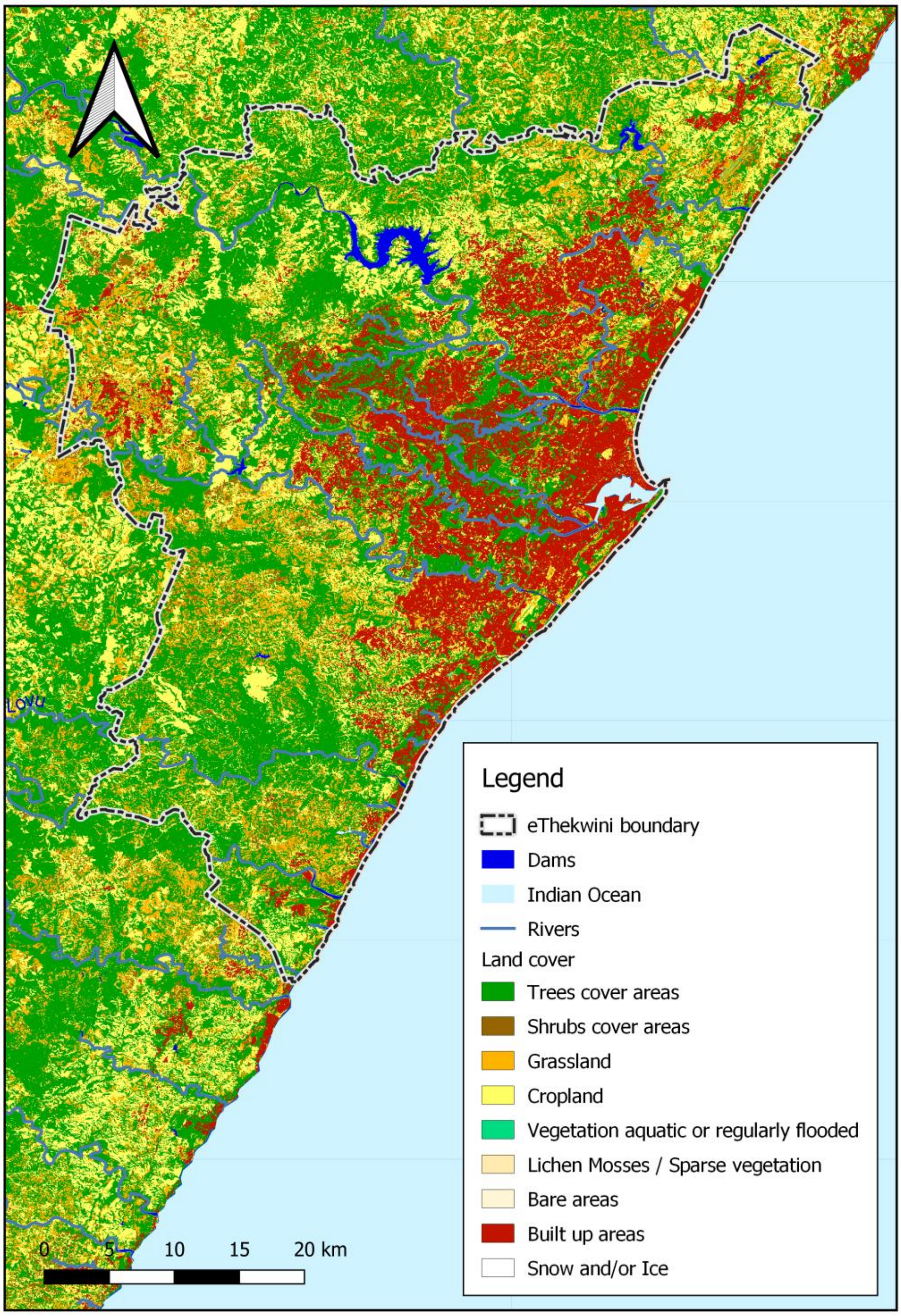

Figure 11. Landcover of the eThekwini area

3.5 Geology

The eThekwini district has a geological succession extending back to approximately 1,200 million years, from the most recent aeolian beach deposits of Berea formations to the Natal Metamorphic Province.

The succession starts at the basement with the Precambrian Natal complex consisting of megacrystic feldspar granite and gneiss, with some amphibolite. The complex is part of the Namaqua-Natal Province (Bell and Maud, 2000).

The basement is unconformably overlain by the Ordovician-Silurian Natal Group consisting of sandstones, siltstones, subordinate conglomerates and mudrocks. This group has a total thickness of approximately 200 m and is divided into the Marianhill and Durban Formations. The sandstones have a medium-to-coarse grained size and include thin, interbedded, micaceous shale and conglomerate horizons. Though there are several resistant quartz arenite members that give rise to escarpments in the succession. Soils developed above these sandstones are thin and sandy giving them the ability to be well drained under normal infiltration rates.

The Natal Group is unconformably overlain by Dwyka Group which consists of diamictite and massive dark bluish-grey tillite with many inclusions of older rocks deposited during the Permo-Carboniferious glaciation (Bell and Maud, 2000).

The Dwyka group is overlain with a sharp contact by the Ecca Group which is divided into the Pietermaritzburg and Vryheid formations based on their grain size and mica content. The Pietermaritzburg is the lower most unit of the Ecca Group and consist of dark silty mudrocks, which coarsen upward with bioturbated deformed sandy and silty beds towards the top (Johnson et al., 2006). The upper Vryheid formation is characterized by the alteration of bioturbated sand, dark siltstones and mudstone deposits in an anoxic water environment of moderate depth. Within this formation coal seams are visible which originated from peat swamps that developed on broad alluvial plains. The Dwyka and the Ecca group together form the Karoo Super Group (Ndlovu, 2018).

The Permian Ecca Group is unconformably overlain by the Quaternary coastal deposits of the Maputaland Group. The lower most formation is the Buff formation consisting of a 200 m strongly cross-bedded sandstone, which is the parent material for the Berea Formation. The Berea Formation is part of the coastal dune deposits overlaying the Ecca Group to a considerable distance inland and is a result of marine transgressions. The dunes are unconsolidated, quartz-feldspathic and characteristically red in color from weathering of minor iron-bearing silicates, giving the material the local name of Berea Red Sand. The formation is found in the upper inner part of the Durban Bluff and the Berea Ridge which runs parallel to the coast to the west of the central city and harbor area (Bell and Maud, 2000).

The youngest formations are the Isipingo formation and the Harbour beds Formations. The Isipingo Formation consists of the rocky shoreline along the Bluff in Durban. This formation consists of basal aeolianites truncated locally by the late interglacial age calcified beach and dune deposits at 4-5 m above mean sea level (Ramsay and Cooper, 2002). The formation extends to a depth of about 100 m below sea level at the northern end of the Durban Bluff and decreases to the southern end to 37 m below sea level.
The Harbour Beds Formations consist of the alluvium and estuarine deposits and have an average thickness of 15 m and in some place can be up to 60 m extending just from south of Isipingo to north of Durban.

Over the whole district area there are fault-bounded blocks inclined towards the east with an average dip of approximately 12 degrees. The rocks are intruded by dolerite sills and dykes of Karoo age (Bell and Maud, 2000). These intrusions and other lineaments can concentrate groundwater locally and are therefore interesting for groundwater resources.

4 Managed Aquifer Recharge (MAR) through SUDS

4.1 Hydrogeology of the eThekwini district

In this chapter, hydrogeology of the eThikwini district is assessed to identify potential areas for MAR.

Three types of aquifers are defined for the eThekwini district based on their hydrogeological characterization, which are:

- Intergranular aquifers of the Maputaland Group coastal deposits;
- Fractured aquifers of the Natal Group and Dwyka Group;
- Weathered and fractured aquifers represented by the basement crystalline rocks of the Natal Metamorphic Province, lower Karoo Supergroup sedimentary rocks, and the Karoo dolerite intrusions.

The intergranular aquifers of the Maputaland Group consist of the Bluff, Berea Formations and recent alluvium and estuarine deposits (Harbor Beds Formation). These unconsolidated coastal deposits form the primary aquifers in the KwaZulu Province. The Harbor Beds Formation have an average thickness of 15 to 60 m extending from the south of Isipingo to north of Durban with a borehole yield of 6-36 l/s.

The Berea Formation has a varying thickness ranging from 0.5 to 45 m covering most of the coastal area and has a borehole yield of 2.5 - 45 l/s where the dunes overlie the bedrock at shallow depths. The Bluff Formation has an average thickness of 53 m with a borehole yield range from 0.1 to 16 l/s. This formation is primarily seen at the Bluff ridge south of Durban City (see Table 4). Groundwater in these intergranular aquifers occurs in shallow depths ranging from 2 to 7 m below ground level.

The fractured aquifers consist of the Natal Group, Dwyka Group and the Vryheid Formation sandstone. The Natal Group has a thickness of 350 m with a borehole yield range of 0.2 to 18 l/s. Due to the presence of extensive faults and fractures groundwater is found in a confined to semiconfined conditions along these faults and fractures. The Dwyka Group has a low hydraulic conductivity due to the diamictite and shale resulting in a borehole yield of 0.1 to 3.2 l/s. Though favorable borehole yields in the tillite are found in low-lying sites on faults and major joints (Van Wyk ,1963). The Vryheid Formation has a borehole yield of 0.01 to 16 l/s.

The weathered and fractured aquifers consist of the rock units of the granitic basement, Jurassic dolerite intrusions and the shale of the Pietermaritzburg Formation. Groundwater in these smaller aquifers occurs in the intergranular interstices in the saturated weathered zone as well as in joints and fractures. The granitic basement has a borehole yield ranging from 0.2 to 8.3 l/s. The groundwater in this unit is stored in the weathered zones near the surface but due to the clay content the hydraulic conductivity is low. The dolerites have a borehole of 0.5 to 3.2 l/s and they act mostly as barriers to the groundwater movement. The shale of the Pietermaritzburg Formation has a very low hydraulic conductivity, 0.03 m/day, making it an aquitard where the groundwater circulates along the fractured zones.

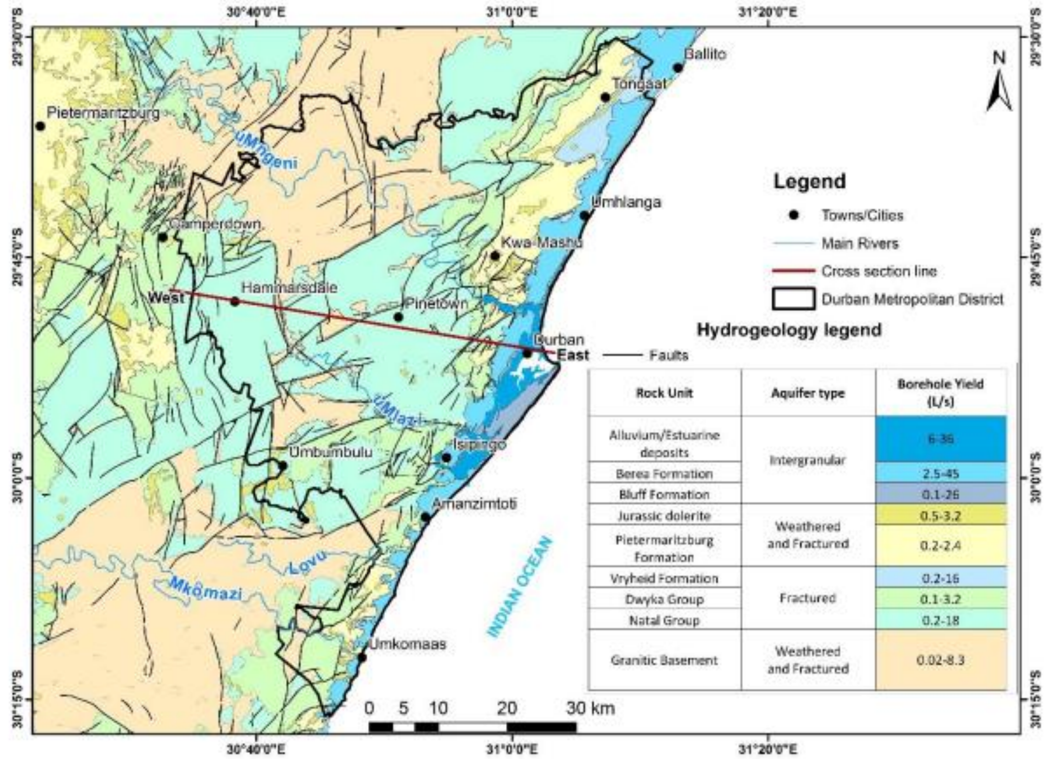

Figure 12. Hydrogeological map of the Durban Metropolitan region based on groundwater occurrence and borehole yields (Ndlovu, 2018)

Table 4. Mean hydraulic characteristics of the geological unit within the study area (Ndlovu, 2018)

Geological Unit		Thickness (m)	Average hydraulic conductivity (m/d)	Trans-missivity (m²/d)	Borehole yield (l/s)
Group	Formation				
Maputaland Group	Alluvium & estuarine deposits	2-73	6.5	13-470	6-36
	Berea Formation	0.5-45	5	3-225	2.5-45
	Bluff Formation	10-75	3.2	3-225	0.1-26
Ecca Group	Pietermaritzburg shale	15-105	0.03	0.45-3	0.02-2.4
	Vryheid sandstone	15-105	0.17	2.5-18	0.01-16
Dwyka Group	Diamictite & tillite	5-135	0.8	4-110	0.1-3.2
Natal Group	Sandstone & siltstone	20-350	2.8	50-1000	0.2-18
Mapumulo, Oribi and Mzumbe suite	Granitic basement	-	0.56	3.9	0.02-8.3

Berea Formation

MAR is generally more favorable in intergranular aquifers than in weathered or fractured aquifers. Multiple intergranular aquifers can be found towards the coast: the Bluff formation, the Berea formation and alluvium/estuarine deposits. Of these aquifers, the Berea formation shows highest potential: high hydraulic conductivity values and yields are reported as well as the highest transmissivities. Moreover, the extent of the Berea formation is generally relatively well-defined (see Figure 13).

Alluvial/estuarine deposits

The alluvium/estuarine deposits show comparable hydraulic conductivity and yields (even a bit higher than the Berea Formation), but are generally thinner and more spread out throughout the landscape. Within this formation two distinct separate and significant aquifers can be identified: the Umgeni alluvial deposits (2) at the Umgeni river mouth and the Harbor beds (3) around downtown Durban.

Natal Group Sandstones

Of the weathered and/or fractured aquifers, the sandstones of the Natal Group Sandstones (NGS) are reported to provide the best aquifers (4). Aquifers in this formation are confined to fractures: separations or breaks in the rock formation. Within fractures of the NGS, hydraulic conductivities, transmissivities and yields are relatively high. This formation has the largest areal extent. Its suitability for artificial recharge will also be considered in this study; due to the widespread occurrence of this aquifer, even low infiltration rates could surmount to large volumes of infiltration.

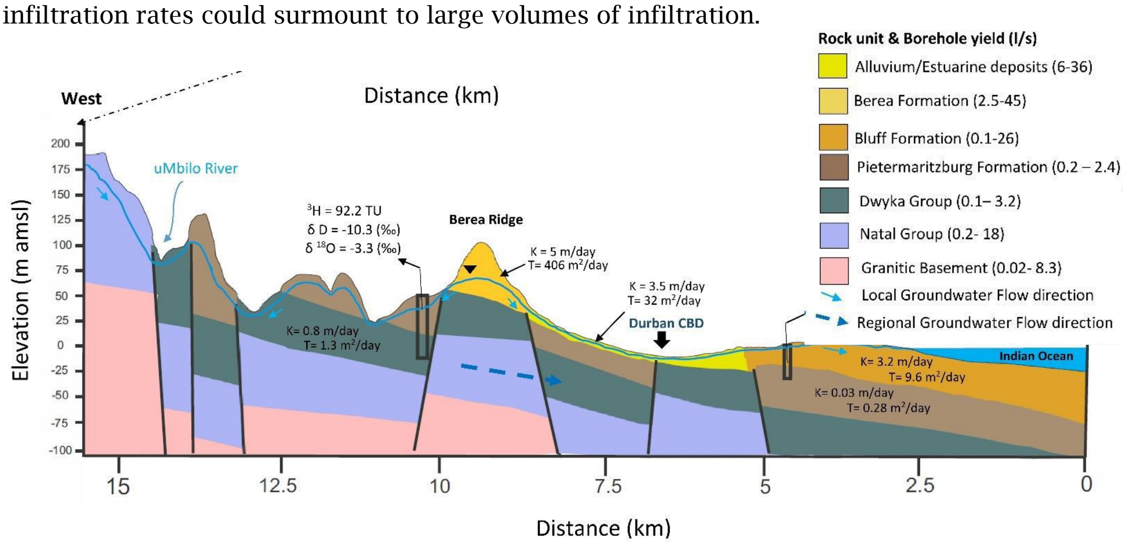

Figure 13. Hydrogeological concept model from west to east (Ndlovu, 2019)

Conclusion: preliminary assessment has yielded four potential formations for MAR:

1. The Berea formation
2. The Mgeni alluvial deposits
3. The Harbor Beds
4. The Natal Group Sandstones (NGS)

In the next chapters, these four areas will be characterized for its feasibility and potential for MAR through SUDS.

4.2 MAR in the Berea formation

The Berea formation consists of a few separated deposits, stretching in a southwest-northeast direction following the coast and separated by incision of the major rivers (see figure below). It is bordered almost directly by the ocean in the north (Uhmlanga) and south (Amanzimtoti) and separated from the ocean by the estuarine beds and Bluff formation around central Durban.

About five different major units can be identified. From northeast to southwest. All five of these units could theoretically be exploited, but focus will be on one specific unit for now to be able to go into greater depth. This will be unit indicated with number 2 in the figure, located between the Umgeni and Umbilo rivers and locally known as the Berea ridge. This unit is chosen for its relatively large size (second largest of the five major units), central position in eThekwini and the availability of local data.

First, MAR will be considered for this specific unit to identify the potential of a smaller specific system. Second, the analysis is extrapolated over all units to obtain an estimate of full potential.

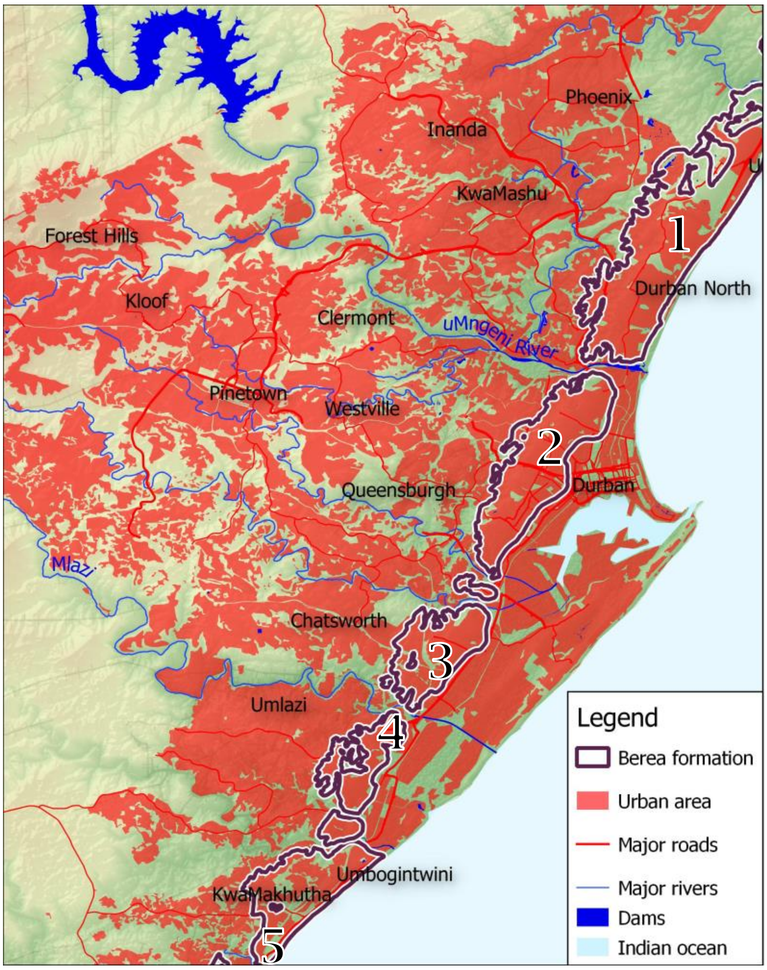

Figure 14. Berea formation extent in eThekwini area

4.2.1 Water availability and provision

Potential for infiltration

With a total area of 20 km^2 and a rainfall of 1000 mm/y, the Berea ridge aquifer receives an annual input of around 20 Mm^3.

Meanwhile, the total area of the Berea formation is 200 km^2 with a slightly lower rainfall of around 900 mm/y on average, receiving a total yearly input of 180 Mm^3.

The Berea formations are relatively high areas in the landscape and thus do not receive runoff from other areas. There are rivers in close proximity to the formations however (like the Umgeni and Umbilo rivers for the Berea ridge) which could potentially be harvested for infiltration through heavy infrastructure and piping. This would be a relatively costly measure and will therefore not be explored further in this study.

There are two limiting factors on the Berea formation to harvest this water for infiltration. The natural and artificial physical features limits the potential of larger SUDS (like retention basins and wetlands), which need to drain larger areas to be effective. Meanwhile, the existence of less permeable layers limits the potential of superficial infiltration. The best measures for infiltration here are deep infiltration trenches and soakaways, which can be installed at strategic locations (favorable soils) and potentially bypass superficial less permeable layers.

Additionally, there are good opportunities with existing infrastructure. There exists a number of old sub-surface storage basins for stormwater collection on the Berea ridge. They have fallen into disuse, but the stormwater department of eThekwini is considering rehabilitating these. These storage basins were originally designed to capture stormwater for a limited time and then release the water to drains. Instead, if the infrastructure is re-designed to infiltrate the water instead of open water release, they will act essentially as a SUDS (a small retention basin), increasing water provision while being able to capture more stormwater for flood mitigation.

Assuming a design infiltration of the trench of 240 mm/d in loamy sand (infiltration rate 10 mm/h), aiming to capture 25% of the rainfall in the area, effective over half a year (the wet season). For the Berea formation, this implies a needed infiltration trench surface area of 110,000 m^2 to infiltrate 5 Mm^3/y. With a design of 1 m width of infiltration trenches, around 5 km of trench would need to be installed within every square kilometer. This means installment of 110 km of infiltration trench over the Berea ridge. For implementation over the full Berea formation, 990,000 m^2/990 km of infiltration trench would be needed to infiltrate 45 Mm^3.

Aquifer size

Information on current water availability within the aquifer is scarce, but local data suggests current groundwater stored in the aquifer is quite limited. It is observed however that the area used to support a number of which are now dry. The biggest spring was Curries Fountain spring in the Durban Botanical Gardens. This spring was in fact one of the principle source of water for people in the area until the opening of the Umbilo waterworks in 1886. Hydrogeological analysis indicated the presence of an artesian waterway from a fault, increasing groundwater availability. This case clearly illustrates the presence of favorable hydrogeology while expressing the potential of increased infiltration through SUDS to set up a viable MAR scheme.

The Berea ridge aquifer has an extent of 20 km^2 and an average effective porosity of fine sand of 33%. Targeting a rise in water levels of 1 meter (which seems easily feasible), this would give an added potential storage capacity of 6.7 Mm^3. Compared to an infiltration rate of 5 Mm^3/y, this potential storage capacity is more than adequate for the purposes of MAR.

Abstraction

In Figure 15 below, a west-east cross section is illustrated of the Berea ridge aquifer with data gathered in the construction of the Glenwood tunnel. From this cross-section, a general idea of the shape of the formation is formed, with an incline of the bottom of the formation from west to east. Infiltration into the aquifer will thus have a tendency to move as groundwater towards the central east part of the aquifer (although this needs to be confirmed with actual flow lines in a follow-up study).

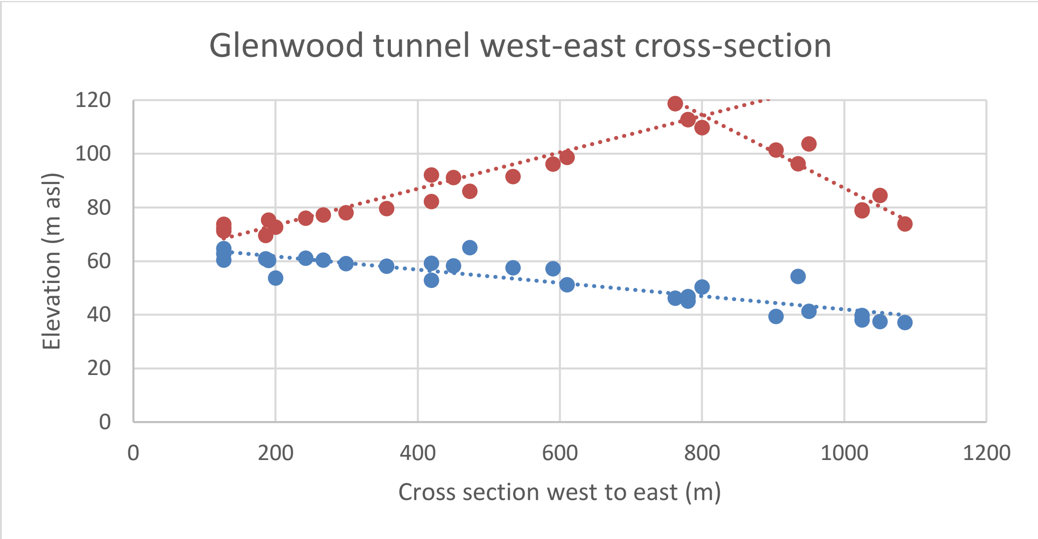

Figure 15. Cross-section of the sandy layers within Berea formation, where red dots and lines depict the top of the formation and blue dots and lines depict bottom depths of the formation. Based on borehole logs taken during construction of the Glenwood tunnel

Figure 15 indicates that abstraction (recovery of stored water) in the Berea formation should focus on the eastern boundary of the formations. In fact, this observation of an eastern drainage points in the Berea ridge more or less coincides with the former presence of springs as described in the previous paragraph, which highlights the favorability of the eastern boundary as an abstraction area.

In Figure 16, the targeted abstraction area is illustrated for the Berea ridge as well as the Durban North/Umhlanga area (the largest Berea formation unit of eThekwini). How many boreholes are needed and whether they need to cover the full extent as illustrated below is dependent on the design and siting, but for an abstraction of the full potential infiltration (5 Mm^3) at least ten to twenty boreholes are needed, which is reasonable.

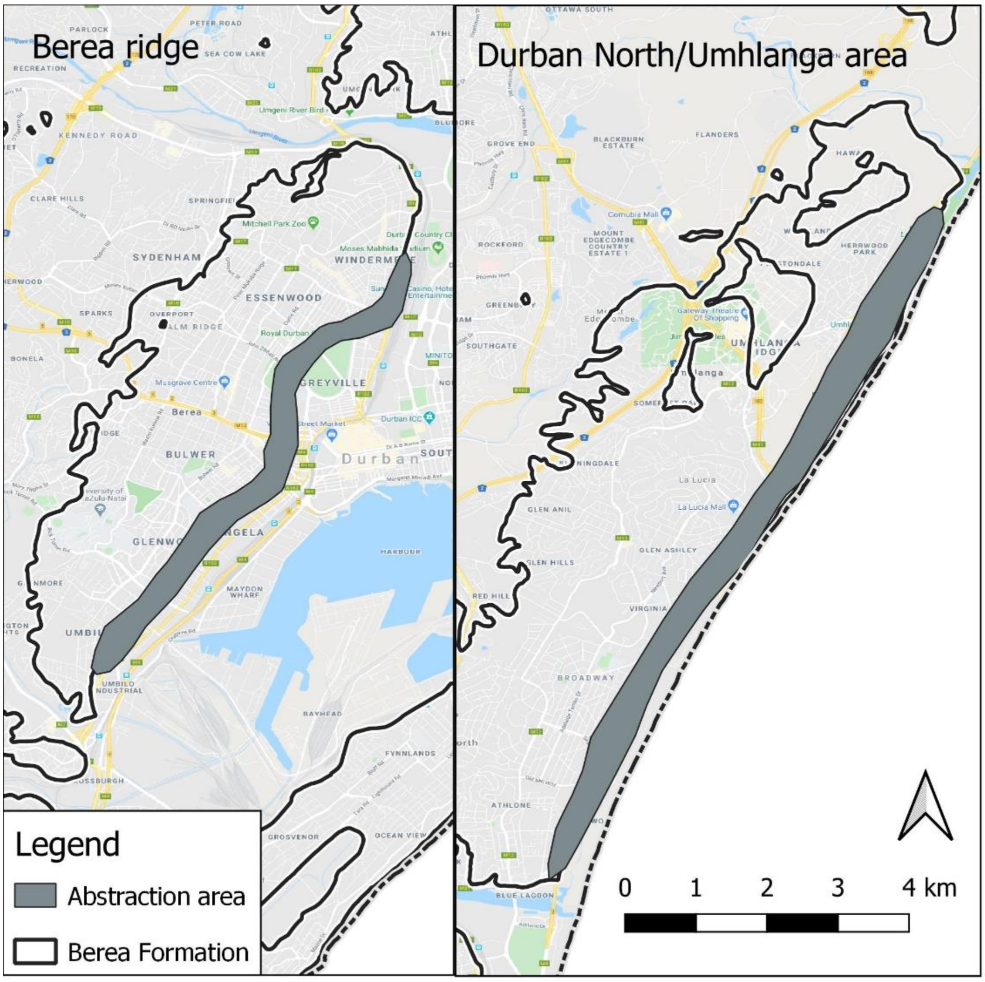

Figure 16. Abstraction area for potential schemes in the Berea formations of the Berea ridge and the Durban North/Umhlanga area

4.2.2 Key factors

Quality

Little data is available on groundwater quality in the eThekwini area, this includes for the Berea formation. Reports do describe the groundwater as potable. As the described scheme is focused on increasing the current water storage of the aquifer, the groundwater quality will mainly be dependent on the quality of the infiltrated water.

Areas are mostly residential, and the quality of water is assumed to be good.. For the Berea ridge specifically, there are no major concerns for heavy contamination of infiltration water. For other areas within the Berea formation, assessment of runoff water quality is advised in the feasibility phase.

Flood mitigation

Proposed SUDS infrastructure (infiltration trenches) targets to capture 25% of runoff. At full capacity, the infiltration infrastructure is able to drain 26,000 m^3 in a single day and has an innate storage capacity of 50,000 m^3. This corresponds to a rainfall event of 3,8 mm. This implies that at most, the SUDS infrastructure will be able to completely absorb small events up to 3,8 mm, and can reduce larger storm events by this amount.

Flood mitigation through infiltration trenches will thus be limited. As local flooding does take place within the target area and directly below the target area however, the mitigating effect it does have is very direct. In other words, this option does contribute to mitigating floods although it needs to be supplemented by other interventions to properly reduce flooding issues; interventions like the described opportunity of repurposing old stormwater harvesting infrastructure.

Social/institutional challenges

. As calculated, to provide 5 Mm^3/y in the Berea ridge or 45 Mm^3/y over the full extent of the Berea formation, 110 to 990 km of infiltration trenches/soakaways are needed. Topographically there is no obstruction foreseen, and challenges in accessibility is more expected related to ownership and land rights. While there is enough space to implement this in theory, it will mostly depend on what space is available for how much can be implemented in the end.

The Berea ridge is a residential area where people have unrestricted access. Industries or other likely heavy polluters are not present, and pollution is likely to be limited and have negligible effects on groundwater quality. However, there is no guarantee a sudden case of heavy pollution occurs due to unforeseen interventions (e.g. illegal dumping). To secure public health, quality at abstraction need to be tightly monitored. In case of detection of serious pollution the organization needs to have a contingency plan, figure out the source of pollution and start a recovery plan. Meanwhile, sensitization of local people for groundwater protection will help cultivate an understanding of MAR, helping with management in the long term.

4.2.3 Conclusion

The Berea formation provides significant aquifers of decent characteristics for MAR options. Infiltration, storage and abstraction can sustain a provision of 5 Mm^3/y within the Berea ridge and 45 Mm^3/y for the entire Berea formation area. The most suited SUDS infrastructure are infiltration trenches, with additional opportunities for re-purposing old stormwater harvesting infrastructure. Abstraction should be focused on the east side of the areas, with 10-20 needed for the 5 Mm^3/y of the Berea ridge area. SUDS infrastructure could capture up to 25% of rainfall, although direct reduction of flooding is limited. Management and quality protection are assumed to be challenges and should be closely monitored. Detailed hydrogeological investigation to confirm aquifer characteristics is required.

4.3 MAR in the Umgeni alluvial deposits

The Umgeni alluviul deposits are part of the Maputaland Group and is an intergranular aquifer consisting of unconsolidated clay, silt and sand. The total formation extends up to the Indian ocean and extends inland along the main river and some tributaries, but as salinization becomes an issue towards the Indian ocean and aquifer volume is very limited inland, this chapter will focus on the central Umgeni alluvial deposits as highlighted in Figure 17.

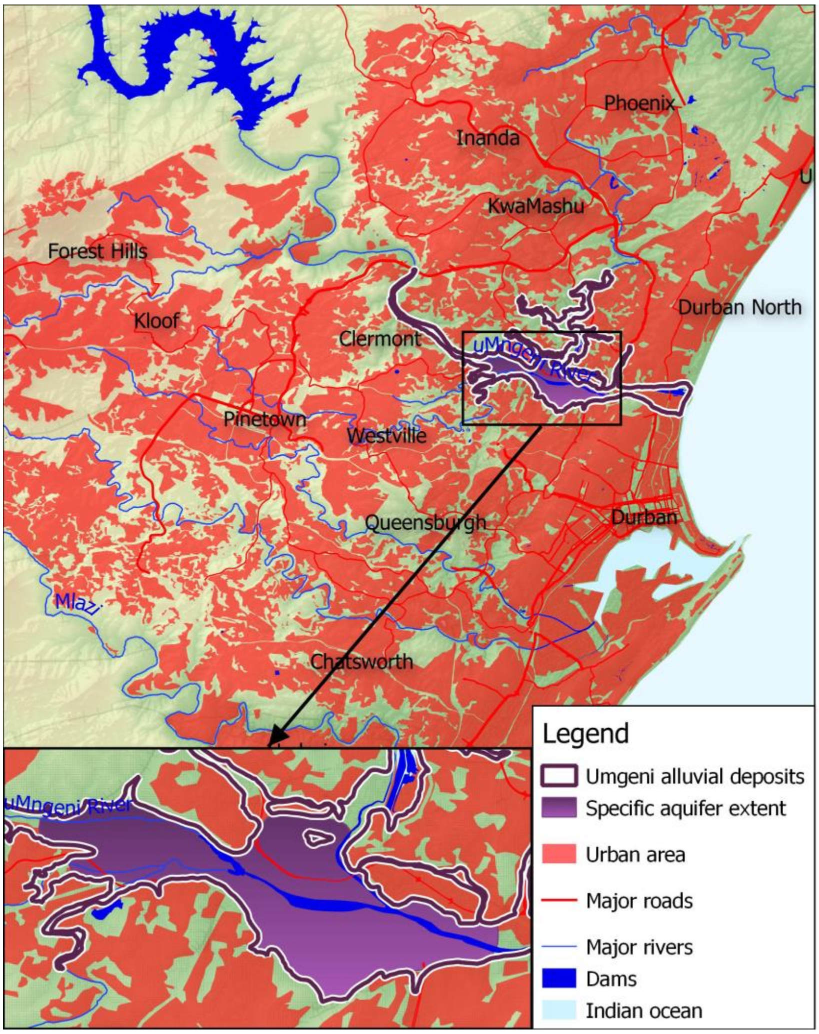

Figure 17. Umgeni alluvial deposits

4.3.1 Water availability and provision

Potential for infiltration

The targeted area has an extent of 5 km^2. With a rainfall of around 1000 mm/y, yearly direct input from precipitation is 5 Mm^3/y.

The real potential however comes from the Umgeni river, which flows right on top of the formation and is a great source of water. Discharge of the Umgeni river is 370 Mm^3/y or 1,000 Ml/d on average at the Inanda dam, and increases towards the Indian ocean. Much of this water flows freely into the ocean, capturing a percentage of this water could be a significant source for provision.

So most of the potentially available water comes in the form of the Umgeni river. Larger SUDS like detention ponds and artificial wetlands can be very effective to capture especially flood flows.

Assuming a design infiltration of 480 mm/d in fine sand (20 mm/h), focused on capturing ~10% of Umgeni yearly flows (40 Mm^3), a wetland/retention basin area of around 0.2 km^2 would be required.

Alternatively, the area shows quite some potential for a riverbank filtration system. Such a system utilizes the natural infiltration of rivers inside riverbeds to use as a source for water provision by establishing a new equilibrium with abstraction. Riverbank filtration systems however are not useful for flood mitigation and is only mentioned as a side note in this study.

Aquifer size

The area covered by the targeted specific aquifer is around 5 km^2. Its thickness is up to 40m in around its central, southern and eastern area but can be shallow along its borders, at least to the west. On average, its thickness approaches 30 meters. Based on this average thickness and with an effective porosity of fine sand of 33% the potential full aquifer storage is 50 Mm^3.

How much of this 50 Mm^3 can be used as storage for SUDS infiltration needs to be more closely assessed. Currently, much of the aquifer already holds water, but exact numbers are missing. If this is over half of the aquifer, infiltration could be limited in the SUDS infrastructure. With abstraction, a new equilibrium could be reached, but how much storage for infiltration can be attained has to be closer assessed. For instance, if only a depth of 5 meter on average can be used for storage of the SUDS infiltrated water, this would mean a storage of 8.3 Mm^3. This amount of storage capacity would be tight to support an infiltration rate of 40 Mm^3/y.

Abstraction

Abstraction is quite straightforward; boreholes need to be drilled in the area around the infiltration infrastructure. Around ten well placed boreholes would be enough, which the area could easily support.

4.3.2 Key factors

Quality

Although there is an adequate water supply for recharge, the water quality appears to be a concern.

Quality issues in the Umgeni are already reported at Inanda Dam, with elevated nutrient concentrations causing eutrophication with a corresponding increased algal count and proliferation of aquatic weeds and reduced oxygen level with a corresponding reduction in the impoundment oxidation potential, which increases the concentration of dissolved metal ions (i.e Iron and Manganese).

The biggest problem however for the quality in the Umgeni river is the pollution from upstream regions sewage flow industrial waste. Water data showed Cr, Cu, Zn and Pd above the stipulated SABS limit while for sediments Cd, Cr, Cu, Pb and Zn were above the EPA limit. In the wet season Cd in water was below the SABS limit and above for sediments (Dikole, 2014).

It is extremely likely that this pollution extends to the groundwater as well. The industrial park which is the source of most of the pollution is located right on top of the targeted aquifer. Moreover, what has been reported as 'Africa's biggest landfill site', the Bisasar Road landfill site (also known as the Springfield landfill site), is located right next to the aquifer. Pollution of groundwater from this source is reported (Ndlovu 2018), specifically levels of Manganese, Sodium and Chloride over SABS limits.

Where the Umgeni alluvial beds meet the Indian ocean, saltwater intrusion could become an issue as well. Issues with salinization are reported up to about 1 km land inwards. The targeted aquifer is over 2.5 km land inwards and thus no problems with salinity connected to the Indian ocean are expected.

Flood mitigation

Proposed infiltration infrastructure aims to capture 10% of Umgeni flows. The Umgeni alluvial deposits are located at the lowest part of the Umgeni river, the largest river of the area. Discharge from Inanda dam alone regularly goes over 20 Mm^3/d during heavy rainfall events, which can easily rise to 30 Mm^3 at the aquifer with additional runoff from the mostly urban lower-Umgeni catchment. Reducing flooding quantities and issues of such a large river meaningfully will require more than capture at a downstream point; it would require runoff reduction and infiltration promoting measures over a large area from up to downstream.

Figure 18. Umgeni river at Ugeni river bridge during regular flow (above) and extreme flow (below)

Social/institutional challenges

Finding the space for infiltration reservoirs or wetlands is assumed to be an issue. The area is densely urbanized, with the Umgeni Business Park covering most of the area. Creating space for infiltration reservoirs or wetlands will require some encroachment into the business park, which would mean some businesses would have to move. This makes it political a sensitive topic.

Before any specific system design is considered at all, quality and management issues need to be dealt with. The challenges concerning quality touch upon the general issue of management and protection. Not only does current quality issues and pollution need to be investigated and dealt with, future quality issues and pollution need to be prevented. This will require a major change in behavior for local people and organizations, which needs to be thoroughly investigated and assessed as well.

4.3.3 Conclusion

The Umgeni alluvial deposits provide a relatively small aquifer of good physical characteristics. Water quality is a major concern however, with open connection to industry and waste sites. Until waste deposition and leakages have been controlled and quality conditions are assured, an MAR through SUDS system is not advisable.

4.4 MAR in the Harbor Beds

The Harbor beds stretch north-south from the Umgeni river mouth through downtown Durban all the way to Umbogintwini (see Figure 19). They underlie the lowest lying, flat parts of the area and are thus also the area where most of the flooding takes place. In fact, one specific part of this area (Isipingo) is known to be a wetland before and still floods regularly.

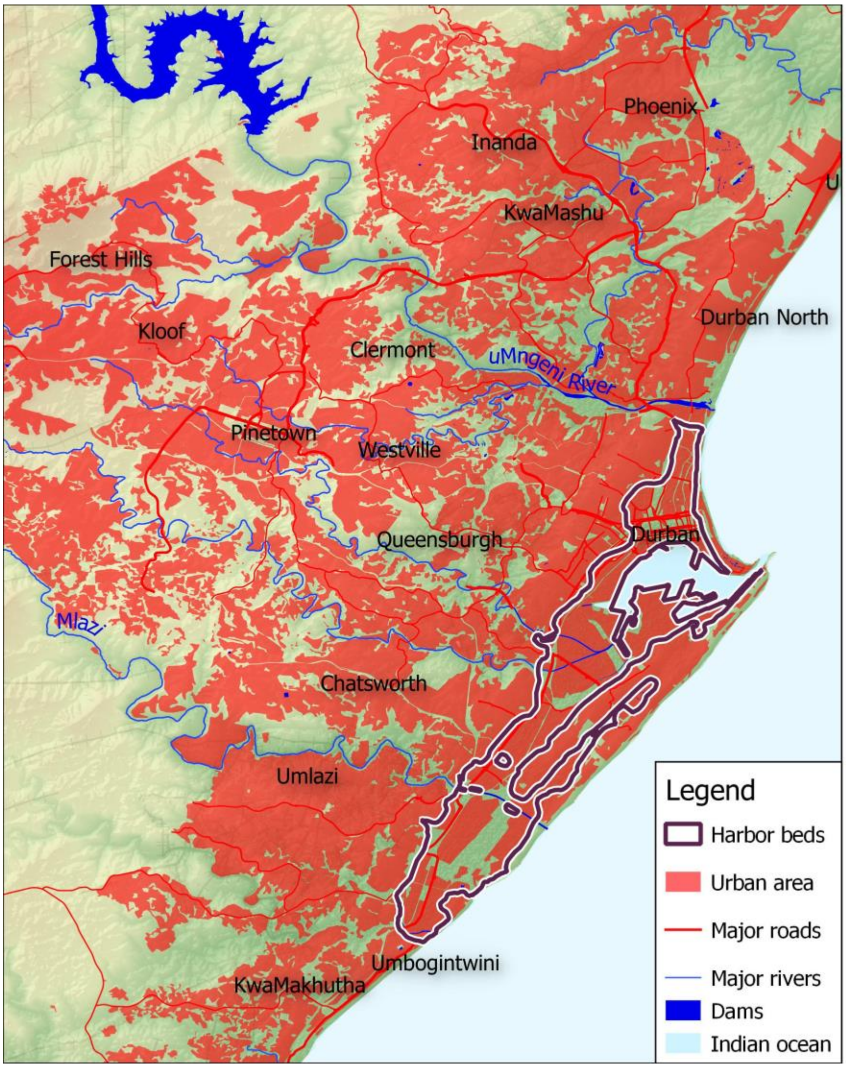

Figure 19. Harbor beds extent

4.4.1 Water availability and provision

Potential for infiltration

The harbor beds have a total extent of 55 km^2. With a rainfall of around 1000 mm/y, yearly direct input from precipitation is already 55 Mm^3/y.

More importantly however, the targeted area drains multiple larger rivers: Umbilo, Mhlatuzana, Mlazi and Amamzimtoti. Together, these rivers drain an effective area of around 700 km^2 and support a flow of around 100 Mm^3/y.

With these significant rivers draining through the area, there is a lot of potential for major infiltration constructions: large artificial wetlands or retention ponds, directly connected to overflows from major rivers.

Targeting to capture 20% of the river flows (20 Mm^3/y), and assuming a potential infiltration rate of 50 mm/d in an artificial wetland, an artificial wetland area of 1.1 km^2 would be required for the entire Harbor beds system.

It makes more sense to focus on specific rivers/flooding areas for infiltration. The largest potential for increasing infiltration is related to the Umlazi, especially its flood flows. Capturing floods in wetlands or infiltration basins will make the water available for infiltration while directly mitigating floods.

Besides Umlazi, another interesting area to focus infiltration on is the Isipingo area. This used to be a wetland but is now paved, and regularly suffering directly from flooding.Capturing 20% of river flow from the Umlazi, or 20% of rainfall from runoff in the Isipingo area, about 5 Mm^3/y of water could be captured for both/either (so a total of 10 Mm^3/y). For this, an artificial wetland area of around 0.55 km^2 would be required.

It should be mentioned that with artificial wetlands and retention basins, water will be lost through evaporation of open water. Calculation of expected evaporation losses should be part of the design in the feasibility phase. However, if high infiltration rates are maintained as planned, evaporation will be a relatively minor factor compared to infiltration.

Aquifer storage

The aquifer of the Harbor beds is the thinnest of the four formations, with an average depth of 15 meters. Moreover, since infiltration opportunities are mostly centered around rivers and flooding areas, it is not realistic to assume the whole extent of the Berea formation can be used for storage; potential aquifer storage area should be more carefully considered.

Focusing on infiltrating water from the Umlazi river and Isipingo area (the 10 Mm^3/y mentioned in the previous paragraph), potentially an area of around 10 km^2 is available. Targeting a water level rise of 1m, around 3.3 Mm^3 of potential aquifer storage would be available. This is a reasonable amount of storage compared to the infiltration rate, although it does leave a small window for buffering.

To confirm potential, exact depths of the aquifer and water levels would need to be assessed in the next phase, but preliminary analysis indicates that aquifer storage is likely sufficient.

Abstraction

Abstraction is quite straightforward, boreholes need to be drilled in the area around the infiltration infrastructure. Around just five to ten well-placed boreholes would be enough to cover the 10 Mm^3/y around the Umlazi and Isipingo targeted area.

4.4.2 Key factors

Quality

Similarly to the Berea ridge, people have unrestricted access to the site. Moreover, industries are present in the area. Specifically, a large compound of Isegen is situated right on top of the aquifer. To what degree these industries pollute current groundwater sources is unknown, but needs to be checked before feasibility can move forward.

Eventually however, quality of the MAR system will mostly be dependent on the quality of the infiltration water. One of the highlighted potential sources is the Umlazi river, for which studies have been done. Specifically, Xaba et al. (2016) report quality was within WHO standards for characteristics like pH, sulphates and COD, but not for turbidity and bacteria like *E. coli*. Wetlands and MAR systems are specifically suited for natural removal of bacteria and suspended particles, implying a great synergy for MAR through SUDS in this case. However, focusing capture of water from large flooding events, quality will likely be poorer. A natural wetland system will help improve quality, but treatment of the water after abstraction will still likely be necessary when targeting large flooding events.

Flood mitigation

Proposed SUDS infrastructure aims to capture 20% of runoff flows. Opposed to the SUDS infrastructure proposed for the Berea formation, artificial wetlands and retention basins are more suited to capture specific high flows.

The Isipingo area is a known hotspot for flooding. Taking the proposed artificial wetland area to capture a specific event, and assuming a potential storage depth of 2 meters on average, a full storm of 1.1 Mm^3 could be captured. This implies that a storm of 44 mm could be potentially captured entirely, and higher storms by this amount. This is a huge potential reduction in flooding.

Social/institutional challenges

The major challenge for any design here is finding the space to capture these flooding waters. The Harbor beds area is relatively high use, and obtaining the required space for the proposed infrastructure might be difficult or costly. Finding out what options are the region is a vital next step for determining full feasibility.

Management and protection could be an issue as well. Just like at the Berea ridge, people generally have unrestricted access to the area, while for the Harbor beds industries and other potential heavy polluters are present as well (as mentioned in the quality paragraph). However, due to the more localized nature of the infiltration infrastructure, the area for protection and management can be more locally focused as well. This needs to be in balance with the aquifer area needed for infiltration, but focusing on a smaller area would make management and protection much easier for this formation.

4.5 MAR in the Natal Group Sandstones (NGS)

The NGS cover the largest area of any formation in the eThekwini area (Figure 20).

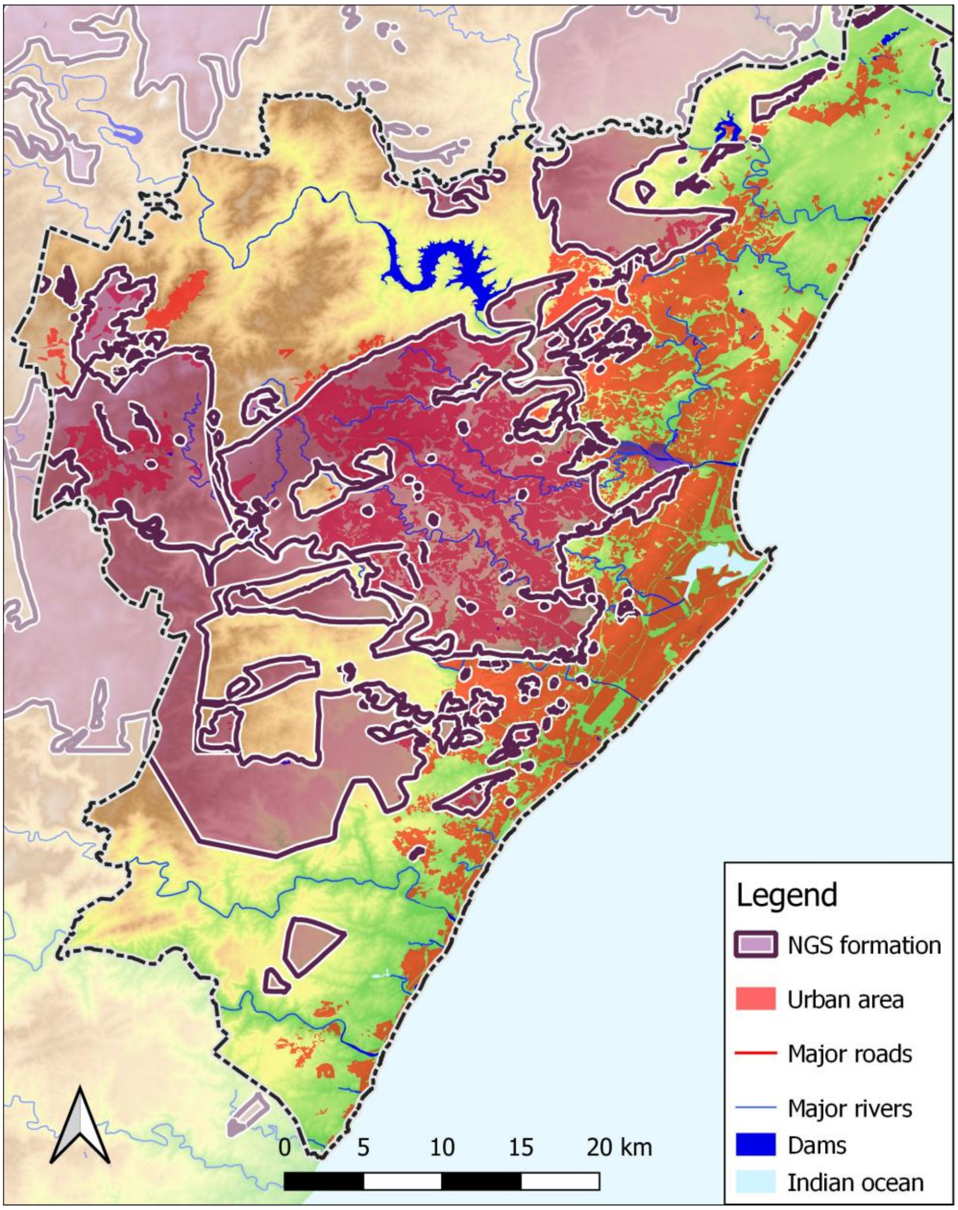

Figure 20. Natal Group Sandstones (NGS) extent in eThekwini area

The aquifers of the NGS are dependent on secondary porosity, i.e. fractures. Exploitation of such aquifers is fundamentally different from sedimentary aquifers such as the Berea formation and alluvial/estuarine deposits. Specifically relevant for MAR through SUDS, groundwater movement in such aquifers is less predictable. In general, groundwater can be found in fractures. Where these fractures are, how fractures are connected, which way they incline and whether they even bare water is not straightforward and requires detailed hydrological investigation to find out. Something that is currently lacking for the study area. Applying a typical MAR system in NGS would need to be preceded by detailed hydrogeological investigations and very carefully planned. Adopting a regional approach however to MAR alleviates much of these worries. In the regional approach, storage and recovery is regarded as a water balance over a larger area, as opposed to a water balance in a single well-defined aquifer unit. The pumped water is not necessarily directly connected to the infiltrated water. Instead, the focus is just to infiltrate the same amount of water that is pumped within a specific region. This approach increases the need of monitoring groundwater levels, and over longer periods might necessitate the drilling of new boreholes in different locations, but allow for MAR systems in such hydrogeologically complex areas without the need for intensive and expensive hydrogeological mapping. This does come at the cost of increased uncertainty. Assumptions need to be made concerning infiltration and abstraction potential, and a willingness to correct on these assumptions when necessary needs to be in place with potential cost implications. With good planning however these drawbacks are surmountable and make MAR a possibility in this high potential area.

4.5.1 Water availability and provision

Potentially available water

The NGS cover about 1,000 km^2 within the boundaries of eThekwini Metropolitan Municipality, and receives precipitation of around 900 Mm^3/y on average, so input from rainfall if around 900 Mm^3/y. Moreover, multiple rivers are running through the area which are another potential source, like the Umgeni, Mlazi and Lovu which drain quite some additional area and have significant flows.

System design of MAR through SUDS in the NGS can be done in different ways. There is a lot of potential for swales and filter strips where urban density is low, or permeable pavements and infiltration trenches/soakaways where urban density is higher. Slope will be a constraint for these interventions as well, so they need to be well-sited. Additionally with good siting, there is potential for larger infrastructure like retention basins and artificial wetlands as well.

Really the main advantage of infiltration in the NGS is its flexibility. Most SUDS have local potential, and the large extent of the NGS ensures that there will be plenty of opportunities. Moreover, the regional approach of MAR in the NGS also means that the infiltration component and abstraction component do not have to be directly linked, which means that planning of infrastructure is flexible for that component as well.

Targeting to infiltrate 15% of the precipitation over the area (135 Mm^3/y), an infrastructure investment would be needed of:

- 3,000 km of infiltration trench (of 1 meter wide and assuming infiltration rates of 10 mm/h active half of the time);
- 280 km^2 of permeable pavement (assuming limited infiltration rates of 10 mm/d due to decreased storage capacity); or
- 7.4 km^2 of artificial wetland (assuming a daily average infiltration rate of 50 mm/d)

Aquifer storage

The regional approach to MAR of NGS makes aquifer storage much less relevant; much deeper groundwater is targeted for abstraction, while the hydrogeology needs to be investigated locally for infiltration potential. Considering the large extent of the formation, it is safe to assume that aquifer storage will not be a limiting factor for MAR through SUDS in the NGS.

Abstraction

Abstraction can be done almost anywhere. Hydrogeological siting needs to take place to limit failure rate of boreholes, and hydrological investigation can help identify higher potential areas but due to the regional approach the site for abstraction can be done relatively separately from the infiltration design. The main additional concern to take into account is an added need for monitoring and the ability to adjust abstraction when needed. If water levels or heads are observed to decrease at a specific point of abstraction, there needs to be an attitude of adjustment: lowering abstraction at that specific location and increasing abstraction somewhere else to compensate (by adding boreholes if necessary). On average, more boreholes are needed for this formation than the other formations due to on average lower yields, but the flexibility and extent of the NGS means that there are plenty of options for a lot of boreholes.

4.5.2 Conclusion

The Harbor Beds provide aquifers with good material and decent storage, and high recharge rates. Moreover, due to its location under the floodplains there is a lot of potential for capturing water and mitigating floods. The depth of the aquifer might limit potential storage and infiltration, which needs to be closer examined to determine full potential. Moreover, pollution might be an issue and is even harder to manage than in the Berea area. Focusing on a smaller area for management and protection would alleviate this problem, which would need to be done in balance with potential aquifer storage and infiltration. In any case, finding available space for infiltration and abstraction infrastructure is the first step for determining feasibility; if an appropriate area can be found, this option shows high potential for MAR through SUDS.

4.5.3 Key factors

Quality

Instances have been found of levels of Sodium and Chloride being above potable levels, but generally quality is good within the NGS (Demlie & Titus, 2015), and within a regional approach the infiltration water quality is less a concern for abstraction.

For infiltration design the quality of the stormwater should be assessed and potential polluters identified. In Figure 21, an example is shown of identification of industries around the Pinetown area in the upper Umbilo catchment (located on the NGS). Assessing industries and the quality of their effluent will inform where infiltration infrastructure can be built and where infiltration infrastructure should be avoided. When focusing on a specific area, quality of local industries' effluent should be closely considered, but the large flexibility in choosing type and location of infiltration infrastructure will make it relatively easy to prevent potential quality issues.

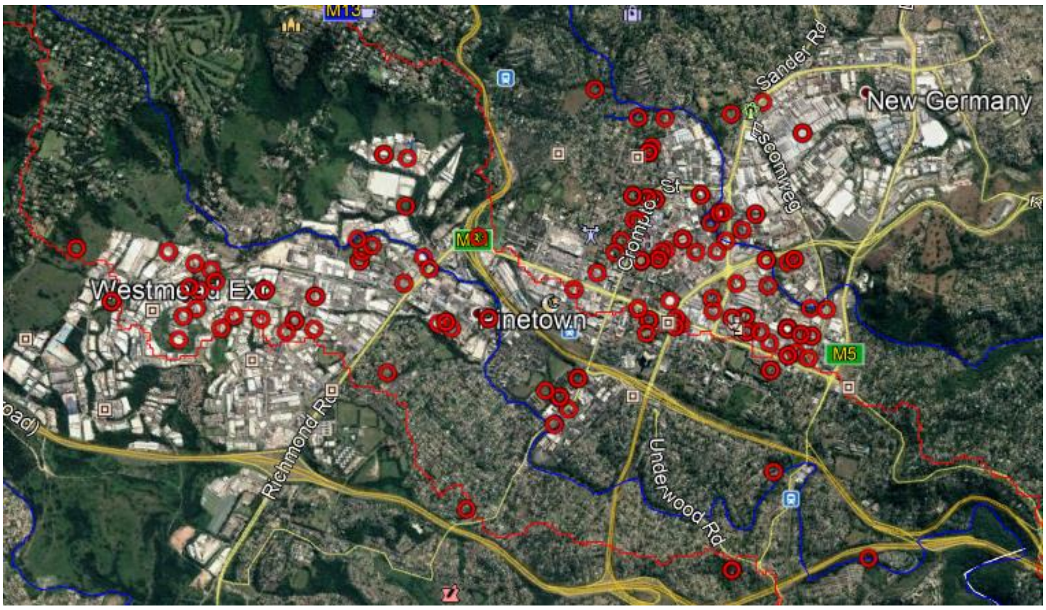

Figure 21. Location of industries around the upper Umbilo/Pinetown area

Flood mitigation

How much floods are mitigated will depend on specific SUDS design and location. Artificial wetlands have higher capacity for capturing high flow events, while permeable pavements and infiltration trenches reduce runoff for more smaller events. Flooding issues mostly take place downstream of the NGS area, so the effect of flood reduction is mostly not seen directly, but upstream measures for downstream effects can have a large impact. Especially due to the large extent of the formation, infiltration measures on the NGS can have a significant impact. With proposed target infrastructure targeting a capture 135 Mm^3/y, this is a potential huge reduction in flooding input. However, the capture would be quite widespread, while flooding areas also take input from elsewhere. This means that while significant, SUDS measures in the NGS for flood reduction should be complimented by measures downstream to have serious effects in flood mitigation.

Social/institutional challenges

Due to the flexibility in designing SUDS and MAR infrastructure, ownership is less likely to be an issue for MAR in the NGS. The regional approach of the NGS comes with the challenge however of ensuring local sustainability of specific boreholes or wellfields. Monitoring of water levels or heads is essential, and protocols need to be made for when drops are observed. Abstraction rates would need to be lowered in that case, which potentially need to be compensated on a different location. Often this will mean drilling new boreholes. Depending on the initial scheme, this might mean a significant extra cost in early stages of the project before a proper balance with the groundwater has been found.

4.5.4 Conclusion

While hydrogeologically complex on a local scale, the NGS is an extremely extensive area with favorable yields. When applying MAR at a regional level, the potential is very large although this approach does require an increased focus on monitoring and flexible attitude to abstraction. Design of infiltration infrastructure is very flexible and when applied extensively have large potential to reduce floods, although this needs to be complemented by downstream measures to have serious effects.

4.6 MAR through SUDS: conclusions

Four different formations have been investigated for their potential for MAR options within an SUDS framework. These four formations and some preliminary indicators for feasibility are summarized in Table 5 and explained below.

Table 5. Overview of feasibility for MAR through SUDS across four formations for both total potential water provision and assessment of multiple key factors

		Berea formation	Umgeni deposits	alluvial	Harbor beds	NGS
Potential water provision (Mm^3/y)		45	40		20	135
Key factors	Quality	+	-		o	+
	Flood mitigation	+	o		+	+
	Social/institutional	o	o		o	+

Berea

The Berea formation provides significant aquifers of decent characteristics for MAR in terms of both water quantity and quality.

The Berea ridge area is an interesting place due to its central location and clearly defined area. In terms of design and cost, there are some potentially good options to repurpose old existing stormwater harvesting infrastructure for infiltration, augmented with infiltration trenches. The cost-effectiveness is however difficult to estimate as the potential and state of the old infrastructure is not yet studied, while infiltration trenches are moderately costly. Abstraction meanwhile needs to be carefully planned. Opportunities exist around the Durban botanical gardens to utilize a local spring, possibly augmented by local boreholes. Clearing space and permits for building at that area might be tricky however due to its cultural importance.

An alternative area would be Durban North/Umhlanga, with a more extensive area and likely less issues with finding a suitable area for abstraction. It is however less hydrogeologically understood and would require more elaborate hydrogeological investigation.

Management and protection are another challenge, as the aquifers are mostly overlain by residential areas. Sensitization will be a key activity while a monitoring and a contingency plan must be in place to detect and react to pollution.

In terms of flood mitigation, the amount of water captured will be modest, although due to its central location the effect will be direct.

Umgeni
A relatively small aquifer but of good characteristics, and with the presence of Umgeni river a huge potential for infiltration through artificial wetlands or detention basins. Quality is however a major concern, not only of the incoming water from Umgeni river but also the groundwater itself from pollution from local industries and landfill sites. Also finding space for building a SUDS and MAR system could be a challenge, while its effects on mitigating floods are extremely limited.

Before quality and polluting sources are extensively mapped and the extent of the need for treatment is established, a MAR system should not be considered here.

Harbor beds
Another aquifer of decent characteristics, although relatively shallow. Large potential for infiltration and alleviating flooding issues as this is the place where most flooding takes place; if instead the flooding can be diverted to a dedicated place where it can infiltrate it is an extremely effective way to reduce flooding issues and increase water provision. Quality, management and protection are challenges but can be mitigated relatively easily if with a centralized local focus on infiltration and abstraction. Finding enough space will be the key factor, if an appropriate area can be found this option shows high potential for MAR through SUDS.

Natal Group Sandstones
While hydrogeologically complicated, an extremely extensive area with favorable yields. Applying MAR at a regional level, the potential is very large although this approach does require an increased focus on monitoring and flexible attitude to abstraction. Moreover, the large extent of the area and the flexibility where MAR through SUDS can be applied mean that institutional, social and quality issues can be minimized by siting.

5 Cost-effectiveness of MAR through SUDS

An important part of a feasibility study is the ability to make a business case showing economic viability. In this pre-feasibility phase, there are too many unknowns and uncertainties to make a full business case however. Instead, a base to assess economic viability will be created approached through two steps. First, the technically viable MAR through SUDS options are qualitatively compared for how cost-effective they are. Second, one specific option for the EWS preferred area will be worked in detail to get an idea of actual figures. This will both serve to inform the overall economic analysis as well as provide input for the other part of the pre-feasibility study in the adjoining report by RHDHV.

5.1 Qualitative comparison of cost-effectiveness

In this chapter, the three different formations where MAR is recommended are compared in a qualitative manner to be able to make a ranked potential between options.

For the Berea formation, the proposed SUDS infrastructure were infiltration trenches; a relatively expensive SUDS. Abstraction is however quite favorable, with high yields of boreholes and thus a relatively low numbers of boreholes are needed. The stretched shape of the abstraction zone does require more infrastructure to connect (piping), increasing costs of abstraction somewhat, but on the other hand the opportunity of re-purposing old stormwater infrastructure for infiltration would reduce cost of SUDS.

For the Harbor beds, infiltration can be done through artificial wetlands or retention ponds which are more cost-effective than infiltration trenches. Meanwhile, yields are similarly high as yields in the Berea formation, while abstraction can be done in a more centralized manner. The only major challenge for costs is gaining access to a large enough piece of land in the right place; depending on local ownership this can be costly. Provided the land needed for the infrastructure can be found, this option is generally very cost-effective, more cost effective than the Berea formation.

The NGS is very flexible in terms of finding land and types of infiltration infrastructure. Yields are quite a bit lower than in the Harbor beds and the Berea formation. Additionally, the regional approach of the NGS comes with the challenge of ensuring local sustainability of specific boreholes or wellfields, with the possibility of the need for new boreholes. These implications for abstraction mean that MAR is generally more cost-effective in both the Harbor beds and the Berea formation. The flexibility of SUDS infrastructure and the wide extent of the area however still make it a very interesting option. In the next chapter, a specific case for MAR in the NGS is worked out to get a better understanding for this formation specifically.

5.2 Specific case: MAR through SUDS at the Umbilo works

In this chapter, a specific case for MAR through SUDS is worked out. This case is part of a larger case worked out with RHDHV in the adjoining report, in the EWS preferred area of the Umbilo and Northdene waterworks.

The Umbilo works and its surroundings are located on top of the Natal Group Sandstones (NGS), which is suited for Managed Aquifer Recharge (MAR) options. Other formations are too for away to consider, therefor MAR through SUDS in the NGS is worked out for this location.

The MAR system consists of two separated components: an abstraction component and an infiltration component.

What is feasible in what area in terms of abstraction and infiltration is mainly dependent on targeted yield. For Effluent Option 2, a total (blended) yield of 21 Ml/d on average is targeted. 10 Ml/d of this will come from the abstraction.

5.2.1 Abstraction

There are two different design options for abstraction.

The first option is to design a wellfield directly around and the near upstream of the Umbilo facilities along the Umbilo river. This design negates the need for extensive piping. The downside of this option is the limited availability of space.

The second option is the design of a wellfield further away, potentially in another catchment as an inter-catchment transfer option. This allows for a much larger area to be potentially exploited but at higher costs due to piping.

Of course, there is always the option to mix; one wellfield near the Umbilo facilities, with yields augmented by other boreholes at a further location.

In any case, the number of required boreholes is dependent on the yield per borehole. Borehole yield in the NGS averages around 0.4 Ml/d, so around 25 boreholes are required to reach the target yield.

The area directly around and the near upstream of the Umbilo facilities along the Umbilo river (see figure below) is approximately 1 km^2 and supports a stretch of river of around 3 km. This should be plenty to support 25 boreholes without interference from each other. However, local hydrogeology is little understood and whether it indeed can support this many boreholes needs to be tested; as such, both options should be considered.

Figure 22. Google Earth screenshot of Umbilo Waste Water Treatment Plant direct upstream

Capital costs for boreholes are around 150.000 R, which means a capital investment needed of 3,8 million rand. Assuming an operational cost of 10% per year and a maintenance cost of 5%, this is a yearly cost of 0,6 million R/y. EUL (Effective Useful Life) of boreholes is around 30 years. Over the long run, this results in a yearly cost of around 6 million rand, and an average water provision cost of 0.17 R/m^3.

For the second (or mixed) option, the costs of piping needs to be taken into account. To calculate piping costs, the use of a 20 mm pipe at a rate of 2,000 R/m will be assumed. This implies an added costs of piping of 2 million R/km. This means if water would need to be piped for instance 5 km for establishing a well field in the potentially suited Mariannhill area, capital costs would go up with 10 million rand.

5.2.2 Infiltration

For the NGS, a regional approach to MAR is most suited, so there is quite some flexibility as to where infiltration should be focused. Even with a regional approach, it still makes the most sense to focus infiltration on the direct upstream of the abstraction site: Pinetown/New Germany.

As explained in chapter 1.3.2, there are many SUDS options, with different advantages and limitations. Filter strips and swales are more suited in low-density residential areas, as which the target are cannot be classified; these are thus not the preferred options. Regional control structures like detention ponds, retention ponds and constructed wetlands require large inputs. Umbilo river would qualify, but infiltrating the desired amount of water would directly take water which was intended to be blended with the treated water (notwithstanding issues with acquiring free and suited land for a large structure). As such, the following SUDS options have been selected as having the highest potential for infiltration in the targeted area:

- Infiltration trenches/soakaways
- Permeable pavements

For both these options, slope is a limiting factor for suitability as much of the upstream area is quite hilly. There is however a significant area of low to moderate slopes where both the options how plenty potential, as demarcated in the figure below.

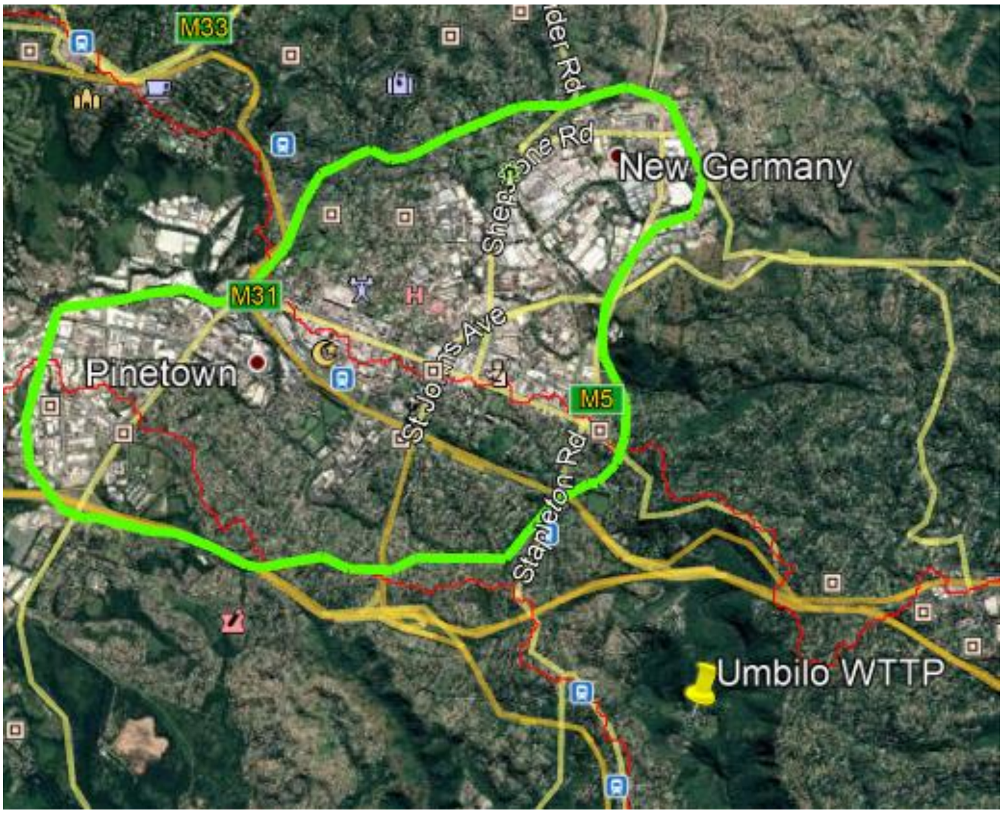

Figure 23. Google Earth image of potential suitable area for infiltration around Pinetown and New Germany areas

For both soakaways and infiltration trenches, a scenario is described below to assess feasibility.

Infiltration scenario 1: infiltration trenches/soakaways
Infiltration trenches and soakaways operate in a similar manner; they collect, store and infiltrate stormwater directly from local runoff (infiltration trenches can be regarded as a serialized connected row of soakaways).

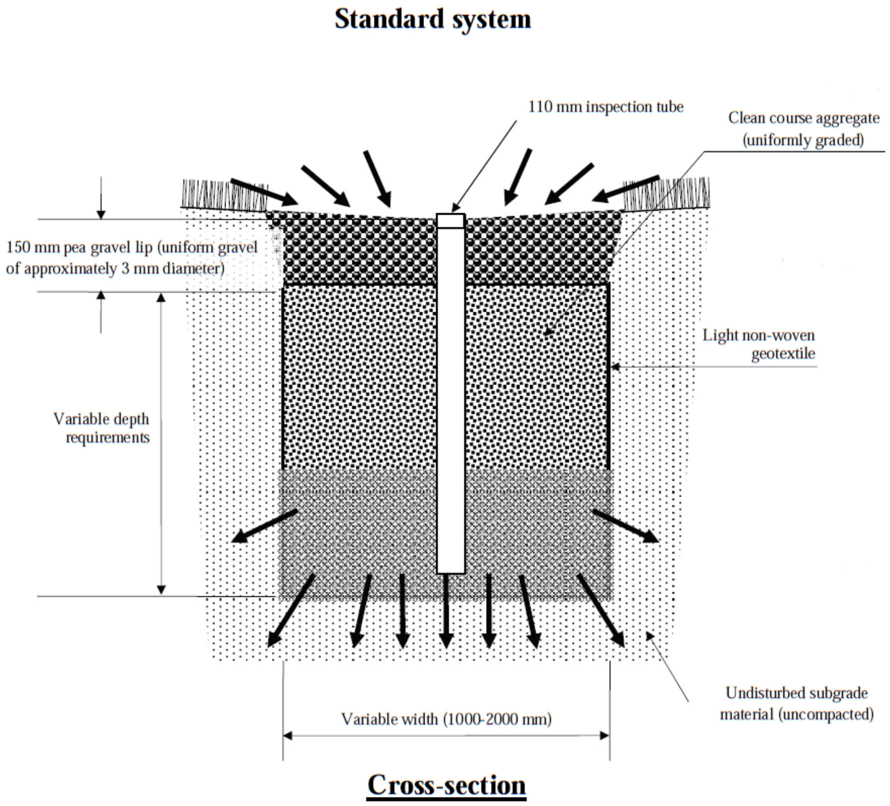

Figure 24. Schematic of potential set-up of infiltration trench

Soils in the area are generally quite shallow, only a few meters thick. The soakaways can therefor also not be too deep. An average depth of 1 m for the infrastructure seems feasible; with a porosity after gravel fill of 0.3 this amounts to an effective depth of the water holding capacity of 0.3 m.

Assuming a design infiltration of the trench of 240 mm/d in loamy sand (infiltration rate 10 mm/h) to capture this 10 Ml/d, active half of the year, 83,000 m^2 of infiltration trenches need to be designed. With a design of 1 m width of infiltration trenches, this means installment of 83 km of infiltration trench over the targeted area, with a total volume of 83,000 m^3.

Standard surface infiltration trench cost around 600 R/m^3 to build with an additional 100 R/m^2. This implies a capital costs investment of 58 million rand. Maintenance is around 0.3 million R/y; EUL is 10 years. Over the long run, this results in a yearly cost of around 6.1 million R, and an average water provision cost of 1.7 R/m^3.

Infiltration scenario 2: permeable pavements

While infiltration trenches are draining small areas, permeable pavements are primarily focused on direct infiltration. Storage is limited in permeable pavements, but even if daily infiltration is assumed to be limited to 10 mm due to limited soil storage capacity, 50% of precipitation could be captured. Infiltration rates are then 500 mm/y. So for an average capture of 10 Ml/d, an area of 7 km^2 is needed.

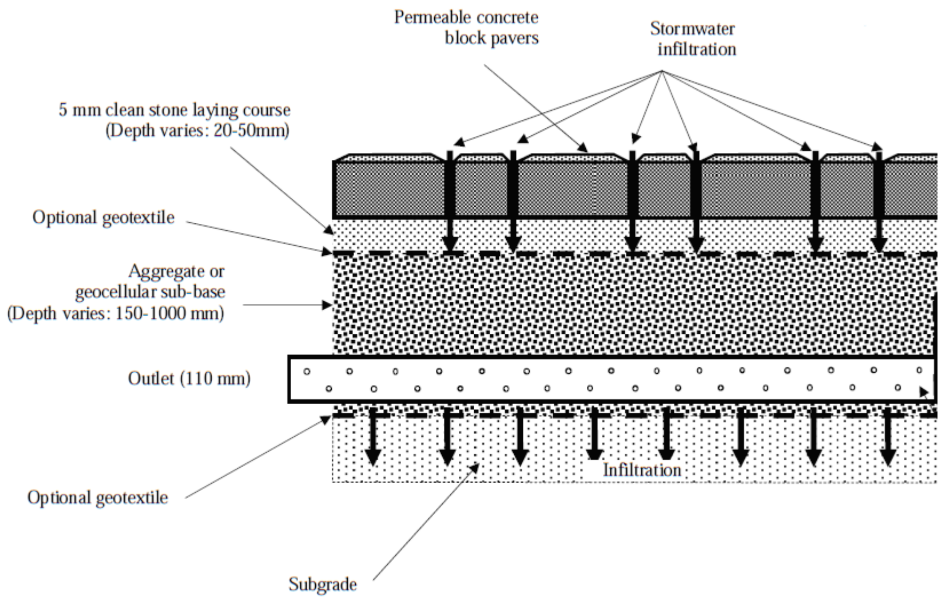

Figure 25. Schematic of potential set-up of permeable pavement

Costs of installment are around 100 R/m² implies a capital investment of 700 million rand, and maintenance costs are around 1.5 million R/y. EUL is around 20 years. Over the long run, this results in a yearly cost of around 37 million rand, and an average water provision cost of 10 R/m³.

5.2.3 Conclusion

A MAR system connected to the Umbilo works is technically feasible, focused on the Natal Group Sandstones where abstraction and infiltration exist as separated components.

Abstraction can be done in the near vicinity of the Umbilo facilities although it might have to be augmented by wellfields from further away.

Highest potential options for infiltration are infiltration trenches and permeable pavements. Infiltration trenches are much more favorable however in terms of costs than permeable pavements. The infiltration component overall is more expensive than the abstraction component.

Table 6. Costs overview of MAR through SUDS options at Umbilo location

	Capital costs (million rand)	Operational costs (million R/y)	Average yearly cost (million R/y)	Cost of water (R/m³)
Abstraction				
Umbilo river wellfield	3.8	0.6	0.73	0.2
Piped wellfield	+2 (/km)			
Infiltration				
Scenario 1: infiltration trenches	62	0.3	6.1	1.7
Scenario 2: permeable pavements	700	1.5	37	10

5.3 Conclusion

Provided space can be found, the Harbor beds provide the most cost-effective opportunity for water provision through MAR through SUDS in the eThekwini area, and the Berea formation the second most favorable. The NGS take up the third place, while the flexibility of application of MAR in the NGS make it still very attractive. For a specific case in the NGS, MAR through SUDS preliminary cost indications require capital investment of 46 million rand and an operational/maintenance cost of 0.8 million rand/y.

6 Rainwater harvesting

In this chapter, the feasibility and potential of rainwater harvesting from rooftops is examined.

6.1 Water capture

Table 7 shows surface area of specific landcover types within the urban area of eThekwini. These numbers will provide the basis for estimations on how much water can potentially be captured.

Table 7. Urban area landcover surface area in 2005

Landcover	Area (km2)
Commercial / Retail	18
Industrial areas	61
Major Recreation Facilities	15
Rail	6
Roads	16
Municipal	27
Under Construction	7
Urban Settlement Formal	422
Urban Settlement Informal	113

6.1.1 Urban settlements

Formal urban settlements provide by far the largest surface area of any landcover type within the eThekwini urban area, 422 km^2. Of this area, about 13% is covered with roof surface, with a total of ~55 km^2. If the entire rainfall on this surface is captured (1,000 mm/y neglecting interception and evaporation), this amounts to 55 Mm^3/y, or 150 Ml/d.

Table 8. Potential maximum water capture through rainwater harvesting in formal urban settlements

Total formal urban area	422 km^2
Roof surface in formal urban area	55 km^2
Potential maximum capture	55 Mm^3/y

Tank size is limited however, and not all rainfall will be captured; using a household specific approach would result in a more realistic figure. In total, 414,000 houses in formal urban settlements are reported in 2011. Roof surface ranges from 2 m^2 to over 2000 m^2, but median size is ~70 m^2. This results in a total of 70,000 l/y of rainfall input per household for capture. Now, it is assumed that enough space households would be able to implement a tank of 5,000 l on average per roof. Additionally, it is assumed that with continued use from the tank, the tank will be able to capture at least half of the total rainfall. Considering the total precipitation input of 70,000 l/y, this amounts to for a total of 35,000 l of water provision per year per house (100 l/d on average), which seems entirely feasible. For the total area, that means an annual water provision of 14 Mm^3/y, or 40 Ml/d; a significant albeit small number compared to the identified current water gap of 130 Mm^3/y.

Table 9. Potential water capture through rainwater harvesting in formal urban settlements considering tank size

Nr of houses in formal urban settlements	414,000
Water delivery per household tank	35,000 l/y
Total potential capture	14 Mm^3/y

6.1.2 Industrial area

Industrial areas make up about 61 km^2 in eThekwini, with a roof surface of a about 33% for a total of 20 km^2. Industrial areas have more capacity for capturing rainwater from roofs than settlements.

There is one specific site known to use rainwater harvesting from roofs for water provision, the Mr Price Distribution Centre in Hammarsdale. Here, a roof surface area of about 28,000 m^2 was connected to a storage tank of 2.455 m^3 with a stormwater attenuation channel to hold storm flows (Figure 26), and subsequently connected to pumps and filters in order to be able to supply clean water to the industry (Figure 27).

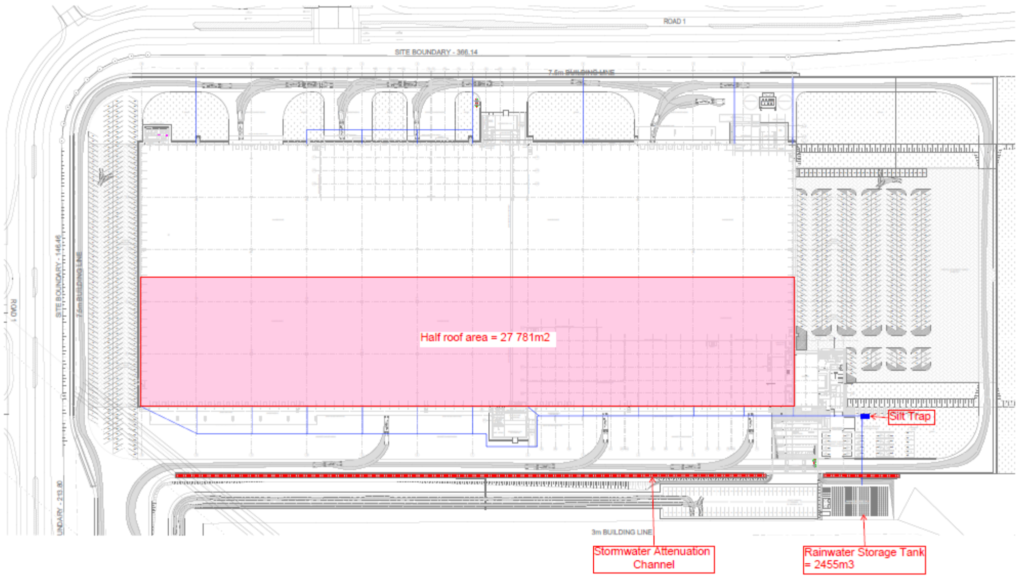

Figure 26. Mr Price Distribution Centre in Hammarsdale rainwater harvesting set-up - roof, storage tank and stormwater attenuation channel

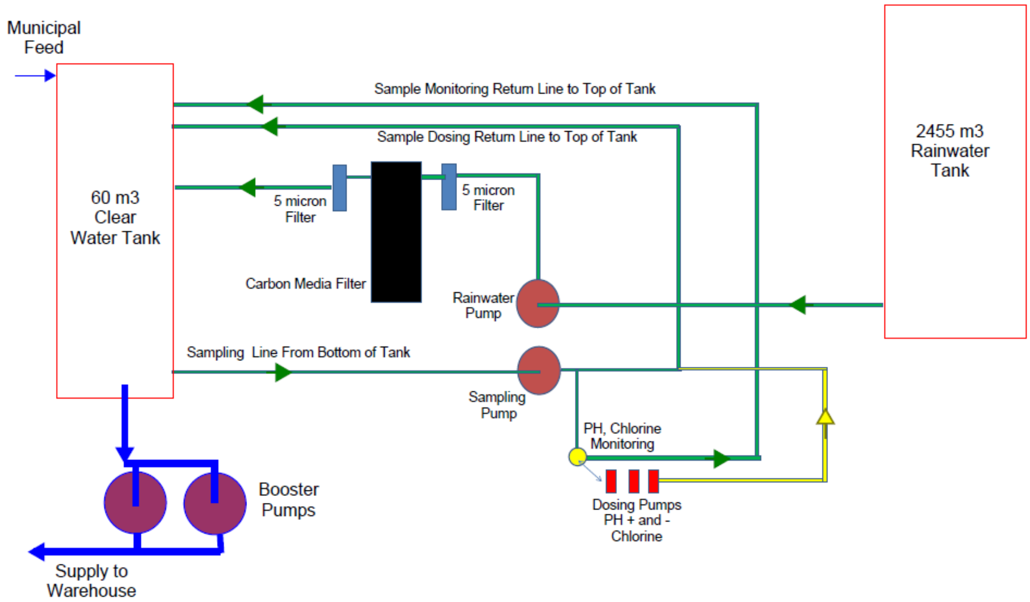

Figure 27. Mr Price Distribution Centre in Hammarsdale rainwater harvesting set-up - from tank to pumps and filters

In the illustrated scheme a provision of 14,500 m³/y is obtained with a roof surface of 28,000 m². Extrapolating this to the total roof surface rea of 20 km², the total potential of rainwater harvesting for industrial areas is 10 Mm³/y or 28 Ml/d, which is a sizeable amount.

Table 10. Rainwater harvesting area and potential volumes for industrial area: from case at Mr Price Distribution Centre in Hammarsdale and total potential

	Mr Price Distribution Centre in Hammarsdale	Total potential for industrial area
Area	28,000 m²	20 km²
Total provision	14,500 m³/y	10 Mm³/y

6.1.3 Informal settlements and municipal area

Informal urban settlements have the second highest surface area (113 km²), and if assuming the same calculations can be made for this type of settlement, total yield would amount to 3.9 Mm³/y or 11 Ml/d. The informal status of these settlements however will make it institutionally much more difficult however to implement a rainwater harvesting implementation scheme, making this a less feasible option.

Municipally owned area is another potential source. While covering a smaller area than the other landcover types (27 km²), it will be the easiest area to implement through policy. Assuming similar characteristics as industrial area, municipal area has a water provision potential of 4.4 Mm³/y or 12 Ml/d. A study by EWS (2019) has even listed potential sites for rainwater harvesting within the EWS infrastructure, which provides a very good start for initial site selection.

6.1.4 Total water capture

Table 11 summarizes potential capture for rainwater harvesting for the different discussed landcover types. Formal urban settlements have the highest potential in terms of water capture. Second highest potential is for the industrial area, while informal and municipal areas have lower potential.

Table 11. Potential water capture for rainwater harvesting per major landcover type

Landcover	Potential capture (Mm^3/y)
Urban Settlement Formal	14
Industrial areas	10
Urban Settlement Informal	3.9
Municipal	4.4

6.2 Quality

Rainwater is of excellent quality, even in urban or industrial areas it has very little contamination. Contaminants can however be introduced into the system after the water has fallen onto a surface. This can be by rooftop material, deposition from air pollutants or contamination in the water tank. These possible contaminants make application of rainwater harvesting systems for potable use risky, and an in-depth analysis of possible roof contaminants, air pollution and prevention of tank contamination would be required, with analysis of home treatment options. In general however, the quality will be good enough in eThekwini for non-potable uses, both in households and industries. As such, roof water harvesting is better considered as a supplementary water source than a main water source for drinking.

6.3 Cost analysis

Cost range widely across the world. For 5 m^3 tanks, as considered in chapter 5.1, cost can range from 50-300 USD. For eThekwini, an individual 5 m^3 water tank costs around 5,000 R, equivalent to ~270 USD. Additionally, with other costs like installation labor, total costs of implementing one rainwater harvesting unit is around 10,000 R (600 USD). Implementation and production of rainwater harvesting at scale will likely drive this number down, but for now this number will be used for calculations. Applied at all households in formal urban settlements, this means a capital investment of 4.1 billion rand for a water service provision of 14 Mm^3/y, or 40 Ml/d

With current water tariffs, a provision of 10 m^3 is charged about 170 R. With a provision of 14 Mm^3/y, this implies an annual revenue of 240 million R/y. To recover the 4.1 billion rand capital investment, it would take 17 years.

Rainwater harvesting variable	Amount
Tank + installation	10,000 R
Households	414,000
CAPEX	4.1 billion R
Potential provision	14 Mm^3/y
Annual revenue	240 million R/y
Return on capital investment	17 years

Besides the tank and installment, maintenance is required as well. Cost numbers for maintenance are low relative to the water tank costs but do add to the picture and will easily add another few years to reach return on investment.

For industrial areas, much larger tanks can be used, which can be much more cost-effective. For the system of the Mr Price Distribution Centre in Hammarsdale, a whole cost analysis was carried out. Here, return on investments were calculated to be about 11 years, much less than the case for tanks in urban settlements. Moreover, this system included treatment, which is still an uncertain factor for the urban settlement model.

The report on the Mr Price Distribution Centre system is included in Annex A.

6.4 Social and practical feasibility

Mainstreaming rainwater harvesting as a normal option within public or communal water supply poses special problems for water authorities. Rainwater harvesting is *not* in its essence a collective solution which can be centrally managed. So even when rainwater harvesting may be cheaper per litre, more potable and more convenient than rival sources, it does not easily fit the practices or criteria of water authorities. Far more than point sources like springs, wells and tap-stands, rainwater harvesting requires the cooperation of individual households. Its equipment has to be located on private property; its management is household by household; it is not easy to monitor water quality or even the quality of installations.

From a economic standpoint, it is difficult for a water service provider to make continued revenue from a rainwater harvesting system. Multiple structures do exist (loans, monthly payments, pre-paid monitors) but they all rely to some degree of cooperation of individual households; once rainwater harvesting systems are installed, payments are hard to enforce. This required cooperation is expected to be low in eThekwini, and therefore the feasibility of rainwater harvesting in in urban settlements is even less feasible. Rainwater harvesting for industries deal with these limitations to a much lesser extent however and do not impact its feasibility much.

6.5 Conclusion

With full implementation of all formal urban settlements, 14 Mm^3/y or 40 Ml/d can be delivered. Return on investment will require over 22 years however, while household cooperation is expected to be limited which will increase this return on investment much further. Overall, due to these factors rainwater harvesting at household level is not a viable business case for eThekwini and should only be considered within the boundaries of the project as an alternative to reduce water demand.

Rainwater harvesting in industrial areas shows more potential. With at a maximum potential provision of 15 Mm^3/y or 41 Ml/d, a lot of water can be captured, while return on investment is reached in 11 years.

7 Conclusion and way forward

7.1 Conclusions

MAR through SUDS provide interesting opportunities for eThekwini, and it is technically feasible to provide up to 200 Mm^3/y.

Three different areas have been identified with suited hydrogeology for MAR through SUDS: the Berea formation, the Harbor Beds and the Natal Group Sandstones (NGS).

The NGS provides the most potential in terms of water provision (145 Mm^3/y), while key factors like quality and social/institutional challenges are favorable.

The Berea formation can support a potential water provision of 45 Mm^3/y, with more favorable hydrogeological characteristics than the NGS. Management and protection are issues however which need to be more closely considered before moving forward with this option.

The Harbor beds provide the best aquifers and has high potential for flood mitigation, although support a lower provision (20 Mm^3/y). Finding the right area however is a challenge, might be difficult or costly, which needs to be assessed in the next phase.

In terms of economic viability, the Harbor beds provide the most cost-effective opportunity for water provision through MAR through SUDS in the eThekwini area. The Berea formation takes second place as infiltration infrastructure will a relatively high cost, although abstraction is favorable here and with cost-saving opportunities exist. The hydrogeological characteristics of the NGS make MAR through SUDS generally less cost-effective than MAR in the Berea formation or the harbor beds. However, the flexibility of application of MAR in the NGS is much higher and potential schemes are still cost-effective, with a cost indication of on average 6.8 million rand per year for a provision of 10 Ml/d for one example case.

Besides MAR through SUDS, rainwater harvesting provides especially opportunities for industrial areas, while implementation at households mainly as an alternative to reduce water demand without a profit motive.

7.2 Way forward

In the next phase, full feasibility for a MAR system needs to be established. This assessment of preliminary feasibility has put forward a few options but some of the higher potential options have some major constraints to be checked before full feasibility can be established, specifically for the Berea formation and the Harbor beds:

Berea formation:

- Investigate infrastructural options for abstraction along eastern side of the Berea ridge area.
- Determine the suitability the hydrogeology in the Berea formation at the Durban North/Umhlanga area (clay content, conductivity, water levels below surface)
- Investigate infrastructural options for abstraction for the Berea formation at the Durban North/Umhlanga area.

Harbor beds:
- Determine what space is potentially available for SUDS options and MAR management
- Determine local hydrogeology at potentially available area
- Identify polluting sources and extent

If investigation of these aspects can alleviate concerns significantly, one of these formations will be identified as most suitable. Otherwise, focus should shift to the NGS for full feasibility.

Full feasibility will require designing a full MAR through SUDS scheme, with:
- Identification of exact locations and extent of infiltration and abstraction infrastructure
- Detailed calculations with tested infiltration rates and storage capacities of SUDS infrastructure and sub-surface
- Design of a full MAR through SUDS scheme, including components for transfer to treatment/water supply system
- Financial cost analysis of full design
- Financial cost analysis of comparable projects (to benchmark cost calculations based on full design)
- Identification of institutional requirements
- Identification of and connecting with possible partners for implementation, ranging from fellow government institutions (like the Stormwater Department of the eThekwini Government), to private organizations (like Geomeasure)., to academic institutions (like Future Water of the University of Cape Town)
- Capacity building of local experts/EWS personnel in MAR and SUDS management, including two specific proposed candidates: Lungelo Khomo of EWS and Hlengiwe Msweli of UKZN (profiles are added in Annex B).

Moreover, working towards a full PPP process should be an active component throughout every phase of the project. In the feasibility phase this starts with discussion with FMO on provision of project preparation funding.

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Annex A
List of relevant reports

Here a list of documents and reports relevant to the pre-feasibility and feasibility is added, categorized by theme.

3R (Retention, Recharge, Re-use)
Three booklets on the 3R concept are included, made by the 3R consortium at different stages including organizations like Acacia Water, Aqua4All, RAIN, Justdiggit, MetaMeta, IGRAC, BMZ and more. 3R is focused on the buffering of water through Retention, Recharge and Re-use, and its broad framework formed the basis of identification of appropriate measures in this report.

- *Management the Water Buffer For Development and Climate Change Adaptation*; this book explores how to maximize the use of groundwater and rainwater for development and climate change adaption through 3R.

- *Reaching the Millions Deal Book 8 investment profiles to achieve 3R impact*; the 3R Deal Book provides insight into how the retention-recharge-reuse (3R) approach can contribute to tackling these global challenges and contributing to many of the SDGs.

- *Profit from Storage The Costs and Benefits of Water Buffering*; this book tries to overcome the limited understanding of water buffering by discussing the costs and benefits of local water storage in particular.

Sponge Towns
The Sponge Town approach applies 3R in an urban context, alongside recommendations on governance, social aspects and more. In two pilot projects in Kenya, this approach has been tested and solidified, with a consortium of partners including Acacia Water, VIA Water, MetaMeta, SASOL, AMREF and more.

- *How to create a Sponge Town? Sponge Town Guideline*; a summary of the findings of the two pilot projects condensed to a specific set of guidelines.

Sustainable Urban Drainage Systems (SUDS)
Reports on SUDS are available from many sources, but Future Water of the University of Cape Town has developed different studies on its application specifically in South Africa.

- *South African Guidelines for Sustainable Drainage Systems*; a study which set out to identify and develop new and appropriate guidelines for the use of alternative stormwater technology in South Africa.

- *Research on the Use of Sustainable Drainage Systems in Gauteng Province*; a set of reports specifically focused on application of SUDS in the Gauteng province
    - *Literature review on SuDS: definitions, science, data, policy and legal context in South Africa*
    - *Selection of three specific study areas*
    - *Data collection on SuDS installations in Gauteng*
    - *Analysis of Study Areas with Recommendations*
    - *Decision Support Tools for Sustainable Drainage Systems*
    - *Best Management Practices for Sustainable Drainage Systems*
    - *Gauteng Sustainable Drainage Systems Implementation Manual*

Managed Aquifer Recharge (MAR)
Literature also exist on the application of MAR specific to South Africa:

- *Artificial Groundwater Recharge Recent Initiatives in Southern Africa*; this booklet provides an overview of the status of artificial recharge in Southern Africa and lists resources that are easily accessible to anyone considering this water storage, treatment and conservation measure.

- *The Atlantis Water Resource Management Scheme 30 years of Artificial Groundwater Recharge*; this report provides a local South African example of a cost-effective artificial recharge solution that has been proven over time, successfully supplying water to both the residential and industrial areas of Atlantis for nearly 30 years.

Rainwater harvesting
For rainwater harvesting, one document is added for a specific case for rainwater harvesting within the eThekwini area, as referenced in the text:

- *Rainwater harvesting system, Mr Price Distribution Centre Hammarsdale;* a presentation on the specific rainwater harvesting case.

Annex B

Profiles of two capacity building candidates

Candidate 1: Lungelo Khomo
Lungelo khomo
BSc Civil Engineer (Hon, UKZN)
2 years post graduate experience at eThekwini Water and Sanitation

Area of expertise:
- Water and wastewater design
- Wastewater treatment plant operation and system optimization
- Water reticulation design modelling

During this study, Lungelo Khomo has played a key role as the local counterpart of Acacia Water in eThekwini. He organized and facilitated discussions between the project team and local experts, provided relevant data from all kinds of sources, and ensured continued cooperation between the project team and the project beneficiaries. Moreover, served as the technical link between the analyses of the report and technical functioning of EWS. Meanwhile, his continued involvement during each stage of report writing means he has good understanding of the proposed solutions and the relevant considerations.

Candidate 2: Hlengiwe Msweli
Hlengiwe Msweli
BSc Environmental and Engineering Geology
BSc (Hons) Environmental and Engineering Geology
3.5 years post graduate experience in academic, consulting, public sector

Areas of expertise
- Environmental assessments including wetlands
- Contaminated land management
- Groundwater and surface water supply
- Geotechnical and engineering geology

This study has built on the work done by Hlengiwe Msweli, who has investigated MAR options for eThekwini at the University of KwaZulu-Natal (UKZN). Her work provided vital information for hydrogeology and other MAR aspects, and she has provided input through data and discussions throughout the duration of the project.

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